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Behavioral and Organizational Dimensions of Underground Mine Fires

**By Charles Vaught, Ph.D., Michael J. Brnich, Jr.,
Launa G. Mallett, Ph.D., Henry P. Cole, Ed.D.,
William J. Wiehagen, Ronald S. Conti,
Kathleen M. Kowalski, Ph.D., and Charles D. Litton**

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
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UNIT OF MEASURE ABBREVIATIONS

cfm	cubic foot (feet) per minute
fpm	foot (feet) per minute
ft	foot (feet)
lb	pound(s)
m	meter(s)
m^{-1}	inverse meter(s)
m/sec	meter(s) per second
m^3/sec	cubic meter(s) per second
nm	nanometer(s)
ppm	parts(s) per million
ppm·m	part(s) per million meters

ACRONYMS AND OTHER ABBREVIATIONS

ANOVA	analysis of variance
CFR	Code of Federal Regulations
CO	carbon monoxide
EMF	*Escape From a Mine Fire*
FSR	filter self-rescuer
GIL	general inside laborer
HCl	hydrochloric acid
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
PVC	polyvinyl chloride
SBR	styrene-butadiene rubber
SCSR	self-contained self-rescuer
USBM	U.S. Bureau of Mines

BEHAVIORAL AND ORGANIZATIONAL DIMENSIONS OF UNDERGROUND MINE FIRES

By Charles Vaught, Ph.D.,[1] Michael J. Brnich, Jr.,[2] Launa G. Mallett, Ph.D.,[1] Henry P. Cole, Ed.D.,[3] William J. Wiehagen,[4] Ronald S. Conti,[5] Kathleen M. Kowalski, Ph.D.,[6] and Charles D. Litton[7]

INTRODUCTION

How do people behave when they are trying to get out of a fire? Are escape activities different in each incident, or will most actions be predictable across events? Do persons make the same sorts of decisions whether they are responding as individuals or as group members?

Because the social costs of fire-related deaths and injuries are likely to continue to rise, societal pressure for greater safety will also undoubtedly increase. There are, therefore, compelling reasons to further our understanding of action in fires. If human behavior in fire is studied scientifically and predicted according to some well-defined principles, the benefits will be significant. Design engineers could incorporate real-world findings into their plans. Equipment manufacturers could gain from insights into how their technology is actually used in fire emergencies. Safety personnel would have a better appreciation of what constitutes adequate evacuation procedures. Trainers could upgrade the content of their courses that teach escape skills. The result would be an overall improvement in the quality of fire preparedness and safety.

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[1]Sociologist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

[2]Mining engineer, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

[3]Professor, Department of Education and Counseling Psychology, University of Kentucky, Lexington, KY.

[4]Industrial engineer, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

[5]Fire prevention engineer, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

[6]Research psychologist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

[7]Research physicist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.

This book is part of a small but growing body of scientific literature that examines the human experience in fire. Some of the first investigations were conducted in the United Kingdom during the early 1970s. These and later studies were directed, for the most part, by psychologists. Consequently, they tended to address perceptions, attitudes and the behavior of individuals. Also, they focused primarily on responses to fires in public structures such as hospitals and nursing homes. The present work differs from those earlier efforts in two ways. First, the research and analysis has been performed by an interdisciplinary team of social scientists and engineers. In developing their analytic framework, team members concentrated heavily upon organizational factors. This research, then, complements the earlier work of psychologists by adding a group perspective. Second, the sites studied are large underground coal mines. Thus, an environmental consideration is introduced, because coal mine fires are qualitatively different from structural blazes.

A review of Mitchell [1990] gives a few points supporting the distinctiveness of coal mine fires: (1) mine workers must evacuate long distances (sometimes miles) in smoke and darkness; (2) the seam height at an operation may be anywhere from several feet down to 19 or 20 inches, meaning that at some mines people must crawl out to escape; (3) access to underground workings is always limited to a few (sometimes only two) openings; (4) a coal mine's roof and ribs are impenetrable, lying hundreds of feet below the Earth's surface; (5) the coal provides an inexhaustible supply of fuel; (6) potentially explosive and lethal concentrations of gases may build up quickly in a mine fire; (7) there is no safe place to vent pressures and smoke; and (8) firefighting logistics are difficult. Given these variables, anyone who delays too long before beginning an escape attempt, who is not able to use an emergency breathing apparatus properly, who cannot travel the necessary distance to fresh air before his or her oxygen supply runs out, or who gets lost in the maze of dark smoke-filled entries will likely die.

On December 19, 1984, 27 miners in Utah Power and Light's Wilberg operation died as the result of a disastrous fire. Exactly what happened during the attempted evacuation of that mine can only be hypothesized from the locations, positions, and conditions of bodies found during the recovery. Those hypotheses do not yield information about the decisions made or activities that took place before these workers succumbed to the irrespirable atmosphere. This disaster is, therefore, of limited value as a case study for learning about human action and interaction during such events. Over the last 15 years, however, scientists at the Pittsburgh Research Laboratory have interviewed 48 workers who escaped from 3 burning coal mines. They have thus gained a unique opportunity to study human behavior in this often deadly context.

The theoretical framework for this study is built on three bodies of technical literature. Selected literature on fire and human behavior provides the first source of background information. Included are the works of social scientists, experts in firefighting, regulators, architects, and computer modelers whose common goal was seeking to understand how people act and react during fire emergencies.

The second building block for this study is social science literature on collectivities and small groups. Some organizational studies used directly for the present research analyze groups in nonroutine situations.

The third area of literature concerns judgment and decision-making in operational settings. This literature helps to create a perspective from which the data will be viewed, because escape behavior is a process of making decisions and taking action.

The group cohesion of coal miners in their normal work environment is well documented [Vaught 1991]. There is ample evidence that this social solidarity also affects escape behavior, because emergency evacuation has been found not to be an individualistic activity. The authors suggest that when a major fire occurs in an underground coal mine, a new type of group will be formed: an escape group. This group may be made up exclusively of members of a work crew or it may be a gathering of individuals who have little or no previous experience working together. Whether the membership is identical with an existing work crew or not, the escape group must handle tasks very different from those that are part of routine work activities. The physical environment and new emergency tasks will help define group dynamics and decision-making during an escape.

The database of this study consists of information collected from 48 miners during open-ended interviews. All interview sessions began by having the workers discuss their actions and thoughts from the time they first became aware that there might be a problem in their mine until they reached safety. Upon completion of these narratives, a second cycle of questioning focused on key decisions and actions. The accounts were then assessed using a computerized cross-indexing scheme. Researchers next placed reported actions within generalized categories of response. Team members discovered an array of decision variables, which can be related to various aspects of individual and group behavior during the escape process. Each major finding in relation to the events has been incorporated into a behavior model of workers escaping from underground mine fires. The individual findings that make up this model are treated as chapter topics in the book.

Because of the importance of this research, an attempt has been made to address as wide an audience as possible. The book is written first for mining engineering students and people already in mining who must, at some point in their careers, plan for and respond to fires. Second, it seeks to expand the knowledge of system developers, who can benefit from insights into real-world emergency decision-making. Finally, social scientists should gain from this exploration of what is still a little understood area.

Since anticipated readership is varied, the content will address appropriately diverse fields. For example, mining experts will read a discussion of social science methods while social scientists are given an overview of the underground workplace. With this diverse audience in mind, the authors have kept jargon to a minimum and presented relevant issues in a straightforward manner. It is hoped that this approach will stimulate the sharing of ideas across the boundaries of specialization.

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CHAPTER 1.—REVIEW OF SUPPORTING RESEARCH

Human beings tend to organize their view of the world according to certain generally accepted standards. Thomas Kuhn [1970] termed these shared viewpoints "paradigms." In relation to research, paradigms function much the same way for science as they do for law: they contain canons for the collection of evidence, determine what is admissible, establish rules for debate, and provide guidance for judging merit. Paradigms, however, also tend to make people blind to issues that fall outside their scope of authority. Thus, while paradigms help to reveal some aspects of reality, they conceal others. Sometimes, though, there is a perceived need so strong that it calls a paradigm into question. A likely result is that someone will innovate and begin to address an issue from a new perspective. The person who first threw a forward pass in football is an example.

The paradigm that has governed thinking about firefighting dates from the last century. During the Industrial Revolution and after, people came to see technological development as a way to conquer their environment. The solution to just about any problem lay in an application of natural science and engineering [Canter 1990]. Conditions not amenable to a mechanical fix were unthinkable. Such a mind-set was carried over into codes around the world, where "people's safety is addressed exclusively in engineering terms" [Sime 1985]. This means that human volition has been left out of the equation, and individuals are treated as inanimate objects about whom designers can determine such things as *Flow Capacity of Door Openings in Panic Situations* [Peschl 1971]. In fact, designs based on such false assumptions about human beings are not sound. For this reason, researchers are taking a closer look at how people actually behave in panic situations.

Fire and Human Behavior

Writers have dealt with human behavior in fire for several years now. The early literature was composed mostly of "anecdotal accounts [that] tended to concentrate on the horrifying, 'panic' reactions" [Wood 1990]. Stevens' [1956] article on the Church Oyster Roast fire panic is a good example. These items were of interest to firefighting professionals and appeared in publications such as the *Quarterly of the National Fire Protection Association*. Some technical design studies also included the human element, although in a very limited way. One example of such work is Galbreath's [1969] *Time of Evacuation by Stairs in High Buildings*. This study, published by the Canadian National Research Council's Division of Building Research, focused on the movement of people while they were evacuating buildings. It did not, however, look at factors that might influence choices of direction, evacuation speed, or other response variables.

The first systematic investigation of human responses to fire threats was completed in the United Kingdom during the early 1970s. Data for this project were collected by interviewing approximately 2,000 individuals who had been involved in almost 100 fires [Wood 1990]. Fire brigade officers did most of this work, administering questionnaires at the fire scenes. In this descriptive study, "behavior was examined both at a general level and with particular reference to two specific behavioral variables, evacuation of the building and movement through smoke." Variables such as age, sex, experience with fire, and prior training were considered. Wood looked at what actions people took and who took them, but did not attempt an explanation of those actions. To achieve such an analysis, Wood suggested that "more intensive studies will have to look at people's attitudes, knowledge and beliefs concerning fire."

After the completion of Wood's study, "there was an intensification of interest and effort, with some major, systematic studies and numerous smaller ones...being carried out" [Paulsen 1981]. A U.K. anthology [Canter 1990] provides an overview of these studies containing chapters "written by scientists with interests in: (1) specific settings in which fire may occur, (2) ideas related to behavior in fire, and (3) building models of behavior in fires. A second edition of the book was "edited to keep the original detailed case studies and to add information about some major incidents that occurred since the first edition was published." This volume remains the best available summary of the field of human behavior in fire.

Four observations may be made about the research mentioned to this point. First, data gathering was typically limited by the scattering of survivors after the event or by the death of those with important information about an attempted escape. Second, the sites studied were frequently structures such as hospitals or hotels. Third, the only nonstructural setting investigated involved a fire in an underground transportation station [Donald and Canter 1990]. While access to the surface was limited in these tunnels, the affected area was small in comparison to mine fires. In any case, most people threatened by the blaze were individuals who did not know each other or their surroundings very well. Further, few had training in how to respond to such a situation. Finally, much of the past work on how humans respond to fire only addressed the behavior of individuals and did not consider group-level variables.

Only recently have researchers begun to consider the behavior of groups during fire evacuations. Sime [1985] tested an "affiliative" model involving patrons of the Summerland Leisure Centre, a seaside complex in the United Kingdom, where 50 people died in a fire in August 1973. His model predicted that people facing potential entrapment would move toward familiar places and persons. Sime contrasted such a notion with the engineering assumption underlying escape route design. Designers, he argued, presume there is a deterministic relationship between an exit's location (assuming availability) and its use in an emergency. In his study of the Marquee Showbar evacuation, Sime found that two important factors other than proximity to an exit affected direction of movement. These were individuals' familiarity with a particular travel route and their ties to others elsewhere in the building. Sime concluded that the variable of affiliation is not addressed sufficiently by those who ought to be concerned with how humans actually get out of structures.

Turner and Toft [1989] point out that during the Summerland Leisure Centre fire individuals based their actions on family group membership: "Instead of immediately escaping themselves, therefore, many parents desperately looked for their children frequently causing additional confusion and panic." Johnson [1987] reported similar findings in a study of the evacuation of the Beverly Hills Supper Club during a fire: "Throughout the...interviews are reports of a concern by one primary group member for another and multiple reports of group members exiting together, often hand-in-hand." Even when family relationships were not present, other forms of groups were evident: "Many...reported from the Empire Room that they were seated at tables with others from their workplace, and both there and in the Crystal Rooms the frequent use of names of others in descriptions of the escape indicated the presence of social bonds." This evidence of individuals reacting to the locations of others and staying with a specific group of people points to the importance of understanding group actions and interactions during various fire emergencies.

Collectivities and Small Groups

Attempts have been made to learn about the behavior of collections of people in other stressful settings. One strategy has been to contrive a "panic" situation and observe the results. Researchers using this approach have created laboratory fabrications of various emergency conditions that might affect small groups or organizational components. Kelley et al. [1965] conducted experiments requiring mutual dependence during mock panic escapes. They found that when members of a group took their cues from each other, one of two things happened: if there was little optimism about escape, interaction proved to be harmful; a high level of optimism, on the other hand, was reinforced by interaction. The authors further determined that public expressions of confidence reduced anxiety and greatly increased the percentage of people who managed to escape. Guten and Allen [1972] studied group panic behavior under varying likelihoods of success. They concluded that the perceived chances of escape influenced the intensity of their subjects' efforts. People tried harder when they were uncertain about the outcome. In addition, individuals tended to panic more in ambiguous predicaments than in those circumstances where danger was high but the probability of escape was very low.

In an attempt to improve the chances of escape in emergency conditions, Sugiman and Misumi [1988] directed two field experiments. One took place at an underground shopping mall and the other was held in a fire school basement. In both cases the problem involved evacuating several dozen participants through one of two or three exits. In their investigation, the authors compared a pair of emergency evacuation methods. The control method consisted of having a leader indicate the direction of an exit with a loud voice and vigorous gestures. This is the traditional approach used in evacuation drills. In the experimental method, a leader quietly chose an evacuee and asked that person to follow along. It was found that this experimental method worked especially well when the leader-to-evacuee ratio was fairly high. A subject directed by the leader, and three or four people who saw what the leader was doing, would begin heading toward an exit. Thus, an escape group formed. Individuals nearby gradually joined this emerging group without any direct influence from the leader. Sugiman and Misumi concluded that more people were evacuated in less time by using small groups as levers to activate the collectivity than by relying on shouted directions.

Korte [1969] investigated the effects of group communication on male subjects' willingness to give help in a staged medical emergency. Sixty sets of three individuals—a true participant and two plants—were placed in small adjacent rooms interconnected by intercoms. Experimental conditions were varied according to levels of responsibility (some subjects were told the other two would be strapped down for monitoring) and communication patterns among the confederates (none, minimal, or total). As an experimenter delivered instructions over the intercom, he pretended to have a severe asthma attack. The test criterion was whether or not a subject would leave the room and locate the victim to see if he needed help. Interestingly, 50% of those who believed they were the only ones available to go to the stricken person's aid did so. Only 37% of those individuals who thought the others were also free went to help. Regarding communication, the highest level of intervention (55%) occurred among subjects who overheard no discussion over the intercom. Participants least likely to respond (35%) were ones who heard the confederates expressing concern and trying to diagnose the problem.

Obviously, such experiments may be of questionable validity because they are often far removed from the actual situations they intend to explore [Sime 1985]. Therefore, attempts have been made to bridge the gap between experimental and real-world conditions through realistic simulations. Drabek and Haas [1969] put three teams of police communications personnel through a series of exercises in order to assess organizational stress. First, they established a baseline by simulating three routine situations. Then, a mock disaster was held. The authors found organizational stress to exist in terms of increased discrepancies between demand for services and the system's capacity to respond. As a result, decision-making processes changed. Officers, who under normal conditions functioned autonomously, began to ask each other for information before making decisions about how to handle calls. This teamwork evolved as the stress mounted.

Reinartz [1993] conducted an empirical study to determine whether a simulated nuclear powerplant incident might be a valid way to gain insight into team behavior under stress. In addressing some of the methodological issues involved, she focused on a critical point concerning validity. There is one important feature of emergencies that simulations are unable to recreate. The life-or-death consequences of one's actions. Noting that this matter is raised often as a form of criticism, Reinartz [1993] offered a counterargument. The complexity of a task, its nonroutine nature and the associated time constraints are stressors in themselves. She found support for this contention in certain behavioral attributes of team members. Individuals were observed to speak rapidly, repeat themselves, show irritation, and pace aimlessly. Additionally, there were performance-related characteristics such as the narrowing of attention. The author concluded that in those situations where direct observation of group processes is not possible, simulations provide a reasonable alternative.

Many researchers are willing to sacrifice classical scientific rigor for a better understanding of what happens in real events. After reviewing 15 years of research on observed behaviors "in actual crowd situations," McPhail and Wohlstein [1983] reached several conclusions, two of which are pertinent here: "First, there is growing evidence that...most individuals assemble and remain with friends, family, or acquaintances. Those social units constitute sources of instructions and sanctions for the individual's behavior. We must learn what participants do; when, where, and with whom they do it; and at whose suggestion and with what sanctions they behave as they do...Finally, while we know far more today than 15 years ago...much of what we know is that traditional characterizations are inaccurate and traditional explanations will no longer suffice."

Aveni [1977] is one of those who argued that existing approaches to the study of behavior in crowds were inadequate. According to this author, most of the literature dealing with collectivities has been based on individual levels of analysis. Aveni collected data on persons in crowd situations and found that a majority of the participants were actually interacting with others. Such findings strongly suggest a need to give group-level variables more consideration when thinking about how people act in mass events. A similar idea was put forth by Shibutani [1955], who pointed out that people tend to adopt the outlook of groups with which they identify. These perspectives influence and reinforce individual behavior in many circumstances that would otherwise be characterized by confusion and indecision.

Levit [1978] reviewed disaster literature in order to abstract several principles of behavior in extreme situations. He listed some of these as generalizations. They are included here, along with a few illustrative points by other authors:

(1) A distinct syndrome is associated with response to emergencies. Its expression, however, differs by culture context. Jacobson [1973] described this effect in her discussion of group reactions to confinement in a skyjacked plane.

(2) Individuals tend to perceive and interpret disaster cues in reference to familiar aspects of their environment. Tornadoes, for instance, are thought to sound like approaching trains [Taylor et al. 1970].

(3) People will see the initial problem in different ways and hence make survival decisions that vary in quality. Spitzer and Denzin [1965] found that one contributing factor, level of knowledge, varies widely among affected populations.

(4) The incidence of nonrational behavior (panic) is much less prevalent than popular accounts imply. In fact, it is hard to understand why this stereotyped image has hung on for so long. Sime [1990] speculated that the concept has proven useful in minimizing responsibility when designs do not work as expected.

(5) Good preparation leads to a more effective response. Experience really is the best teacher, according to Sorensen [1983]. The main point in Levit's seven principles of behavior is that planning for emergencies must take into account anticipated behavioral patterns of collectivities.

Dynes and Quarantelli [1968] connected what is known about real life "unstructured" behavior with scientific theories of organization. Their rationale was that much of the activity taking place in nonroutine events involves institutionalized behavior. The authors viewed group behavior in extreme situations as being one of four different types. They derived this typology from a cross-classification of two variables: the nature of group tasks during a crisis (regular or nonregular) and whether group structure is old or new. Each cell of the resulting two-by-two matrix will characterize one type of group, as shown in table 1.1.

Table 1.1.—Types of group behavior in disasters (after Dynes and Quarantelli [1968]).

	REGULAR TASKS	NONREGULAR TASKS
OLD STRUCTURE	Type I - Established	Type III - Extending
NEW STRUCTURE	Type II - Expanding	Type IV - Emergent

An example of type I is a police force directing traffic around the scene of a disaster. Type II could be a group, such as Red Cross volunteers, that exists only on paper until an emergency takes place. Type III is illustrated by a construction company using its workers and equipment in a rescue operation. Type IV might be an ad hoc group running a command center. The concepts and vocabulary developed with this typology have been used and extended in a variety of related research projects [Bardo 1978; Drabek 1987; Johnston and Johnson 1989].

One reason researchers have revised Dynes' and Quarantelli's typology is to address the time element. For example, Drabek [1987] added phases used by the Federal Emergency Management Agency (FEMA). These phases are: mitigation, preparedness, response, and recovery. Another modification of the typology recognizes that some disaster tasks and structures may not be routine, but also are not necessarily new. Bardo [1978] introduced the concept of latency. Latent tasks and structures do not exist in day-to-day operations, but are in place to be used when needed. For example, a safety department may have an emergency response plan that covers actions to take during any large-scale disaster. As these events occur infrequently, tasks are not routine, but are defined in the plan and used occasionally. They could, therefore, be considered latent when not in use. A similar argument can be made for structures, e.g., the local Red Cross chapter will be activated as a functioning emergency response organization when needed.

Several insights may be drawn here. First, emergency activities (including escape) are not individualistic. They tend to be group responses. Therefore, models based on assumptions of individual behavior will be inadequate for certain purposes, such as in the creation of design features. Second, leaders can have a significant impact on people's perceptions and subsequent behavior. Thus, they may influence the group's survival chances. Third, individuals are more likely to help others in some situations than in others. Generally, if the responsibility is perceived as diffuse, a person is less apt to offer assistance. Fourth, informal groups may emerge in organizations for the purpose of dealing with nonroutine situations. Finally, team decision-making may become more common under conditions of stress, even in organizations that do not encourage teamwork.

Decision-Making

Much early work on decision-making was done by cognitive psychologists, resulting in an individualistic orientation to the research. From this perspective, the person is actively involved in a process characterized by a number of elements: (1) the detection of a problem, (2) a definition or diagnosis, (3) consideration of available options, (4) a choice of what is perceived to be the best option given recognized needs, and (5) execution of the decision based on what has gone before [Flathers et al. 1982; Baumann and Bourbonnais 1982]. At any moment in this process it is possible for a person to miss elements, either because of external factors or because of his or her mental state. When this happens, solving the problem becomes more difficult and at some point will be impossible.

Researchers have focused on a few variables that seem to have significant impact on one's ability to solve complex problems under time constraints. These are (1) an internal state [Hedge and Lawson 1979], which is the sum of an individual's psychomotor skills, knowledge, and attitudes, (2) a condition of uncertainty [Brecke 1982], caused by faulty or incomplete information received from the environment, (3) stress [Biggs 1968; Jensen and Benel 1977], generated both by the problem at hand and by any background predicament that might exist, and (4) complexity, which refers to the number of elements that must be attended to. These factors reflect the underlying demands on decision-makers in most life-or-death situations. Whether the individual is an airline pilot, a firefighter, a nurse, or a coal miner, an emergency event imposes the necessity of dealing with an enormous quantity of sometimes faulty information in a very short timeframe.

Kuipers et al. [1988] conducted a "thinking aloud" experiment to determine how three expert physicians made decisions when choosing among difficult diagnostic and treatment alternatives. The authors found that when these doctors were faced with considerable uncertainty and risk, their thought processes did *not* resemble a classic decision tree. Rather, decisions were constructed through an incremental process of planning by refinement. Kuipers et al. [1988] noted that early decisions were made using simplified, abstracted information about alternatives. More specific data that might have had a bearing upon choices were not considered until later. Additionally, the physicians tended to express likelihoods not as numbers, but as symbolic representations. Conclusions reached by these researchers suggest that humans use a more primitive category system in their decision-making processes than a "rational man" model would indicate.

Nakajima and Hotta [1989] studied information-seeking as it related to task complexity. They examined several features of predecision behavior: (1) perceiving the existence of a decision to be made, (2) searching needed information, and (3) evaluating and integrating this knowledge. There were 75 subjects, who were required to choose among 3 or 6 alternatives described by 6 or 12 attributes. The investigators discovered that people shifted their search processes to adapt to the environment. Moreover, their subjects were prone to make a tradeoff between effort and error. More difficult tasks were tackled by employing simplification strategies, even when it was obvious the resulting decision might not be optimal.

Dorner and Pfeifer [1993] looked at strategic thinking behavior among 40 participants in a computerized forest firefighting game. Twenty of the subjects were placed under conditions of stress involving disturbing "white noise." The others were left free to focus on their tasks. Everyone then went through five hour-long exercises having differing levels of difficulty. Dorner and Pfeifer found that subjects under stress saved as much of their forests as did those who were unhindered. However, behavior patterns were not the same. Stressed persons worked with general outlines of the situation, while nonstressed individuals relied more on in-depth analysis. As a result, stressed participants made fewer errors in setting priorities. Nonstressed players, on the other hand, were better able to control their firefighting operations.

Jaffray [1989] discussed findings from several experimental studies calling the standard model of decision analysis (expected utility theory) into question. Stated simply, the premise underlying this concept is that people attach units of value to the probable outcomes of certain courses of action. Therefore, assuming rational behavior, a person will seek to maximize the value (utility) of his or her efforts. The motive to act is based on some utility of that behavior's outcome combined with a perceived chance of success. A problem, according to this author, is that activities under risk do not fit the paradigm. Real-world behavior is affected by factors such as shifting reference points, simplification, and other biases that make attempts to equate rational behavior with utility maximization very difficult. Jaffray closed his article with an expressed opinion that the expected utility theory of decision-making under risk has lost its dominance.

Using such a model to describe group decision-making is even more of a stretch, because, as many social scientists realize, group behavior is the result of more than aggregated individual motives. There are system properties that people create through interaction [Tuler 1988]. Communication is one of these properties that has received a considerable amount of attention recently. Jarboe [1988] tested small group problem-solving effectiveness. Forty discussion groups, composed of four subjects each, were set to work on a contemporary issue. Their task was to report out a solution. One of Jarboe's most intriguing and relevant findings involved the role of solidarity. Solidarity, formed in the communication process, led to increased satisfaction with procedural details. Jarboe concluded that too much solidarity, however, tended to affect productivity. It was in situations marked by a certain amount of tension (though not stress) that the most ideas were generated.

Klein [1993] noted that stressors that affect individual decision-making may have an even greater impact on team performance. He listed several of the more common ones: (1) time pressure can throw off coordination; (2) ambiguity is multiplied, because not only do individuals feel uncertain but no one can be sure how others are interpreting events; (3) noise, which does not always affect individual performance, may seriously degrade group communication; (4) team members who feel responsibility could experience frustration since they have less control; and (5) high work loads are a problem insofar as people have to cope with coordination difficulties when tasks are not completed on time. In Klein's opinion, much can be learned about team decision-making by considering how it functions under stress conditions.

Tuler [1988] reviewed research on individual, group, and organizational decision-making during technological emergencies. He identified four categories of factors that can affect performance and result in decision failures. First, structural characteristics such as physical layout, organizational hierarchy, and work rules can have a great impact on the interactions of people. Second, workplace culture is very important. Human information processing and decision strategies depend heavily on subjective criteria. Third, communication networks are critical. Recovery from a system failure may hinge on the ability of information to flow quickly, accurately, and reliably. Finally, the kinds of tasks that individuals must perform will have a bearing on their proficiency in emergencies. Tuler concluded that scientists and engineers need a better understanding of behavior in real systems.

Discussion

There are three general themes in the literature reviewed above. The first is that, as far as system design procedures are concerned, human behavior is a "black box." This means that designers have assumed people will act in whatever way the system demands. At times, such an approach has led to disastrous or nearly disastrous consequences [Klein 1993]. For example, at the Indian Point No. 2 nuclear powerplant, one of two sump pumps blew a fuse and the other developed a stuck float mechanism. Since these were redundant systems designed *not* to fail at the same time, workers decided that an indicator light showing high water in the sumps must be defective. In other words, confronted with an obvious malfunction somewhere, personnel chose to render the *simplest* explanation (a faulty indicator light), rather than believe a fail-safe system had failed and act on *that* assumption. This allowed 100,000 gallons of water to accumulate at the bottom of the reactor vessel. It was only when another failure required technicians to enter the building that the water buildup was discovered and a catastrophe averted [Perrow 1984].

In fact, individuals are not limitlessly tractable. Their thinking is structured and their behavior is patterned. They will bring their own interpretation and response to such things as warning indicators. This fact led Tuler [1988] to comment: "Great attention should be given to developing systematic design and implementation approaches that enhance the correspondence between the behavior demanded of individuals...and the behavior of which they are capable."

A second general theme points to the fact that emergencies tend to involve *groups* rather than individuals acting alone or in aggregate. Groups respond differently than individuals. Group decision-making is not just a mental process; it has a social element. "Social processes suggest that organizational, social, and cultural values are important factors in behavior and error generation" [Tuler 1988].

A final theme regards rational choice which, insofar as designers incorporate people into their plans, is the model used to explain human behavior. This theory implies the existence of complete information, a set of utility functions attached to alternatives, and individuals who make decisions according to maximization rules. Even if persons acted in conformity with this model, "evidence suggests that organizations [do not]" [Tuler 1988].

In the process of examining worker responses to underground mine fires, this book explores significant areas that Tuler [1988] identified as needing further research. They are (1) the effects of faulty or incomplete information on decision-making, (2) ways in which knowledge bases and organizational structure affect decision behavior and outcomes, (3) how communication constraints can hinder strategic thinking, (4) the impact of time pressure on group acts, (5) development of shared mental models, (6) how group think leads to bad decisions, and (7) the role of simulations and other training in enhancing respondents' proficiency and performance. These issues will be addressed from a perspective that sees "little to be gained from proving one more time that the model of rational choice is counter to mountains of evidence" and instead "views processing of information as secondary and recognizes that the main context for making decisions lies in...cultural, and above all, structural factors" [Etzioni 1992].

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CHAPTER 2.—OVERVIEW OF THE UNDERGROUND ENVIRONMENT AND STUDY SETTINGS

This chapter details the perspective from which collected data have been examined. The first part, intended primarily for lay readers, discusses several topics related to mining as an enterprise. Initially, the organizational functioning of a typical large mine will be described. It is the formal structure above a miner that decides the conditions of his or her work. A second point of concern is the technology itself. An underground coal mine is a sociotechnical system, with workers and machines organized in particular ways during production. Third, general conditions and dangers underground will be described in detail. The physical environment of an operation is a powerful factor in the work life of miners. Fourth, a discussion of the process of formal training is given. During this training, a new worker is taught what the organization expects of him or her in the role of safe, productive, coal miner. Next, there are outside organizations that act as significant forces in the workplace. Examples include the Mine Safety and Health Administration (MSHA), State agencies, and the United Mine Workers of America (UMWA). The roles of these entities will also be examined. The second part of this chapter will depict each study site as a concrete setting, so that findings can be interpreted in their proper context.

The Organizational and Technical Nature of Mining

A coal mine is a complex system. It is defined as all parts of a mining plant's property (both underground and surface) that contribute, under one management, to the extraction or handling of coal [American Geological Institute 1997]. As suggested, many functions that must be carried out at an operation are only indirectly related to coal mining and processing. Even the jobs that are directly related tend to be numerous and varied [Wallwork 1981]. According to Palowitch [1982], the chief reason for this sophistication is that "after more than two centuries of exploiting our coal resources, today's coal industry finds itself saddled with a horrendous legacy of human impairments and environmental damages which society demands be corrected." Now, the effects of government regulation are evident in every aspect of the mining industry. Any operation, if it is to survive, must be administered with an eye for social efficiency and accountability.

Long-range planning is needed to ensure that the mine produces coal in a cost-effective manner. One of the first things that must be considered is location and method of access. To extract coal from an underground mine, a coalbed (or "seam") must be reached from the surface. The term "portal" is generally given to any entrance that provides access to a coal mine. In hilly terrain, such as is found in Appalachia, the coal may "outcrop" on a hillside. This allows direct entry to the coal seam via a horizontal tunnel ("drift") opening. At other locations where there is no outcrop, it may be possible to open a "slope" tunnel that angles down from the surface and intersects with the coal seam. If the seam is too deep for a slope to be feasible, a "shaft" must be constructed. This shaft, which may be 20 ft or more in diameter, is opened vertically from the surface to the coalbed and allows access via a large elevator.

During long-range planning there is a general focus on such essentials as equipment type, deployment, utilization, and haulage. Laying out a mine also involves auxiliary factors including ventilation arrangements, roof support plans, power distribution, and communications. All of these planned systems are incorporated into a "projection map" that is developed by a team of technical specialists. This team will include, at various times, mining engineers, electrical engineers, industrial engineers, and company geologists, among others. The mine map serves the same purpose for a person running an operation that an architect's blueprint serves a building contractor. It provides an overview of the project, shows where features should be located, helps management direct crews effectively, and serves as a tool in the planning of everything from maintenance schedules to capital expenditures for major equipment purchases.

Responsibility for translating the long-range plan into day-to-day operations belongs to a mine superintendent. This person is in charge of the overall mine complex, including surface facilities. An assistant superintendent helps the superintendent perform his duties and at some sites oversees all underground operations. At least one general mine foreman reports to the assistant superintendent. This individual directs day-to-day underground operations. For each working shift at the mine, there is at least one shift foreman ("shift boss") who reports to the general mine foreman. The shift boss is in charge of mining-related activities including coal extraction and service work. Each production crew in the mine is placed under the direction of a section foreman ("face boss") who manages mining operations on his or her section and who reports to the shift boss. There are also supervisors who oversee specialized support work underground. These foremen manage (1) maintenance, (2) belt installation, (3) supply activities, and (4) track laying and repair. All of these individuals report to the shift boss or the general mine foreman.

The long-range plan provides structure for a superintendent's short-range planning. If coal is to be mined productively, it must be obtained systematically. This requires the integration of several weekly plans into a smooth limited projection. One of the most important functions of a superintendent and his subordinates is to maintain an effective extraction cycle at the point of production. To do this extraction, plans must incorporate the following factors: (1) a determination of the shift for each section at which coal production will take place, (2) a decision about when the section will be idled so that belt and power moves can be made, (3) the scheduling of regular equipment maintenance, (4) provision for special projects such as the installation of belt head drives, and (5) preparation for any tasks that cannot be accomplished during regular workdays, such as shutting down and repairing the ventilation fan. The better a mine superintendent is at planning for and taking care of all of these details, the more smooth-running and efficient an operation will be.

After entering their portal and reaching the underground workings, a typical production crew will board a self-propelled personnel carrier known as a "mantrip" and travel to their "working section." This is where coal is extracted, and may be miles from the portal. "Working faces" are the individual places on a working section where mining activities take place. Here, sets of parallel tunnels ("entries") are driven through the coal seam following a predetermined plan developed by a mining engineer. Mine entries are 16 to 20 ft wide and as high as the coal seam is thick. The number of entries being mined in a working section varies from 2 to 10 or more depending on many factors. As parallel entries are developed, they are connected by perpendicular tunnels ("crosscuts"). Like entries, crosscuts are also usually 16 to 20 ft wide and as high as the coal seam is thick. Crosscuts, or "breaks" as they are sometimes called, allow workers and equipment to move between and among the entries. The walls of entries and crosscuts are called "ribs," while the ceiling above is called the "roof" or "top." The mine floor is typically called a "bottom."

As coal is mined, a working section advances toward the boundaries of the coal property. This advancement is generally known as "development mining" and follows a "room-and-pillar" mining plan. With a room-and-pillar plan, entries and crosscuts are opened through the seam while large blocks of coal ("pillars") are left in place to help support the mine workings. In the United States, most development mining following a room-and-pillar plan uses "continuous mining" technology. Work crews on a continuous mining section are usually composed of 8 to 10 individuals. A typical crew might consist of (1) one face boss, (2) one continuous miner operator and a helper, (3) two roof bolting machine operators, (4) two shuttle car operators, and (5) one mechanic. These workers perform two operation cycles at the working face that include (1) cutting and loading of coal and (2) support of the mine roof above the entry or crosscut.

With continuous mining, operations progress sequentially at each face on a working section. First, an area from which coal has already been extracted (commonly called a "cut") must have its roof supported. The roof is "bolted" by one or two miners who operate a "roof bolter." The roof bolter is a rubber-tired, electrically powered machine with rotating drill heads. It puts holes in the mine roof. Steel bolts (48 to 96 inches long) are then inserted into these holes and tightened. They bind together layers of rock strata located above the cut. This, in effect, creates a supporting beam between coal pillars and across entries and crosscuts. Thus, the roof is prevented from collapsing. Next, a "continuous miner" is "trammed" into the face. A continuous miner is an electrically powered machine that moves along on crawler tracks similar to bulldozer treads. The machine has a rotating drum ("ripper head") about 10 ft wide and 3 ft in diameter, on which cutting bits are mounted. The ripper head rotates and cuts coal from the face. A pair of mechanical gathering arms, located beneath the ripper head, then sweeps the dislodged coal onto a short conveyor. This conveyor moves the coal to the rear of the machine, where it is dumped into a shuttle car (or "buggy"). A buggy is a rubber-tired electrically powered haulage vehicle that can carry 6 to 10 tons of coal. Usually, two buggies transport coal from the face to a conveyor belt dumping point. From this dumping point on the working section, coal is typically transported out of the mine via a series of conveyor haulage belts. In some mines, however, coal is dumped directly into small rail cars. Groups of these cars, known as "trips," are pulled by electrically powered locomotives to a main underground dumping point. From there, the coal is transported out of the mine via conveyor belt.

Once a mine (or a portion of it) is developed, the development sections may then become "retreat" mining sections. In retreat mining, coal pillars that were originally left in place for support of the mine entries and crosscuts are themselves extracted. The basic approach is to mine in a series of cuts, supporting the roof with timbers, bolts, or a combination of both. As these pillars are removed completely, the mine roof they once supported collapses.

In many large mines, retreat mining has been replaced by longwall mining. To establish a longwall, two parallel continuous miner sections, each consisting of two to four entries, are advanced 5,000 ft or more to a predetermined point. They are then turned and driven toward each other until they join. Once these sections are joined, they have created a large block of coal, 600 to 1,000 ft wide and approximately a mile long, that is known as a longwall "panel." Crews on a longwall mining section are made up of 8 to 10 individuals. A crew might consist of (1) one supervisor, (2) two shearer operators, (3) two shield operators, (4) one headgate operator, (5) one tailgate operator, and (6) one mechanic. These workers run large specialized equipment, which has been dismantled on the most recently mined longwall section, then brought in and set up at the new face. Panel extraction consists of completely removing this large block of coal that was created during the development process. Strata are allowed to cave behind the longwall as coal is mined back in the direction from which the parallel "setup" sections were started.

Longwall mining operations depend on the use of self-advancing hydraulic roof supports called "shields." These are massive overhead steel structures supported by large multistage hydraulic jacks. The jack system allows shields to be raised and lowered mechanically as a face is advanced. Shields are placed side-by-side in a row so that they form a protective canopy along the entire length of the working face. Coal is removed from the face by a rotary drum shearing machine or "shearer." This shearer rides on top of a flexible, segmented conveyor ("pan line") that runs along the face. It is attached to the front of the shields by hydraulic jacks. The shearer has circular cutting heads mounted on long arms that are affixed to each end of its main body frame. A cutting head is equipped with carbide bits arranged in a spiral formation. The head rotates to cut a strip of coal 30 to 40 inches deep from the longwall face as it is moved across the panel. This extracted coal falls onto the pan line for transportation across the face to the panel's belt conveyor. The panel conveyor then moves the coal to the mine's main haulage belt for transport outside.

Fresh air must be supplied to all working areas of a mine. Air is drawn into a mine from the outside by one or more propeller-type, axial-vane fans that may be as large as 8 ft in diameter. These fans can move several hundred thousand cubic feet of air per minute. Entries serve as "intake" (fresh) and "return" (contaminated) aircourses that channel the air through a mine. Intake and return aircourses are separated by concrete block walls ("stoppings") that are built in the crosscuts between entries. Where intake and return aircourses must cross each other, air bridges ("overcasts") are used. Air moving through the mine and sweeping across its working faces carries away smoke, dust, and accumulations of methane gas. The intake and return aircourses also function as escapeways for miners should a fire or other type of emergency occur. Federal mining law requires that underground mines must maintain two separate and distinct travelable passageways designated as escapeways from each working section. At least one of these two escapeways has to be located in fresh air.

While an underground coal mine is in some respects like a factory, the working environment is very different. The only lighting, for instance, comes from miners' battery-operated cap lamps or from localized sources on various equipment. At the face, production crews must contend with work areas that can be dusty, or wet and muddy depending on the amount of water that may be present. These places can also be extremely confined, especially in mines where the seam thickness is not great. To extract coal, miners must operate large machines under such conditions. Outby[1] support personnel are scattered through the labyrinth of underground entries. They are needed to help maintain the many auxiliary subsystems found in the mine. Work done by these miners includes building and maintaining air stoppings, installing supplemental roof supports, cleaning coal spills around or under conveyor haulage belts, moving supplies, maintaining electrical installations, and conducting hazard inspections. Generally, these support workers do their tasks singly or in small crews, usually without direct contact with other miners, supervisors, or the outside world. They also have to deal with poor footing due to uneven or muddy bottom. In sum, all miners must do their jobs in an environment that is harsh and potentially dangerous.

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[1]"Outby" means away from the working face of the mine. The opposite is "inby," or toward the face.

Mine Dangers

No matter which technical division of labor is being used, miners create a void under the Earth's surface—a void that is potentially deadly, as Palowitch [1982] has illustrated. To reduce the risks associated with mining, all face equipment must meet permissibility standards set forth by MSHA. In addition, all sources of open flame such as matches and cigarette lighters, welding equipment (except in designated areas), and unsealed lights are strictly prohibited. Even in mines where these regulations are rigidly enforced, however, there is still the danger of ignition from steel bits striking rock or pyrites, from sparks caused by slabs of roof falling against metallic surfaces, or from willful violation of the standards and prohibitions.

Increased mechanization and the introduction of greater numbers of electrical machines have resulted in mine fires being ranked just behind explosions as a major cause of mine disasters. Of 877 mine fires that occurred between 1952 and 1970, 351 happened at or near the working face, and the remaining 526 were at various spots throughout the mine. Sixty-nine percent of the fires at or near the face were determined to have had an electrical source [Palowitch 1982]. The origin of fires outby the face were most often frictional ignition of conveyor belts, or spontaneous combustion in abandoned sections of the mine [Kutchta 1978]. A survey of coal mine fire reports conducted by Allen Corp. [1978] showed that the number of fires increased from 28 in 1951 to 184 in 1960, then decreased to 25 in 1977.

However, mine fires are still occurring, sometimes with disastrous consequences. An example is the fire disaster that took place at Emery Mining Co.'s Wilberg operation on December 19, 1984. On that date, company officials informed miners on the Fifth Right longwall panel that the mine would attempt to break a world record for 24-hour longwall production. On second shift, with the record within reach, nine extra workers were sent to the section and eight management people accompanied them to see the record broken. When fire (ignited by a faulty compressor near the intake of Fifth Right) broke out, smoke and carbon monoxide poured in on the 28 people on the section. Unable to don their self-contained self-rescuers (SCSRs), evidently because of lack of adequate training, most of the miners attempted to escape barefaced down either the intake or belt entry. They were quickly overcome, and died. Three miners tried to get out through the tailgate return entry. That entry had been allowed to collapse several weeks before, and the cave-in made it impassable. The miners' bodies were found at the blockage. The last survivor wriggled through a "squeeze" in the bleeders where the roof had caved in and the floor had heaved up. He made it into the clear and walked several hundred feet before being overcome by carbon monoxide poisoning and dying, with an unopened self-contained self-rescuer around his neck [Moore 1987].

There are several system failures implicit in the Wilberg disaster: (1) nonessential personnel were in attendance at a time when workers and equipment were being pushed to break a production record; (2) the faulty air compressor was allowed to run unattended in a nonfireproofed area; (3) at least some of the miners died, not necessarily because there was a fire, but because entries running off the tailgate of the longwall were blocked by a cave-in; (4) firefighting preparedness was inadequate; and (5) the miners were not adequately trained in how, and under what conditions, to employ nonroutine safety skills such as the use of their emergency breathing apparatus.

The Training Process

All persons entering an underground coal mine must be trained. The type of training required, and the amount individuals receive, depends on their status and function in the mining environment. 30 CFR 48 stipulates that each operator of an underground mine must file, for approval by MSHA, a plan that contains programs for (1) training new miners, newly-employed experienced miners, experienced miners assigned to new tasks, (2) annual refresher training, and (3) hazard training for miners and visitors. The course content and minimum hours of instruction for each of these programs vary. It has been argued that U.S. miners may be comparatively poorly trained for many nonroutine events they are likely to encounter. McAteer and Galloway [1980] summed this notion up in a report comparing training in the United Kingdom, West Germany, Poland, Romania, France, Australia, and the United States: "Training and supervisory certification requirements in the United States are less thorough than those of any other nation studied."

New miner training, which is what people receive before reporting to work, prescribes at least 40 hours of instruction in miners' rights under the law, the use of self-rescue and respiratory apparatus, procedures for entering and leaving the mine, transportation and communication, emergency evacuation and barricading, roof and ground control, rock dusting program, hazard recognition, electrical hazards, mine gases, health and safety aspects of assigned tasks, miner health, and an introduction to the specific work environment. Each year, all miners working underground must receive a minimum of 8 hours of annual refresher training that covers many of the topics just listed. All training, in order to comply with 30 CFR, must be given by instructors who have been approved by the Mine Safety and Health Administration, and is expected to be adapted to the mining operations and practices in existence at the company whose workers are being trained.

There is much technical information miners need, not only because of the hostile physical environment they face, but because continuing technological and organizational changes cause new problems in the workplace. An example may be gotten from the use of longwall technology in this country. Wala and Cole [1987] incorporated choices about where to place brattice curtains and take airflow readings into paper-and-pencil simulations of longwall operations. The researchers then administered the simulations to 90 mine workers responsible for making ventilation arrangements during cut-throughs at their respective operations. Nearly one-half of the respondents were shown to have potentially fatal misconceptions about the behavior of airflow during longwall setup procedures.

A factor in miners' lack of proficiency regarding some aspects of their work environment is that instructors often draw upon their stock of knowledge and present discrete bits of information unconnected to any grounding that would make them useful [Briggs and Digman 1980]. At times the training delivered this way may not be very well thought out. An example of this is provided by a segment of the hazard training offered to mine visitors under 30 CFR 48.11. The self-contained self-rescuer (SCSR) instruction traditionally consisted of an SCSR being shown by the mine's safety instructor, who would explain the procedure for putting it on "at the first sign of smoke."

The weakness of this demonstration is apparent, especially when one stops to consider the nature of SCSRs. First, SCSRs are complex closed-circuit breathing devices. Improper use of compressed oxygen rebreathers (one type operates on this principle) can lead to hypoxia and death. SCSRs that generate oxygen chemically are more fool-proof, but still must be handled correctly to be of any benefit in an unbreathable atmosphere. Second, unlike firefighting apparatus or mine rescue gear, which is donned and activated before the wearer goes into danger, an SCSR is meant to be put on under extreme conditions such as fires. From this perspective, it requires little imagination to understand that the intended user should be thoroughly task trained. Yet, it was not until September 1987 that MSHA, citing research begun shortly after the Wilberg disaster [Cole and Vaught 1987; Vaught and Cole 1987], promulgated regulations at 30 CFR 48 and 75 requiring hands-on instruction in the use of self-contained self-rescuers.

Cole et al. [1986], after observing and participating in many training sessions, made several generalizations about how classes are conducted: (1) The most commonly used technique of mine trainers is instruction for the rote learning of information. (2) There is a heavy reliance on the same sets of training films and procedures from year to year. (3) Trainees frequently fail to pay attention to the instruction, devoting their attention to what is going on around them instead. (4) When games are used as teaching devices, they usually focus only on factual recall of information and commonly detract from the content of what is being taught. (5) In many classes, great amounts of time are wasted, in the sense that it is not spent in instruction. (6) Segments of the day's program may degenerate into gripe sessions, with little of a substantive nature being accomplished. In short, the typical miner training class is not always effective.

Outside Organizations and the Mine

The U.S. Department of Interior's Bureau of Mines (USBM)[2] was created in 1910 as a legislative response to a seemingly interminable series of fires and other disasters that touched communities from Franklin, WA, to Belle Ellen, AL, to Wilkes-Barre, PA [Keenan 1963]. Although this was the Federal Government's first venture into mining regulation, it followed legislation enacted by the various coal-producing States by 20 to 30 years [Palowitch 1982]. Moreover, the USBM had no sanctifying authority. Its primary function was to conduct mine safety research and issue reports. Mine disasters have historically driven legislation, however, and following a rash of these disasters in 1940, the U.S. Congress passed the Federal Coal Mine Safety Act, which granted the USBM inspection authority, but only in order to gather and publish information on safety conditions. After a further string of incidents, the U.S. Congress took the next step: in the summer of 1952, the Federal Coal Mine Safety Act of 1952 (Public Law 82-552) was enacted. It contained section 209, which stipulated that USBM inspectors could issue an order of withdrawal from portions of a mine faced with imminent danger [National Research Council 1982].

The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) was the first comprehensive plan to protect "the health and safety of persons working in the coal mining industry of the United States." The Act provided for each underground coal mine to be inspected four times per year. It also set forth an array of interim mandatory safety standards covering roof support, ventilation, combustible materials, electrical equipment, blasting, transportation, and communication, among others. It also set forth a hierarchy of penalties for individual and corporate violations of these standards. On July 1, 1973, the Mining Enforcement and Safety Administration was formed within the U.S. Department of the Interior, but separate from the USBM. The USBM's inspection functions were vested in this new agency.

Federal regulations governing the mining of coal are currently contained in the Federal Mine Safety and Health Act of 1977 (Public Law 95-164). This act was promulgated in the wake of yet another round of disasters including the Sunshine silver mine fire. Perhaps the most significant innovation of the 1977 Act, besides the creation of an enforcement arm with enhanced rule-making and sanctioning capabilities, was the establishment of mandatory health and safety training. For the first time, the Federal Government was taking a proactive approach to removing "acts of God" as explanations of workplace accidents. There has existed, since 1977, a total package of administrative rules, periodic inspections, workforce preparation, and technical assistance. This comprehensive

[2]The safety and health research functions of the former U.S. Bureau of Mines were transferred to the National Institute for Occupational Safety and Health in 1996.

package is aimed at not only correcting, but also preventing health and safety hazards in the Nation's mines.

There is a second level of oversight at underground coal mines. State enforcement agencies station inspectors in districts around the coalfields. Beyond writing citations, some States also provide technical support for mines needing help in achieving and maintaining compliance. Finally, there may be a training and education division whose staff conducts various training and certification programs in the State. West Virginia and Kentucky have the most extensive education and certification programs for rank-and-file miners. For instance, all new miners are required to complete a course of formal instruction followed by an underground orientation, serve an apprenticeship, and pass an examination (oral and/or written) to receive his or her "miner's papers" [McAteer and Galloway 1980]. In essence, State and Federal regulations ensure a regular presence by government officials at an underground mine.

After the National Recovery Act, the United Mine Workers of America managed to insert safety and health provisions into the next several contracts. These included "reasonable" rules for safety and health (1937), union inspection of the mine (1939), establishment of safety committees (1941), clean working conditions (1943), a protective clothing allowance (1945), benefits for long-term injuries (1946), and the right to withdraw for safety and health reasons (1947). During the period of rationalization, however, no new provisions were negotiated. It was not until the 1971 contract that safety and health clauses were again added, largely as a response to specific sections of the 1969 Act [Short 1982]. Generally, there are now contractual provisions stipulating that at each union mine there must be a Mine Health and Safety Committee and a Mine (grievance) Committee.

The United Mine Workers of America has traditionally been a high-profile entity at operations it has organized. Rank-and-file employees at the three mines in this study were all members of the UMWA. Thus, the union was an organizational component that, along with Federal and State bodies, helped to shape the nature of workplaces at these sites. The following section describes each setting in turn, paying special attention to such things as personnel numbers, production figures, and technical layout. These sketches will provide readers a better understanding of the underground environments from which the miners were required to escape.

The Study Settings

Adelaide Mine

Adelaide Mine was an underground operation established in 1903. This mine was opened by six air shafts into the Pittsburgh Coal Seam, which had an average thickness of 72 inches. A total of 327 workers were employed at the operation; 278 worked underground and 49 had jobs on the surface. Coal was mined on five production sections. Three of these conducted development mining and two were on retreat. All working sections used continuous mining technology and the room-and-pillar mining method. Entries were on centers of approximately 70 ft with crosscuts on centers of approximately 90 ft. The mining company ran two production shifts per day, 5 days per week. Average coal output at this operation was just over 4,100 tons per day.

Coal was transported from the sections by 36- and 42-inch belts to an underground storage bunker. It was then loaded into 10-ton mine cars for transportation to a skip hoist. A 10-ton capacity skip hoist was used to raise coal to the surface. There, it was deposited into a raw coal silo to await processing at the mine's preparation plant. Supplies and machinery were lowered into the mine by an equipment hoist. Trolley locomotives were used to haul coal, supplies, and implements inside the mine. Trolley mantrips were used to transport miners to and from the working sections. Three exhausting axial-vane mine fans located on the surface provided ventilation to the workings. Permanent stoppings, overcasts, check curtains, and line brattices were used to control air flow throughout the mine.

Three working sections were located inby the source of combustion at Adelaide Mine. These are shown in figure 2.1.

2 Northwest

The 2 Northwest submains, where the fire occurred, was developed from the Southwest Mains. As development of this section progressed, panels were driven off to the left and connected at the back end of the section with bleeder entries. At the time this fire occurred, mining in 2 Northwest and the two panels driving off it was being done with two sets of face equipment. Machinery included continuous miners, shuttle cars, roof bolting machines, and battery-powered scoop tractors. An axial-vane exhausting mine fan located on the surface at Peterson shaft provided ventilation for all three sections in the 2 Northwest submains area of the mine.

At the mouth of 2 Northwest submains, entries were identified by numbers 1 through 8 (from left to right facing inby). Entries 1, 2, and 8 served as return aircourses, with entries 2 and 8 designated as alternate escapeways. Entries 3, 4, 5, and 7 functioned as intake aircourses, with entry 7 designated as an intake escapeway. The trolley haulage was located in No. 4 entry, with the conveyor belt located in entry No. 6. As the section advanced from Southwest Mains, a ninth entry was added at approximately 2,300 ft inby Southwest Mains. Entry 9 served as a return aircourse and became a designated alternate escapeway. A 10th entry was added to the section at about 4,200 ft inby Southwest Mains. This entry also became a return aircourse and designated alternate escapeway.

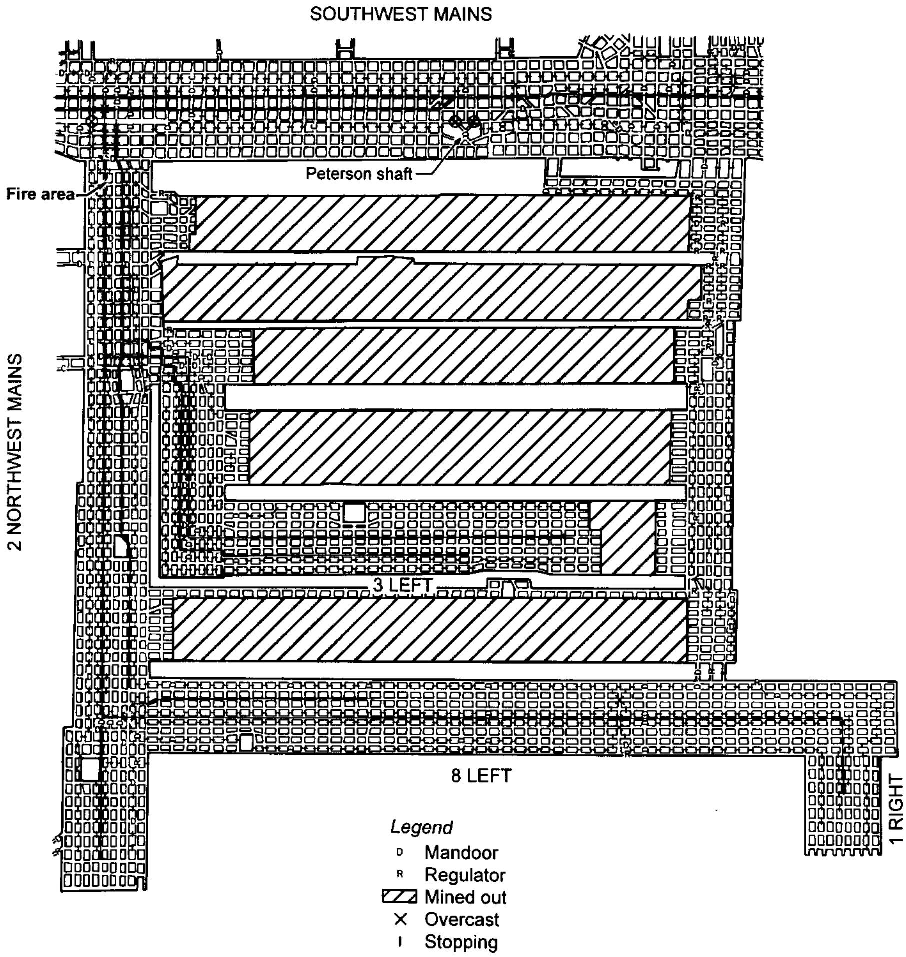

Figure 2.1–The three sections affected by fire at Adelaide Mine.

Because of a limited number of intake aircourses at the mouth of 2 Northwest, and since working sections were being advanced to greater distances from the main ventilating fan at Peterson shaft, mine management requested and received permission to use air from their belt entry also to ventilate the active working places. As part of their approval plan to use belt air for ventilation, the mine was required by MSHA to install a carbon monoxide (CO) monitoring system. This system had to be capable of detecting CO at a level of 1 ppm, using sensors installed in the belt entry every 1,000 to 2,000 ft (depending on air velocity). The system also had to be equipped with audible and visual alarms that activated automatically in the dispatcher's office and at the underground dumper's shanty when one or more sensors detected CO concentrations of 10 ppm or greater. Finally, the approval plan included a provision for elimination of a requirement that the belt and trolley entries be separated with stoppings. Separation of belt and trolley entries was continued in the 2 Northwest and 1 Right sections but was discontinued on 3 Left.

3 Left

At the time of the fire, 3 Left was a retreat section. This panel, consisting of nine entries, had been turned off 2 Northwest and driven approximately 3,500 ft to a point where the section connected with a set of bleeder entries. After all entries had been connected with the bleeders, pillar extraction was started. The section had retreated about 500 ft outby. Entries on this section were numbered 1 through 9, left to right facing inby. Entries 1 and 9 served as return aircourses, with No. 9 entry designated as the alternate escapeway. Entries 2 through 8 functioned as intake aircourses. No. 8 entry was designated as the primary escapeway and was separated from entries 7 and 9 by stoppings. The belt conveyor was located in entry 5, and the trolley haulage was in entry 7. As mentioned earlier, the belt and trolley haulage entries on 3 Left were not separated by stoppings.

1 Right

1 Right off 8 Left was a nine-entry development section that also turned off 2 Northwest submains. The section had been driven approximately 4,800 ft before it was turned 90E to the right. Entries on this section were numbered 1 through 9, left to right facing inby. Entries 1 and 9 served as return aircourses, with No. 9 also serving as the alternate escapeway. Entries 2, 3, 4, 6, 7, and 8 functioned as intake aircourses, with No. 6 designated as the primary escapeway. Trolley haulage was located in No. 3, and the belt conveyor was located in entry 5.

Brownfield Mine

Brownfield Mine was opened by one slope and eight shafts into two underground coal seams, one above the other. Both the Upper Kittanning (or CN) and Lower Kittanning (or B) Seam average 48 to 54 inches thick. At the time of the fire, Brownfield Mine employed 869 workers. Of this number, 804 individuals worked underground and 65 worked at various locations on the surface. There were 17 continuous mining units and 3 longwall sections that produced an average 7,000 tons of coal each day during 3 production shifts. Entries and crosscuts were developed 18 to 20 ft wide and were on centers of from 60 to 120 ft. This operation was ventilated by six axial-vane, exhausting mine fans located on the surface. Underground ventilation was controlled by permanent stoppings, overcasts, regulators, check curtains, and line brattices.

Coal from the faces of working sections was transported by shuttle cars and discharged onto conveyor haulage belts. A series of conveyor belts transported coal from each section to a loading area where it was dumped into mine cars. From this load point, coal was hauled in mine cars to a main rotary dump area underground. From the dump area, coal was taken via conveyor belt out of the mine to a cleaning plant for processing. Supplies and equipment were moved within the mine by rail using trolley locomotives. Trolley mantrips were used to transport miners to and from the working sections. On longwall panel development sections, miners would dismount their rail mantrips at the mouth of the section. They would then board rubber-tired personnel carriers and go to the faces.

6 West Mains

6 West Mains, where the fire occurred, had developed eight entries using continuous mining technology and the room-and-pillar mining method. Entries on 6 West Mains were numbered 1 through 8, left to right facing inby (figure 2.2). Entries 1, 2, and 3 served as return aircourses, with entry 3 designated as the alternate escapeway. Entries 4, 6, 7, and 8 functioned as intake aircourses, with entry No. 4 designated as the primary escapeway. Trolley haulage was located in No. 6, and the conveyor belt was located in No. 5. As coal extraction progressed in this area, longwall development panels were driven off to both the left and right of 6 West. Two of these were situated inby the fire's location.

4 South

The 4 South section was a three-entry longwall development panel that had been advanced approximately 2,000 ft from 6 West Mains. Entry 1 served as the return aircourse for this section and was designated as their alternate escapeway. No. 2 entry was the intake aircourse and functioned as a primary escapeway for the section. A conveyor haulage belt, located in entry 3, was ventilated by a separate split of intake air that moved from the section mouth inby to the belt tailpiece.

5 South

The 5 South section was also a three-entry longwall development panel that had been advanced about 1,000 ft inby from 6 West Mains. On this section, entry 1 served as the intake aircourse and was also the primary escapeway. The conveyor belt was located in entry 2 and was ventilated by a separate split of intake air that moved from the mouth of the section inby to the tailpiece. Entry 3 was the return aircourse and served as a designated alternate escapeway for this section.

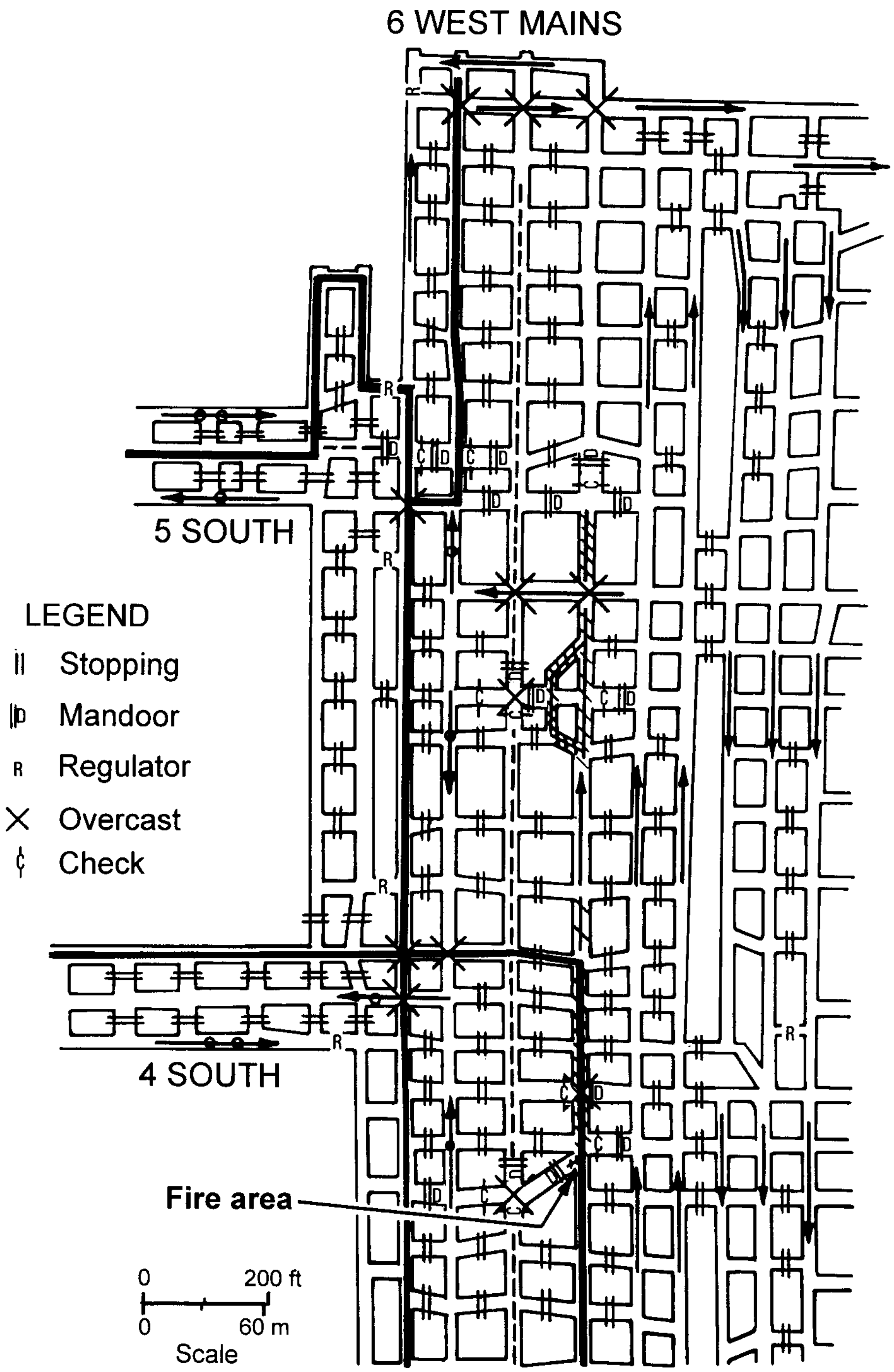

Figure 2.2–Area affected by fire at Brownfield Mine.

Cokedale Mine

Cokedale Mine was originally started in 1944. At the time the Cokedale Mine fire occurred, this operation was opened by one drift and eight shafts into the Pittsburgh Coal Seam. Here, the Pittsburgh Seam averaged 66 inches thick. A total of 408 persons were employed at the mine, 319 working underground on 2 production shifts and 1 maintenance shift per day, 5 days per week. The mine operated seven active sections and had three spare sections. Workers produced an average of 6,500 tons of coal per day. All sections were mined using the room-and-pillar method, with coal extraction being done by continuous miners. Entries and crosscuts were mined to a width of 16 ft. Entries were normally developed on centers of 64 ft, with crosscuts mined on centers of 96 ft.

Coal was transported from the faces by shuttle cars and dumped onto belt conveyors. These conveyor belts transported coal from the sections to underground loading tipples, where the coal was loaded into mine cars. From the tipples, 37- and 50-ton track locomotives transported trips of loaded mine cars to the surface, where coal was then processed at the mine's cleaning plant. Ventilation to the mine was provided by six exhausting axial-vane mine fans located on the surface. Intake air entered at the drift entrance and at seven intake air shafts. Permanent stoppings, overcasts, and undercasts were used to control air flow and provide the required separation between various aircourses. Permanent stoppings were constructed of concrete blocks with mortared joints or blocks plastered on one side. In areas of short production duration, steel panel stoppings were used. Face ventilation was accomplished using auxiliary fans and tubing.

From Cokedale Mine's drift opening (pit mouth), a series of seven or eight entries (main headings) were driven in a westerly direction. The fire at this mine originated in the loaded track entry of these mains (figure 2.3). It started at a point about 6 miles inby the pit mouth and 1,000 ft outby Steiner portal. At the time, entries 1, 2, and 3 were functioning as return aircourses, while entries 6, 7, and 8 served as intakes. Near the fire, entries 4 and 5 were track entries and accommodated Cokedale Mine's main trolley haulage from working sections to the pit mouth. Entries 4 and 5 also served as intake aircourses, and air velocity in these entries exceeded 250 fpm. They were developed before the Federal Coal Mine Health and Safety Act of 1969, which limited air velocity around trolley haulage systems to 250 fpm.

8 Face

The 8 Face section consisted of nine entries and had been developed in the mid-1950s to the left off the main headings. Entries 1 through 4 were intake airways, while entries 5 through 8 served as return aircourses. A series of eight-entry panels were developed to the right of 8 Face. After development, these butt panels were retreated back to 8 Face.

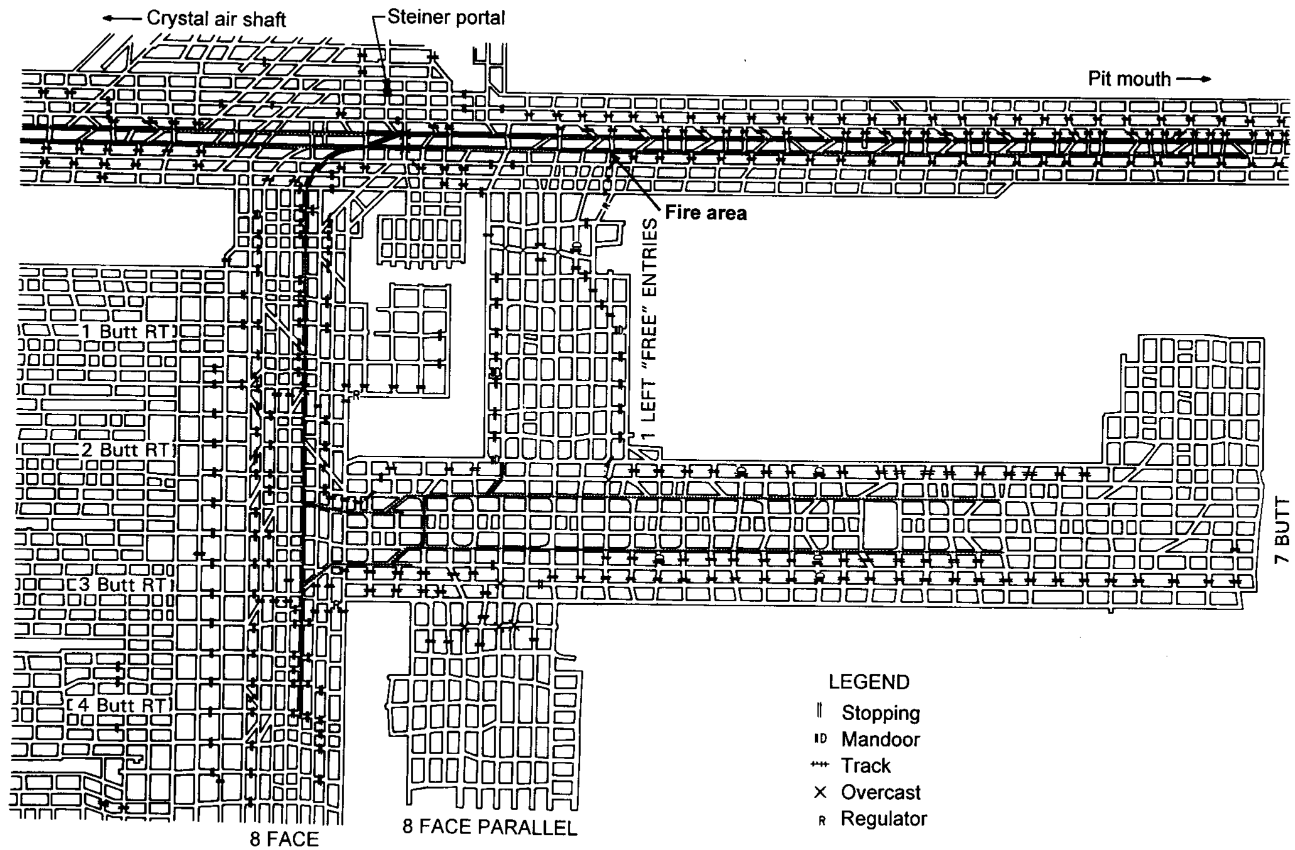

Figure 2.3.–Site of combustion source at Cokedale Mine.

7 Butt

In the late 1980s, a new series of nine entries, known as 7 Butt, were developed to the left of 8 Face about 1,000 ft inby the main headings. These entries were driven some 3,200 ft before the section was turned to the left. In this section, entries 1, 8, and 9 were designated return aircourses, while entries 2 through 7 served as intake aircourses. After 7 Butt had been advanced approximately 1,000 ft, a set of seven entries, known as the 1 Left "free" entries, were driven 90E off 7 Butt and connected with the haulage mains. The purpose for driving this set of entries was to provide more air to the developing sections.

8 Face Parallels

Just outby the 1 Left "free" entries along 7 Butt, a series of nine entries were developed 90E to the right. These entries, known as 8 Face Parallels, were being driven parallel to the old 8 Face entries. For 8 Face Parallels section, the primary (intake) escapeway followed No. 7 entry to its intersection with 7 Butt. The primary escapeway coming out of 7 Butt followed No. 8 entry out to the intersection of 7 Butt and old 8 Face. The old 8 Face entries were developed before the Federal Coal Mine Health and Safety Act of 1969; as a result, the intake escapeway from old 8 Face was routed onto the track entry. The alternate (return) escapeway off 8 Face Parallels followed No. 9 entry to the intersection with 7 Butt. The alternate escapeway off 7 Butt followed No. 9 entry to the intersection with old 8 Face. At this point, the return escapeway crossed over old 8 Face to the right-side return (No. 7 entry) of old 8 Face. The secondary escapeway in old 8 Face followed No. 7 entry to the section mouth. From there, the secondary escapeway followed the left-side return (No. 3 entry) of the main headings to Crystal air shaft.

Discussion

This chapter has depicted an underground coal mine as a well-planned, complex, and regulated system operating in a harsh environment. Additionally, it profiled the three fire settings to be discussed later. Since mines contain numerous pieces of electrical equipment, have various friction sources, and possess an almost inexhaustible supply of fuel, it is not surprising that they sometimes catch fire. Actually, small fires are somewhat common. Those that force an evacuation, however, are nonroutine events. While miners may be highly skilled at their jobs, the task of responding to this type of emergency requires a different set of proficiencies.

Earlier, it was suggested that safety training classes may not always give miners competencies they need to face contingencies in their workplaces. This brings up an interesting point as it relates to fire. Even though mines are potentially dangerous, they are not emergency organizations. Their goal is to extract a product—coal—and to do it profitably. Preparation for an event that may never occur will obviously not be given the same priority in a mine that it would merit on a naval combat vessel, for instance. What, then, is the appropriate way to view behaviors that will be reported in the chapters to follow? Workers at these operations did not display the discipline that well-drilled mine rescue teams would have, but is such an expectation realistic? Perhaps the best way to approach this analysis is to note that some groups responded much more effectively than others and to explore what factors led to such variation. That way, any recommendations for improvement are likely to remain in context, recognizing that mines are not emergency organizations.

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CHAPTER 3.—RESEARCH DESIGN AND SAMPLE PROFILE

Homans [1950] offered a working definition of group that is useful for this research: "We mean by a group a number of persons who communicate with one another often over a span of time, and who are few enough so that each person is able to communicate with all the others, not at secondhand, through other people, but face-to-face." This chapter begins with a discussion of the group concept in reference to the hypothesized escape groups mentioned earlier. It then moves to an examination of analysis techniques used by the authors. Finally, the subjects themselves are profiled according to their demographic characteristics.

The Nature of Groups

Warriner [1956] took a realist approach to understanding groups: "(1) the group is just as real as the person, but (2) both are abstract, analytical units, not concrete entities, and (3) the group is understandable and explicable solely in terms of distinctly social processes and factors, not by reference to individual psychology." Warriner's realist position merely holds that "group" occupies a different domain in which it is no more or less concrete than "person." At this group level the unit of analysis will be those relations that indicate social rather than individual behavior. It is possible to investigate these group properties empirically—if a researcher avoids confusing conceptual entities with concrete ones. Most people seem to accept that group attributes must somehow be inferred, but think personal attributes will be directly manifested, requiring little or no interpretation [Snizek 1979]. In other words, nobody would equate physical components of an underground working section with the actual work group, yet social scientists (as well as laypeople) very often confuse real individuals with notions of the person. In actuality, neither groups nor persons are directly disclosed to the senses; both are inferred by experience and observation. One can "see" a group just as clearly as one can "see" a person, given the proper perspective from which to do so. It is necessary, in developing this perspective, to begin with a sound definition of the thing being examined.

Besides communication, or more generally, social interaction, Homans [1950] included three other components of group makeup. "Sentiment" is characterized as the feelings people tend to form about one another when they interact often. These feelings include not only friendliness and dislike, but attitudes such as approval or disapproval. A "norm" is an idea, held in common by group members, that specifies how people *ought* to behave in given circumstances. In lay terms, norms are simply those informal rules individuals abide by in order to get along together in social situations. Finally, "activity" refers to those things persons do with others. In work groups, as an example, many of the activities are cooperative and goal-directed.

Most underground mining activities are carried out as team work. Workers at the face interact routinely to coordinate various tasks in the extraction cycle. Crews that work outby also communicate and assist each other in order to do their jobs. These reciprocal relations exist in a daily context of danger. A mistake on one worker's part could injure or kill others. The need to deal with this danger and predict what one's coworkers are likely to do in a given situation has resulted in a complex of sentiments and rules governing individual behavior. Simply stated, miners pressure each other to behave in terms of collective expectations and use a range of sanctions to ensure conformity [Smith and Vaught 1988]. A result is what Lee [1970] termed the "illusion of universality." This is a general feeling that group members have the same outlook and tend to define things similarly [Shibutani 1955]. Thus, a miner's attraction to his or her "buddies" is seen as right and proper, where "one's very self, for many purposes at least, is the common life and purpose of the group...the simplest way of describing this wholeness is by saying that it...involves the sort of sympathy and mutual identification for which 'we' is the natural expression" [Cooley 1909].

For underground miners, the sentiment that "we must stick together" may be a "sacred code" [Lucas 1969] so strong it has a bearing upon how individuals behave toward each other during a fire. Johnston and Johnson [1988] noted that an emergency does not necessarily signal the breakdown of social organization. Rather, functional roles that already exist are merely adapted and extended into the crisis. In a mine, where workers feel that survival under ordinary circumstances may well depend on "having a good buddy who watches out for you" [Wardell et al. 1985], it is almost certain they will be trying to help each other escape. How and under what circumstances this helping behavior occurs is a concern of the research team. Since the literature reviewed in chapter 1 suggests that group escape attempts may actually increase an individual's survival chances, what then makes an effective escape group? At what point does a situation dictate that "it's every man for himself," as one respondent reported, and how might this sentiment be avoided? To answer these and other questions about escape behavior, it is necessary to explore the nature of those groups that evacuated the three fires reported in this study.

Research Strategy and Method

A general case study strategy has been used in this research and the design should not be confused with any particular method of data collection and analysis. Nevertheless, such misunderstanding occurs frequently and tends to cloud discussion [Platt 1988]. This issue can be clarified succinctly. Case studies are nothing other than a way to "explain wholistically the dynamics of a certain historical period of a particular social unit" [Stoecker 1991]. In other words, they set the boundaries of a research effort rather than determine how it will be carried out. For the present study, each of the eight escaping groups is treated as a separate case having unique aspects as well as certain commonalities. The time periods are well-defined, beginning with a warning and ending when group members reached safety. Likewise, each social unit is clearly identifiable: those miners who came out of their operation together. The research task is to explain the dynamics of these different groups.

Analysis of each subject of interest was first done within the escape group. "A single case can undoubtedly demonstrate that its features are possible and, hence may also exist in other cases and, even if they do not, must be taken into account in the formulation of general propositions" [Platt 1988]. A multiple-case design was used so that variations across cases could also be examined. "In a multiple-case study, one goal is to build a general explanation that fits each of the individual cases, even though the cases will vary in their details." [Yin 1984]. Multiple cases are not used as a sample of the population, but as replication of an analysis. Each case "(a) predicts similar results (a literal replication) or (b) produces contrary results but for predictable reasons (a theoretical replication)" [Yin 1984]. In this study, the resulting explanations were based on what was learned about each group, as an individual case, and about subjects of interest as they were exhibited (or not exhibited) across the eight groups.

Information for the present study has been taken from various sources. Existing literature was used to provide a theoretical notion of how escape groups might be expected to function. Mine Safety and Health Administration investigative reports helped researchers build pictures of each fire situation. These narratives also provided insights about the efficiency of given escape efforts. The main data source, however, is a set of open-ended responses collected during interviews with workers who escaped through smoke in the three mines. Forty-eight miners, supervisors, and State or Federal inspectors gave accounts of their experiences. "An account is the personal record of an event by the individual experiencing it, told from his point of view " [Brown and Sime 1981]. Thus, the focus of analysis are these qualitative data. Further, while some responses in the database refer to individuals, only data that lead to a better understanding of the group will be considered here. Each escape group will be portrayed through the accounts of its members.

Quantitative methodologists often profess difficulty understanding how a qualitative strategy and its related activities can be made legitimate. The use of open-ended data, such as personal accounts, is frequently criticized by those who are more familiar with experimental or quasi-experimental quantitative methods. These scientists usually raise issues of reliability and validity when questioning the soundness of qualitative research. In general, reliability denotes the tendency of a measuring procedure to behave in a constant manner each time it is applied. The concept of validity is not quite so intuitive. Essentially, however, a valid procedure is one that measures what it is supposed to measure. From a traditional (or empirical) frame of reference, the type of information-gathering that depends on subjective responses has some major flaws.

First, independent and dependent variables may not be well specified and probably could not be measured accurately even if they were [Stoecker 1991]. Since reliability depends on the degree to which a finding "is independent of accidental circumstances" [Kirk and Miller 1990], it is vital that any variable of interest can be linked with an empirical indicator. It will then be possible, through repeated trials, to determine the constancy of this indicator as a measurement tool. Consistent measurement is necessary if researchers are to separate legitimate findings from accidental factors that introduce error [Carmines and Zeller 1987]. Without this type of rigor, empiricists argue, potential bias would be obscured and hence undetected. Thus, there could be no guarantee of internal validity. Internal validity allows the researcher to conclude that it was a specified independent variable, rather than some third factor, which caused change in a dependent variable [Yin 1984]. Because it is very difficult to establish the reliability and internal validity of open-ended responses in a traditional sense, such data get labeled as "impressionistic" and unusable for causal analysis.

A second shortcoming of qualitative research, according to quantitative methodologists, is that data obtained under uncontrolled conditions do not allow the use of probability statistics and therefore are not generalizable. This question of representativeness involves the problem of external validity: "To what populations [and] settings...can this effect be generalized?" [Campbell and Stanley 1966]. In situations where a proper sample has been taken, it is possible to control statistically for interactions of factors that may have an impact on the dependent variable. A researcher can then draw conclusions about some measured observation and infer how it will impact infinite similar circumstances. Since the qualitative methodologist neither takes broad and random samples nor calibrates responses, it is deemed there is no way to answer the question of "whether the researcher sees what he or she thinks he or she sees" [Kirk and Miller 1990]. This "nonquantitative" scholar is also viewed as being unable to make any empirical leap from particular events to those universal axioms that are the ultimate goals of science.

Yet qualitative methods, which became virtually ignored in most disciplines following the rise of computer analysis and sophisticated statistical techniques, have had a phenomenal resurgence in the past decade [Miles and Huberman 1994]. Perhaps the chief reason for this renewed interest in, and use of, open-ended data has been the growing recognition that quantitative science leaves gaps in our attempts to answer "how" and "why" questions. Stoecker [1991] listed three basic responses to the proponents of experimental or quasi-experimental research that suggest what some of the foibles are: "First, probability samples and significance tests do not insure accurate explanation.

Second, the scientific method does not control for researcher bias. Third, the survey research preferred by scientific method advocates is not useful for applied questions." No matter how well a study is controlled, a scientist who wishes to go beyond the immediate evidence and make statements about some population or universe must assume he or she "knows the relevant laws" [Campbell and Stanley 1966]. The strength of one's assumptions rests upon knowledge, experience and creativity, i.e., any type of science is only as good as its practitioners.

If there is a place in science for nonquantitative research, what might that place be? Insofar as case studies are concerned, they usually are thought of as exploratory or descriptive in nature. This is especially so for work that relies on qualitative analysis (such as the present research). The appropriateness of a particular strategy, however, should be decided not by its nature but by the purpose for which it is being used. Yin [1984] listed three conditions that need to be considered before choosing a research strategy: (1) the type of research question being posed, (2) an investigator's extent of control over actual events, and (3) whether the events being focused on are current or historical. Questions that consider how or why certain contemporary events occur, but over which the researcher has no control, are particularly amenable to a case analysis. Furthermore, a qualitative case study, used as an explanatory mechanism, "provides evidence to show how both the rule, and its exceptions, operate" [Stoecker 1991].

The present qualitative research makes no effort to count something or measure a quantity. Instead, team members have attempted to determine the presence or absence of group behavior in a fire setting and then explain its variability in those instances where it is seen to exist. The question relevant to reliability, in this case, is whether group behavior was studied by the researchers in a way that created a false reflection of it. Kirk and Miller [1990] suggested the proper response to that question: "For reliability to be calculated, it is incumbent on the scientific investigator to document his or her procedure." As in reports of quantitative research, the qualitative methodologist must make explicit the way the study was designed and carried out. In so doing, he or she guarantees that other scientists can determine whether or not the methodology is sound. They then have an occasion to replicate the techniques, if appropriate, in other settings.

Validity, in the case of these three fires, involves an assumption that USBM researchers did, in fact, observe or detect what they were attempting to investigate. In qualitative studies, the fundamental tools used are a researcher's powers of observation or an ability to ask appropriate questions at the right time. A qualitative researcher often gains confidence in findings by using a structured instrument to examine an issue or variable of concern. The primary instrument used to gather data during this research was an interview guide (see appendix B).

This guide requested individuals to provide an account of their personal experiences in the fire from which they escaped. Brown and Sime [1981] addressed the appropriateness of such an approach: "Fundamental to the philosophy of an account methodology is the recognition that people can and do comment on their experiences, and that these commentaries are acceptable as scientific data." If a person making an observation is skilled and his or her instruments properly constructed, then any subsequent conclusions ought to be considered valid. In reporting these results, of course, it is important to recount the methods that were used. Their appropriateness and proper use can then be evaluated by other researchers. Each of these scientists will ultimately decide if the instrument was constructed correctly and if the researchers were skilled in its use.

In each case, after hearing about an event, researchers involved in this study contacted officials from both the affected company and the United Mine Workers of America (the labor union that represented rank-and-file employees at all three sites). Investigators requested management and labor's cooperation with an ongoing study of miners' responses to underground mine fires. At mines A and B, union officials agreed to set up interviews with miners who had escaped their fires. One union and one management official set up the interviews that were conducted with those individuals who escaped the fire in mine C. Worker accounts were gathered at locations convenient for the participating miners. Interviews of mine A workers were conducted in a room at the local union hall. Individuals who escaped mine B were interviewed at a motel close to the mine where they worked. The interviews at mine C were conducted in offices on mine property.

Nobody except one subject and two research scientists was permitted in the room during an interview. The miner was first asked for permission to tape record his account. All subjects agreed to be taped. A written schedule (mentioned previously and shown in appendix B) with a series of open-ended questions and related probes was used to guide every account. Each interview began with an investigator reiterating that participation in the study was voluntary and that the miner had an option of not answering any particular question.

After obtaining general demographic information, an interviewer next asked the miner to tell, without interruption, his story about escaping the fire. Followup questions were then used so that specific details about each escape could be included. The sessions, which were 30 to 90 minutes long, ended when a researcher had asked all questions on the interview guide and a miner did not have any additional comments. These interviews were completed 1 to 6 months after each fire had occurred.

The audiotapes were transcribed and stored on computer disks as text-based data. This data set has been analyzed with the assistance of a program that acts, in effect, as an electronic substitute for scissors and paste [Seidel et al. 1988]. The computer application allows files to be sorted by category and cross-referenced according to some predetermined coding scheme. This feature enables the easy retrieval and juxtaposition of specific categories during analysis. Analysis can then begin with a series of coding passes. The first pass might simply identify instances of situations in which a group property either exists or explicitly does not exist. The next level of coding could include concepts such as composition, stability, or interactions. The coding scheme can be further defined during this process and coding continued as needed. Findings may then be used to create a group behavior model.

After the accounts were gathered, a comparative method of qualitative analysis was employed [Glaser and Strauss 1967]. In the comparative approach, a researcher develops as many categories as will clarify the problem. Next, he or she starts integrating categories and the properties that make them up, beginning to connect concepts with their indicators [Claster and Schwartz 1972]. After integrating categories and properties, the researcher is then ready to move toward simplicity and a broader scope [Glaser and Strauss 1967]. Over time, a theory of the event under investigation will emerge and be modified as more data are added. As the theory is streamlined, researchers are able to arrive at an assessment of how typical those occurrences that went into its construction are likely to be [Becker 1970]. The logic underlying this assessment is the same as that which supports probability: instead of adopting an either/or stance about the accuracy of particular assertions, one addresses the likelihood that his or her conclusions are correct. The magnitude of evidence from various data sources enables an observer to advance a particular conclusion with a greater or lesser degree of confidence.

Profile of the Sample

Across the 3 mines and 48 subjects, 8 separate groups of workers escaped through smoke. Table 3.1 shows the number of miners in each escape group and the number who were actually interviewed. The sample includes workers from various job categories. Forty-two of these individuals were rank-and-file miners who worked throughout the mines. One mine inspector and five supervisors were interviewed. These workers were 41.7 years old on average. They had a mean of 16.8 years of experience in mining with about 15 years at the operation where they were working at the time of their fire. The average age and number of years of experience for each group are shown in table 3.2. All of the miners included in this sample were male. One female did escape with a group from Adelaide, but she chose not to participate in the study. To further define the context within which these people were required to act, each escape group and its situation will be discussed briefly below.

Table 3.1.—Number of miners in each escape group and number in sample

Group	Mine	Population N (total ' 65)	Sample N (total ' 48)
1	A	10	8
2	A	8	6
3	A	10	7
NAp	A	NAp	1
4	B	8	7
5	B	9	7
6	B	3	1
NAp	B	NAp	1
7	C	8	5
8	C	9	5

NAp Not applicable.

Table 3.2.—Average ages and years of experience of miners in escape groups

Group	Mine	Average age (N ' 42)	Average years (total ' 16.8)	Average years at this mine (total ' 15.2)
1	A	41.8	17.1	17.1
2	A	39.3	14.3	14.0
3	A	39.7	17.6	15.0
4	B	41.7	17.2	16.7
5	B	40.3	17.6	14.4
6	B	56	25	15
7	C	38.8	13.9	13.9
8	C	40.0	14.7	13.9
Total	—	41.8	16.8	15.2

Escape Profiles

Group 1 (1 Right - Adelaide) was a production crew. This group had a new section foreman who was working his first shift in the mine after a 5-year absence. He was not familiar with the affected area; As one worker put it: "The boss, I can't blame the boss. This was the first time he was on the section in 5 years." Additionally, the crew had recently been "split up," and some regular workers had been replaced with experienced miners from other sections. As a result, at least three group members besides the foreman were unfamiliar with this part of the mine. Group 1 started the evacuation riding their mantrip. This mode of travel continued until the crew encountered heavy smoke. At that point the driver stopped the vehicle and everyone got out: "We had two or three running—everybody was panicked." After some initial confusion, the group members gathered and started walking together out their intake escapeway. They soon hit smoke in this entry as well. Group 1 moved into a return airway and continued walking. Shortly thereafter, the group members encountered smoke again. At this point, they donned their self-contained self-rescuers and walked through smoke to safety.

Group 2 (2 Northwest - Adelaide) was also a production crew. These workers had all been together for a significant amount of time. They had a section foreman who was very familiar with the affected area. One other resource in this group was an individual who had been a mine rescue team member for many years. "We had the boss and the mine rescue man set it up, the boss in front, he was in the rear." Group 2 started to leave the mine on a mantrip. The group members had only gone a short distance when they encountered smoke. They did not leave the mantrip at this point, however. Instead, they rode back up into the section to where they had started. They then got off the vehicle and started walking down their intake escapeway until they encountered smoke. Group 2 next moved into the return to avoid the smoke and continued walking. When smoke was found in the return, this group donned the self-contained self-rescuers and proceeded for about 1 mile to reach safety: "We were about as organized as you're going to get. We did real good." "We all stuck together real well."

As with group 1, miners in group 3 (3 Left - Adelaide) had some new members the night of their fire. Most, however, had worked together for several years. At the beginning, everyone rode together until they encountered smoke. As in the first group, they next started walking down their intake escapeway and hit more smoke. They then moved into a return and walked until they got into smoke, at which point they decided to don their self-contained self-rescuers. The next phase of their escape, however, differs from group 1. They did not escape as a cohesive unit, instead spreading out to form three subgroups. While walking through smoke, this crew became lost and was actually moving deeper into the mine: "We went in a little circle and come back around." They had gone approximately 200 ft when one of the miners recognized their mistake. At that point, everyone turned around and this time successfully found their way out of the mine.

When group 4 (4 South - Brownfield) gathered, smoke was already visible in the intake entry. In addition to the section foreman and regular crew, group 4 contained a Federal mine inspector who had been on the section. This group, unlike the others, did not choose the return as a second option. The group thought that smoke would also be found in that entry: "The boss and the inspector was there, and they were discussing which way to go—which would be the best way to get out. So they decided it would be down the belt. We all went down the belt." However, the belt was not clear. Like group 3, group 4 spread out, with some slower workers lagging behind, accompanied by the inspector. They completed the escape in the belt entry through the smoke.

Group 5 (5 South - Brownfield), a production crew, was led out by its section foreman with help from a rank-and-file miner who knew the affected area well: "[The foreman] is our boss. He...done right. He got us on the right track and kept us on the right track. Between him and [the other guy]." After group 5 assembled, the group members walked down the intake entry until they encountered smoke. Like group 4, they tried the belt entry next. The smoke there was not as heavy at first. When it became heavy, they moved to the return. The return was also smoke-filled, but they traveled on through the smoke. Some of the workers had difficulty due to age or physical problems and slowed down. The section foreman stayed with these people to make sure that everyone reached safety.

Members of group 6 (6 West - Brownfield) included three individuals. These were a maintenance foreman and a mechanic (who worked together regularly) plus a State mine inspector. All three donned their self-contained self-rescuers as soon as they assembled at the intake escapeway. Even though their haulage was clear initially, this group, influenced by input from the State mine inspector, decided against attempting to travel in a vehicle. They started their escape walking down the intake entry. When they reached heavy smoke, they retreated and moved into a return: "I mean, the inspector, when I turned around and said we got to go back, he says no, and I says, you can do what you want to do, I'm going back." The men made a couple of turns, but basically followed the return out of the smoke to clear air: "The markers (reflectors) were there. I mean, I really wasn't looking for them...the return is double-timbered. I just stayed between the props and went."

Group 7 (7 Butt - Cokedale) was a collection of individuals working in an area on midnights, which was a maintenance shift at their mine. Here, a construction foreman took charge and led them out of the mine: "I was a foreman in charge of that area, and when I said to these people what we had to do, there was no second guessing my decision." As with groups 1, 2, and 3, these miners also started their escape by attempting to leave the section on vehicles. When they judged the smoke to be too heavy for continuing safely, everyone started walking in a return entry: "I felt pretty confident...because I knew [the foreman] had been up there for a long time walking returns and...he was real familiar with the area." In all, they walked through smoke for about 1.5 miles. Throughout their escape, respondents recalled, the construction foreman displayed knowledgeable, decisive, and confident leadership.

None of the individuals in group 8 (8 Face Parallels) were engaged in coal production, because they were also working the maintenance shift at their operation. Most of them were involved in such support work as construction and supply activities. Additionally, two motormen were in the section when fire was discovered. Everyone gathered and began their escape on foot. Like all of the groups except 5 and 6, they started out in their primary intake escapeway: "There was a lot of confusion...the boss couldn't figure out how to get into the intake escapeway." When they encountered smoke there, the men turned around and returned to the section, as group 2 did. They then attempted to travel down a return entry. After walking about 0.25 miles, someone realized that they were not in a designated escapeway: "The guys were more or less talking amongst themselves and I said, you know, this is real serious and this boss if we're not careful, he's going to get us killed." At this point, everyone returned to the section for a second time. They then found a designated alternate escapeway and followed it through smoke to safety.

Discussion

All eight of the escapes took place under potentially deadly conditions. The miners traveled in smoke for thousands of feet. Individuals had to use self-contained self-rescuers to protect their lungs as they moved through this smoke. Some of the escape routes were objectively more complicated than others, but all were difficult to traverse.

The summaries above give very general overviews of each escape in order to suggest some of that associated complexity and difficulty. This is done to help readers more fully identify with the study's context. In the chapters that follow we will discuss at length details of each group and the area from which it escaped. Subjective analyses of danger and the effects of those perceptions on group behavior will be a large part of that discussion.

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CHAPTER 4.—EXAMINATION OF GROUP BEHAVIOR DURING MINE FIRE ESCAPES

It is suggested in chapter 1 that emergency activities (including escape) are not individualistic. They tend to be group responses. If escapes from mine fires are group activities, then preparation for such events must take group behavior into account. This chapter explores the hypothesis that the miners who escaped from the three mines under study did so as members of groups. For development of this chapter, the database was examined for evidence of the existence of escape groups and for instances when individualistic behavior was paramount. Illustrations of group and/or individualistic behavior were analyzed and representative examples are provided in the following discussion.

The nature of groups was discussed in chapter 3 and the following working definition was offered: "We mean by a group a number of persons who communicate with one another often over a span of time, and who are few enough so that each person is able to communicate with all the others, not at second-hand, through other people, but face-to-face" [Homans 1950]. To determine whether or not groups existed during the fire evacuations, it is important that the concept of group be clearly defined. Therefore, the discussion started in chapter 3 will be elaborated here. The defining characteristics of group given in chapter 3 were taken from Homans [1950]. They include size, person-to-person communication, feelings that members have for each other, explicit and implicit rules for behavior, and common activities.

An additional characteristic that is sometimes used to define groups is cohesiveness. Kiesler and Kiesler [1970] state, "Cohesiveness would include not only the attraction that the group holds for its members but also any other force operating on the individual to stay in the group." Variables said to contribute to cohesiveness include "(1) the attractiveness of a group for its members," and "(2) the coordination of the efforts of the members" [Keisler 1970]. One source of the attraction to a group occurs when "the goals or exterior tasks confronting the group are consistent with those of the individual person, and can best be handled by group action" [Cartwright and Zander 1968, in Davis 1969]. In other words, a common goal and a coordinated effort mounted to achieve that goal contributes toward the creation of a cohesive group.

As discussed in the earlier review of research (chapter 1), groups have frequently been studied in laboratory or simulation settings. These methods allowed control over variables of interest. Kiesler and Kiesler [1970] state, however, that they "find group variables conceptually imprecise and experimentally difficult to work with." Experimental control, in other words, is difficult to achieve in the study of groups. The richness of the naturalistic mine fire data may provide an opportunity for an examination of groups that cannot be found in laboratories or simulations because this environment was not contrived and the groups were not artificially created. While there are limitations in the data set, it provides an opportunity for examining naturally occurring groups experiencing an extremely stressful situation. Furthermore, it offers views of those groups developed from the perspective of potential group members.

The remainder of this chapter will be organized into four sections. The first section will focus on characteristics of the groups. The beginning of group formation for each work crew will be examined in section two. The third section will explore counterexamples or cases when individualistic behavior took precedence over group actions. The last section will be a discussion of the ramifications of the findings for mine evacuation preparedness.

Group Characteristics

To document the existence of the escape groups, group characteristics that were defined earlier in this chapter will be considered. The most objective measure is group size. All except one of the groups studied had 8-10 members. The one outlier had only three members. These sizes would meet Homan's [1950] criteria of being, "few enough that each person is able to communicate with all the others, not secondhand, through other people, but face-to-face." The following discussion will address each group in terms of its make-up and the more subjective criteria.

The groups that were formed on each section varied in composition. Five of the eight groups were made up of production crews. In two of these cases, the crews from 2 Northwest at Adelaide and 5 South at Brownfield, stable work groups had existed for quite some time and included a section foreman or another miner with leadership capabilities. The 4 South crew at Brownfield Mine was composed of a stable work group and a mine inspector who happened to be on the section at the time of the fire. The inspector was, however, well-known to the section foreman and was trusted as a capable individual. The production crews from Adelaide Mine's 1 Right and 3 Left sections were composed of new miners and/or supervisors. While these individuals were not new to mining and the roles they assumed, neither were they familiar with each other. The smallest group, which escaped from the 6 West section at Brownfield, consisted of three individuals who were involved in the repair of a piece of equipment. Two of them were well-known to each other and routinely worked together. The third was a mine inspector who was conducting an inspection in that area. Two of the groups, from Cokedale Mine's 7 Butt and 8 Face Parallels, were formed during a maintenance shift. These groups contained collections of individuals who were performing construction and supply activities on these sections. In both of these groups, foremen were present. Some of the individuals in each group were familiar with each other, but others were not. Similarly, some miners were familiar with the sections from which they were required to escape while others were not. In all eight cases, regardless of the prior affiliation between the people on each section or familiarity with the work area, the first action taken when warning of an emergency was received was to warn others on the section and for everyone to gather in one location.

It is not surprising that miners on a section would come together under some conditions. Coal miners typically work in groups. Each production crew conducts activities in the section with individuals filling various roles and being assigned to certain jobs. During the accomplishment of those jobs, however, the members of the crew may be dispersed throughout the section. For example, on a continuous mining section, the miner operator and helper will be in one entry while the roof bolter operator and helper are in another. The miners who are responsible for transporting coal from the face to the section's dump point for haulage to the outside will travel between the continuous miner and the dump point. Therefore, while a person can think of a section as having one work group that together complete the tasks necessary to mine coal, these miners are also doing discrete tasks within a system that may or may not allow them to be in direct communication with each other at any given time during the work shift. Casual workers and visitors such as mechanics, bratticemen, supplymen, surveyors, inspectors, and others may also be on the section. Workers were dispersed in this way on each section when the mine fire threat began at each of the mines.

Regardless of their particular location on the section, miners have certain understandings of their roles and expectations of other miners. In other words, they have what was earlier termed "explicit and implicit rules for behavior." Under these "rules," a miner is expected to come to the assistance of another during a mine emergency if at all possible. When conducting a study in a community where a major mine emergency had occurred, Beach and Lucas [1960] determined that:

> In common with many mining communities, the norms shared by all individuals guaranteed mutual help. The miners' code of rescue meant that each trapped miner had the knowledge that he would never be buried alive if it were humanly possible for his friends to reach him. This code was so widely understood and unconsciously accepted that no miner-rescuer was faced with serious role conflict. At the same time, the code was not rigid enough to ostracize those who could not face the rescue role.

These rules also include strong ties between a miner and a "buddy." It is understood that these two workers hold a special relationship and are expected to come to each other's aid. These implicit rules and role definitions existed at the study mines.

When asked how concerned the workers on one section were when they first gathered together, one miner explained that most were calm but one miner was upset. "We had trouble with really only one guy on our crew, [he] just left his buddy." Saying that the miner "left his buddy" was intended to show that this individual was extremely upset. The miner's actions were explained by the coworker's comment, "He's a nervous person." As Beach and Lucas found, the expectation is that a miner will help other miners, especially a buddy, but it will not be held against an individual who is not up to the task.

The excerpts presented throughout this book offer, again and again, examples of miners expressing versions of this code and discussing attempts to live by it. It is within the context of such a code that the actions of individuals and groups must be understood. Miners living by this code would therefore set goals of not only self-protection during emergency situations, but also protecting other miners whenever possible. Potential escape group members therefore, would have an obvious common goal during the threatening situation of a mine fire.

Escape Group Formation

As mentioned earlier, production workers and other miners were scattered throughout their sections in groups of two to four individuals when they determined, by receiving warning or by their senses, that something was wrong and some action should be taken. Details about the discovery of the fires and how warnings were communicated will be discussed in chapter 6. For the purposes of this chapter, however, it is important to note that upon learning some kind of nonroutine problem existed, each miner was typically with only one or two others.

The first thing that happened after the individuals or small groups learned of a problem was the gathering of everyone in each section at one location. This group formation occurred on all eight of the affected sections. The behavior was displayed regardless of the form or content of the warning and across all job titles and individual situations. This point, which will be expanded below, is of consequence because it provides the foundation for the argument to be made that evacuation procedures and related training should focus on group action and interaction, as individual miners will naturally form such groups during emergency escape attempts.

Providing warning to the other miners on the section was the initial priority of those workers who first received word of a fire or who observed and recognized the signs of a serious fire. In some cases the supervisor, usually a section foreman, received a call or spotted smoke. It is not surprising, given the responsibilities of their positions, that these individuals instructed the miners on their sections to meet at a given location to begin evacuation. The foreman with the crew from 7 Butt at Cokedale asked a miner to help give warning to the other miners. He directed the miner to "just make sure everybody meets up here at the [track] switch." It could be suggested that the supervisor in these situations has responsibility for the other employees and is motivated by that responsibility to warn them and to gather them together where they can be given any assistance needed during the evacuation.

While it may be true that supervisors feel responsible for the safety of miners during an emergency, this is not a complete explanation for the behavior of gathering everyone in the section together before taking other actions. This same behavior was exhibited by everyone who had earlier knowledge of the problem regardless of that person's position or job title. When a roof bolter operator answered a phone call and was told of the fire, he asked other miners nearby to help him spread the word:

> I said, "I'll go to the left side. You get the guys on the right side." So I went up and told them, and we came down and the guys from the right side came down...[to the load center].

In giving warning, it was assumed that everyone would meet somewhere on the section before starting out of the mine. A shuttle car operator reported his actions upon learning of the fire in his mine as follows:

> I stopped at the bolters first and I told them that there's heavy smoke coming up the intake and we're supposed to get out of here right away. See you back at the power center. That's where the rescuers were.

When hearing of the potential danger, no one started his or her evacuation alone. In every case, warning of the situation was given and instructions to join the other miners at a specific location were given.

It should also be considered that miners routinely enter and leave their working section as a group. Frequently their transportation to and from work areas is via a mantrip, which workers ride into and out of the mine with the others who work in that section. It is not remarkable, therefore, that miners went to a given location to begin the process of leaving the mine. What is of interest, however, is that in these far from routine situations, miners still adhered to this pattern of leaving together. In fact, none of the miners interviewed gave any indication that they considered starting their evacuations without the entire group. They often spoke of the actions of the groups, at this early point, as if they were of one mind:

> We met at the dinner hole and all of us just went down to the mantrip and all in a single file line and we got in the mantrip and we started out. We all met down at the tool boxes. From there we walked down to the

> self-rescuers and everything. Everybody picked up a self-rescuer. We had a full crew. Everybody got a self-rescuer, and we checked to make sure they were all good. We turned around and we were going to go down the intake.

In most cases, the miners interviewed seemed not to question whether or not the person notified of a danger would spread the warning throughout the section and then wait at a given location, (formally or informally designated) for the rest of the section members to arrive before proceeding out of the mine.

It is also interesting to note that miners at this early stage of group formation remained with the group regardless of their personal opinions about the safety of the groups' behavior. A utilityman told of beginning his escape riding a vehicle even though he did not think that was the best method.

> [The boss] came back up and said, "Get all the fire extinguishers and let's go. We'll get in the mantrip." I went down there. I really wanted to go to the intake escapeway or something like that when he said there was a fire. I'm going to go the other way. I don't want to go that way. So we got in there and, gee, we only went a couple blocks.

The authority of the boss was not questioned, even in this potentially life and death situation. The utilityman remained a part of the group, under the boss's leadership. In another case, a similar situation arose for a miner who did not ride a jitney even though he thought that was the best way to reach safety. In this case, a mine inspector, who happened to be on that section, was the authority figure to whom he deferred the decision.

> [The fire boss] said there was a mine fire and I says okay, and then I run and get my buddy and we went up the track entry. [There is no track there at that point.] We went up and around, and I had to go over in the belt entry to get the inspector. We got on our rescuers right there. And we also took a spare rescuer with us. I was going to ride the jitney out of there, but he [the inspector] wouldn't let us, so we went on foot.

What these actions say about leadership is discussed in chapter 9. However, note that once the groups gathered together, individuals started their escapes with those groups even when they felt the initial actions being taken were not the best choices given the situations at hand.

Counterexamples to Escape Group Behavior

While each of the miners started evacuation with a group made up of individuals who had been on the section at the time of warning, at times there were situations when individualistic behavior took precedence over group actions. As mentioned previously, miners accept the role of assisting others in emergency situations, but also pardon those who cannot offer that assistance. Instances of individualistic activities and of excusing others for lack of assistance were recounted in the accounts of the mine fire escapes.

Individual decisions seemed to outweigh group behavior when the individual was convinced that there was real danger and that the group's activities were not the best response to the threat. An example is provided by the 6 West group at Brownfield Mine. The group from this mine was composed of three individuals: a maintenance foreman, a mechanic, and a mine inspector. The group started together and even remained together when the maintenance foreman was not convinced that the group's response was the best. However, as the maintenance foreman perceived an increase in the danger of the situation, he decided to act as an individual regardless of the choices made by the other group members:

> When I turned around and said we got to go back, [the inspector] says no. And I says, "You can do what you want to do, I'm going back." I said, "You can follow me or do what you want." At that point I didn't give a damn who followed me or who didn't. I was getting out of a heavy concentration [of smoke].

The maintenance foreman affirmed his belief in the code of assistance, while at the same time justifying his attitude regarding acting alone if necessary:

> The only way I wouldn't stay with somebody was if they disagreed with me and I knowed I had the right decision made; I mean the right escape road or something. Then if they would give me any trouble, I would go.

The maintenance foreman suggested that the other group members should follow his lead, but if they did not follow, then he would have no choice but to act alone. In this case, he was not acting for self-interest at the expense of the group good. Instead, the maintenance foreman was convinced that acting based on his decision would be best for each member of the group, but if group members chose not to follow his lead he was willing to act as an individual. There is no evidence regarding whether or not the maintenance foreman would have followed through with this behavior, because the other group members did follow him at this point.

A more extreme example of group breakdown occurred in the group that escaped from 4 South at Brownfield. At one point the group broke roughly into two smaller groups. Later, one individual was left behind under life-threatening circumstances. There was much information regarding these actions and the reasons for them volunteered during data-gathering interviews. These discussions suggest a high level of concern regarding roles and the appropriateness of the actions of the group members. The members of the 4 South group started their evacuation together:

> Then, like I said, they started separating from the pack, not waiting for the pack, the faster ones. The slower guys, some were stopping 'cause they just didn't have the wind. They were out of shape or whatever, and they just wanted to stop and take a rest.

At that point, the section supervisor went ahead with the faster subgroup and a mine inspector stayed back with the slower subgroup. There was also one individual who was not clearly a part of either group.

> I said, "Let's try to stay together," and the older man, I recall him saying that he has to go at a steady pace, that he can't go fast, that he's just going to stay out ahead of us [the slower subgroup] and try to hold a slow place.
>
> [A faster miner] comes by and says, "What's the matter old man, can't you take it?" I says, "Hey, you just go ahead, you save your own ass, don't worry about me." And that's just the way it was from there on out.

This miner remained in his position between the faster and slower subgroups and safely escaped.

The event most distressing to group members occurred when an individual in the group from 4 South became unable to continue his escape and was left behind. The actions surrounding this situation exemplify the implicit rules regarding miners' responsibilities to each other. At this point in the escape, three miners (the miner operator, the mine inspector, and a mechanic) had formed the slower subgroup and they were too far behind to communicate with the other members of the 4 South group. The continuous miner operator found it increasingly difficult to continue, and the other two miners were trying to assist him down the belt entry. "[The miner operator] said, 'I can't go no more.'" He said, 'I'm just going to stay here.'" The mine inspector felt he should stay and help, but perceived that the oxygen supply from his SCSR was becoming dangerously low. He decided to leave the other two miners behind:

> I looked at the mechanic and I said, "I got to go." I said, "There is no sense in me staying." I don't know if I said that or not, but I thought about it. I know I talked to myself, "There's no sense in me staying." I said, "I can't breathe now." I said, "I know where I'm at. I can send somebody back. I'll go out and get somebody."

As can be seen in his comments, the inspector stayed to help as long as he thought was possible and then reasoned that he had to leave. He did not stop his explanation there, however, and pointed out that he could offer further assistance to the struggling miner by going for outside help. Eventually the mechanic also made this decision and left the miner operator alone.

> I felt so sorry for [the miner operator], and he was struggling too hard, and I guess I made a decision there that he wasn't going to make it and that you might as well leave him and you might make it.

The miner operator was eventually helped to safety by the mechanic and the foreman who returned after they had reached fresh air.

All of the group members who knew about the miner operator's difficulties did everything they thought possible to assist him. Two even went back into the smoke after they had reached a safe area. The miner operator was asked about that point during the escape when he was left alone. His response confirms that the code allows reprieve for miners who cannot help others in need.

> It don't bother me. I didn't expect—I kept telling the mechanic to keep going, don't wait for me. I didn't expect anybody to stay behind for me. I don't hold nothing against anybody.

In summary, the members of the 4 South group started their evacuation together, but as environmental conditions deteriorated, the group split. Eventually, one miner was even left to die. On the other hand, group members returned and helped this individual to safety and he held no hard feelings about the experience. This example of group behavior upholds the code of helping each other whenever possible, but of releasing others from this obligation when it cannot be fulfilled.

Emergency Evacuation Ramifications of Group Behavior

The findings reported in this chapter suggest that individuals will form a group during an emergency situation and will often act with the group regardless of personal opinions regarding the optimum response to the event. Furthermore, miners will assist each other during emergency events whenever possible. This assistance can take such forms as delaying the group's evacuation to wait for a slower group member or individuals returning to a hostile environment after reaching safety to search for a missing coworker. This does not mean, however, that no individual action takes place. Sometimes individual safety does take precedence over group safety. The individual seems to be more likely to act outside of group behavior as the perceived danger increases and as options for group action become limited.

In planning for emergency mine evacuation, group behavior should always be considered. Since miners will probably gather as a group before beginning their evacuation, issues such as time allotments for such activities, strategic locations for gathering, and appropriate leadership should be examined. It is also important to realize that miners will attempt to assist other miners who they perceive to be in danger. Awareness of this response is especially relevant for those who are trying to determine the location of missing miners during a rescue attempt. In these situations, miners may not choose the most direct route out of the mine, but may instead go toward an area where they think they may find a fellow miner needing their assistance. In training miners for escape, it may be appropriate to discuss the issues related to groups staying together versus individuals and/or subgroups splitting from the main group. It is not clear that either situation is always correct. It is clear, however, that both happen during real events. It would be helpful if discussions of when each might be fitting were conducted in a classroom setting.

In summary, emergency response planners must take into account that miners will attempt to evacuate in groups when threatened by a mine fire. Training for evacuations should take this fact into account and include the likely group-related responses in any escape procedures.

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CHAPTER 5.—A MODEL OF THE JUDGMENT AND DECISION-MAKING PROCESS IN MINE FIRES

Various aspects of judgment and decision-making are key themes in this book. The model presented here serves as a loose structure for the chapters that follow this one. The notion of a model is introduced because growing research interest in the subjective aspects of group and individual behavior has led to a debate over whether judgment is a skill that can be understood scientifically. A related point of contention is whether such an understanding could lead to the development of methods for estimating people's ability to make good decisions during an emergency. There is some literature that supports the potential usefulness of this approach. However, little agreement seems to have been reached on how to define and operationalize even those basic concepts necessary to assess the soundness of decisions from within their environmental and group contexts [Jensen and Benel 1977; Godden and Baddeley 1979; Baumann and Bourbonnais 1982; Brecke 1982; Stone et al. 1985]. A look at the real-world process is clearly needed.

The need to attempt a better understanding of judgment and decision-making properties stems from those occasions in the existence of an organization when there is a lot at stake. The process of decision-making (which is part of the exercise of judgment) has been analyzed in situations such as corporate takeovers [Janis and Mann1977], military combat [Begland1979], clinical emergencies [Baumann and Bourbonnais 1982], and aviation events [Billings and Reynard1984]. The fundamental assumption of these analyses is that, while there are untold successes, there are also notable numbers of failures resulting from decisions that can be ascribed to one or more errors in judgment. From a cognitive perspective, any person engaged in decision-making (either alone or in a group) is actively involved in a process characterized by certain elements. These were mentioned in chapter 1, but are reiterated briefly at this point: (1) detection of a problem, (2) definition or diagnosis, (3) consideration of available options, (4) choice of what is perceived as the best option given recognized needs, and (5) execution of the choice based on what has transpired [Flathers et al. 1982; Baumann and Bourbonnais 1982]. At any moment in this process, there are factors at play that have a large impact on one's ability to solve complex problems in a limited time: (1) an internal state [Hedge and Lawson 1979] is the sum of a person's psychomotor skills, knowledge, attitudes, etc.; (2) uncertainty [Brecke 1982] is caused by faulty or incomplete information received from the external environment; (3) stress [Biggs 1968; Jensen and Benel 1977] is generated both by the problem at hand and any background problem that may exist; and (4) complexity, as it is used here, refers to the number of elements involved that must be attended to. These variables are depicted in figure 5.1, and their relationship to each other and to an outcome is indicated. This schema is designed to suggest interaction, because while the judgment and decision-making process may be conceptualized as discrete stages, experience tells us that this is not the way people function in real-world situations.

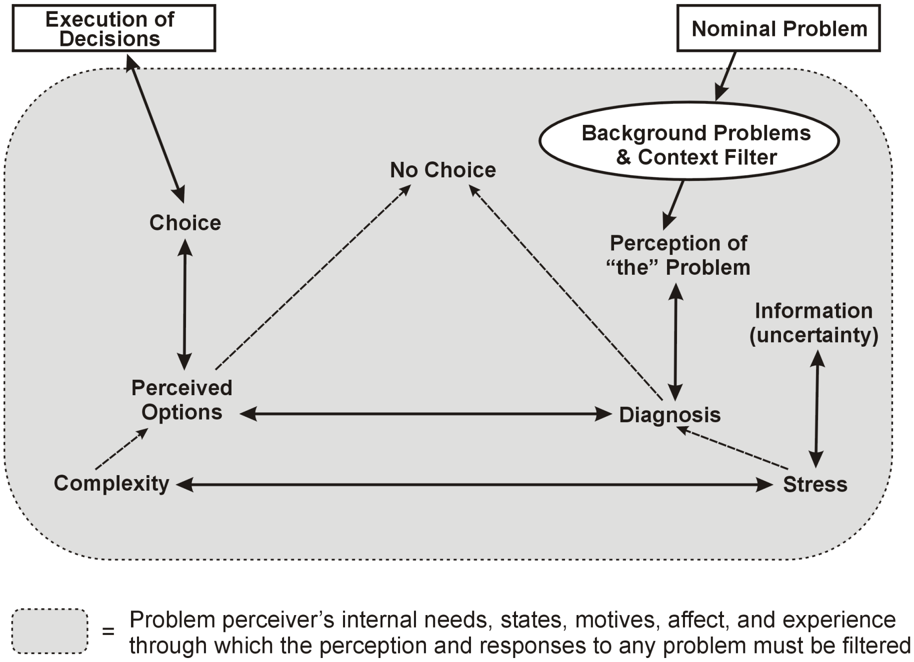

Figure 5.1.–A model of judgment and decision-making.

The interactive model reflects underlying demands on decision-makers in most life or death situations. Whether the individual is an airline pilot, a firefighter, a nurse, or an industrial worker, an emergency makes it necessary to deal with an enormous amount of sometimes faulty information in a rather short timeframe. While (ideally) an understanding of judgment in the context of one event should be generalizable to comparable circumstances in different environments [Jensen and Benel 1977], judgment theorists have typically limited themselves to more specific approaches. The method they have most often used to examine empirically a given aspect of judgment is usually some variation of the situational technique. In situational exercises, the subject is presented with a problem taken from his or her area of competence (aviation, for example) and is given the task of reaching a workable outcome. A majority of existing exercises appear to focus on either one of two elements represented in figure 5.1: (1) an individual's ability to reach a satisfactory diagnosis once he or she has become aware that a problem exists, or (2) a person's choice response after a scenario has been laid out and the diagnosis provided.

Using Judgment and Decision-Making Skills in a Mine Fire

This chapter, rather than reporting the results of subjects' performances on a simulated problem, discusses instead how these eight case studies deal with the complete process of peoples' judgment and decision-making during an actual event (group escapes from a mine fire). Throughout each episode, workers engaged in an ongoing series of activities, some of which seem to have been well thought out and others that (in hindsight) do not seem so logical. Yet, all the while, they were attempting to solve the problem that confronted them. Such behavior is in line with much of the recent literature dealing with human actions in fires, which advances the argument that people engage in adaptive behavior based on choices made from among those perceived to be available at any particular time during the occurrence [Sime 1980; Lerup et al. 1980].

People seem to exercise judgment and make decisions during a fire, although they oftentimes fail to perceive the fundamental problem adequately. This is especially true if they are focused on a task, or are having some type of difficulty. An act that appears irrational when viewed with the 20/20 vision of hindsight, therefore, might have seemed, to the actor in that situation, the most sensible thing to do. Unfortunately for those interested in reaching a more objective understanding of the quality of those decisions, choices are usually judged ex post facto depending on their outcomes. Accordingly, if a person survives, he or she is credited with making sufficient correct decisions and little attention is paid to poor choices; if a victim dies, most second-guessing focuses on what he or she might have done wrong and there is not much analysis of any good decisions that were made.

The settings of this study seem particularly appropriate for an examination of topics such as the quality of thought that goes into choices made during an emergency. That is because mining lore is filled with accounts of tragic outcomes that could have been avoided. Many stories recount how escaping workers advanced to within a few feet of smoke-free air, yet chose to turn back and barricade, perishing in the end [Cole et al. 1988]. The real question then becomes not one of whether the instrumentally "correct" choice was made (it is known in retrospect that this was not the case), but whether those miners made the best use of all evidence available to them in reaching the decision they implemented. To put this another way, outcomes might not always be linked mechanically to the quality of choices. This chapter will show how the qualitative database is being used in the formation of a framework that ought to allow a better understanding of miners' judgment and decision-making activities given such a scenario.

Fire in the Mine as a Nominal Problem

In the model used here, a nominal problem is defined as an environmental or system condition that can be characterized by the type of response it requires [Pew 1994]. Fire is one of those events needing a high level of "situation awareness." Endsley [1988] has identified this concept in terms of its three main components: (1) perception of a situation's elements in time and space,

(2) comprehension of their meaning, and (3) projection of a near future status for the condition in question. Endsley's notion of situation awareness closely parallels two stages (problem perception and diagnosis) shown in figure 5.1 and is discussed below as part of the judgment and decision-making process. The present section offers a brief description of the nominal problem at each study site.

Adelaide Mine

At 9:08 p.m. during March 1988, Adelaide's second shift dispatcher was alerted by a warning of 10.5 ppm on the mine's carbon monoxide monitoring system. This warning cleared almost immediately. A few seconds later the same sensor (at the end of 2 Northwest belt) registered a warning of 11.5, but cleared in less than 30 seconds. The dispatcher continued his normal duties. Sometime after 10:00 p.m., a third-shift supply boss arrived at Adelaide's surface facility:

> I always go to work early, I did all my life. I reported to the mine and I put my dinner bucket down, and I went out to the lamp house to get a cup of coffee. When I entered the lamp house area I heard this beeping sound. It was coming out of the dispatcher's shanty...I walked in and what it was was the CO monitor...I want to know what's goin' on. And they says the monitor's been goin' off and on, and we think we got a fire, but we're not sure. Well, I said, was the crews notified inby the fire area? No we didn't notify anybody yet 'cause nobody contacted us. So I said you better start calling these crews and get them out of the mine whether you know it's a fire or not, you better get a hold of 'em.
>
> At 10:30 I entered the mine. We got up there and they were already trying to fight the fire. We fought it for a good while and we kept losing ground continuously. It just kept going way ahead of us.

Workers continued to fight the fire, which was reported to be in or near the drive head of 2 Northwest's "mother" belt (see figure 2.1), with small foam generators, fire extinguishers, water, and rock dust. By that time, all section crews had been notified to evacuate.

Brownfield Mine

Around 11:00 one summer morning in 1988, a "fire boss" (mine examiner) was in the process of inspecting Brownfield's No. 38 belt conveyor. This belt receives coal from sections being developed off 6 West Mains section and also transports coal from 6 West Mains itself (see figure 2.2). He had arrived just outby the "head drive" (terminus) of 5 South section's belt when he smelled smoke. The fire boss first checked the 5 South belt head, and finding nothing wrong there, walked approximately 600 ft along No. 38 belt to the 4 South head drive. At this point, he detected smoke farther down the 38 belt toward the 3 South head. Continuing along the 38 belt, the fire boss walked another 200 ft to the worked-out 4 North drive area, at which point he encountered heavy white smoke. Retreating back along 38 belt to the 4 South head, the fire boss entered the track entry of 6 West Mains, where the smoke was somewhat less dense. The fire boss hurried along the track back to the old 4 North area, and stopped at its head:

> I could hear...a rumbling like a—at first I thought it was the welder in there burning something and something happened in there...I yelled for...the welder...I yelled about two or three times for him and there was no answer...I run back over and I went through the overcast to go over to the intake...which would be the right side of the track...When I got in there, the smoke was real thick in there too, and I couldn't see...So I dropped down on my knees and I turned around to get my W65 [filter-type self-rescuer] off of my belt...When I kneeled down, I could see the yellow door...So I hurried up and went over to the door, opened that door and got out through there and I was in the intake then...I was coughing around and it really burned my chest at this time, so I probably stayed there a couple minutes to get my bearings again and I went down—I had to go to the intake to 3 South, so I run down the intake... This is—we're talking 4½ feet, so when I say run—I went down the intake to 3...and I came out onto the track and it was clear...So I run up the track then to 4 South and there was...a high spot where they took rock...The smoke was like hanging there and it was clear outby the high spot...The smoke was real thick, but along the left rib, I could see where there was no—it was clear...So I crawled up along the rib, stayed real low, and I crawled up along the rib, cause I still thought [the welder] was in there and...something had happened...I thought there was a man in there...I went up along the rib and I got my head around the corner and I looked in and I yelled...a couple more times and I could see the flames coming off the top—I could see that there was a motor sitting there...I saw the flames coming off the top of the motor.

After seeing these flames, the fire boss disengaged the trolley power by opening a cutout blade. He then called to warn his shift foreman and those miners working in each of the three sections that would be affected by the fire. The fire boss was soon joined by the mine foreman and general assistant mine foreman, who helped him fight the fire. Meanwhile, the three affected section crews were being warned to get out of the mine.

Cokedale Mine

At some time during an early morning in October 1990, a roof fall occurred on one of the haulage tracks at Cokedale Mine. The operation differed from most mines today because primary coal transport was still done by rail. One set of rails was used to move loaded cars and adjacent tracks in a parallel entry were employed for empties. Crossovers were located at intervals along the haulage so that cars could be switched back and forth. It was at one of these crossovers that a lead motorman, bringing a trip of empties into the mine, saw smoke. After alerting his buddy in the trailing motor, this worker dismounted and went to find what he believed was a burning trolley switch. The lead motorman had walked only a few feet into that crosscut where the crossover and trolley switch were located when he encountered heavy smoke.

The lead motorman retreated to his locomotive and attempted to clear the track. Before he could push his 45-car train to the next crossover outby, power went off and the motorman was forced to park his trip on the empty track. At the train's rear, the trailing motorman cut his locomotive loose and was able to coast into the crossover and onto the loaded track. As he drifted down this track, the trailing motorman saw a roof fall with the trolley wire under it and flames coming from the caved material (see figure 2.3). After calling outside to report his discovery to the dispatcher, the trailing motorman grabbed a fire extinguisher from his locomotive and went back to the burning cave-in. Near the fire site he met the lead motorman and these two workers attempted to fight the blaze. Meanwhile, the dispatcher was busy notifying those miners inby the source of combustion that smoke was coming their way and relaying the fire's location to them. The affected miners began an immediate evacuation.

Perception of the Nominal Problem

There are two ways in which any warning about the existence of a problem may be conveyed to an individual: by means of some intermediary; or directly, through the senses. In the first instance, a person is faced with the task of deciding whether to believe the messenger and/or how to interpret the message. In the second instance, a person is faced with the necessity of drawing implications from what his or her senses are revealing without benefit (in many cases) of corroboration. Under both of these conditions, perception is a process that involves a varying degree of uncertainty. The process also requires time, during which a perceiver attempts to get a fix on the problem and begin his or her diagnosis. A lot depends on situational factors. In the model depicted by figure 5.1, these situational factors are shown as a context filter. There were aspects of the context at each operation that had a distorting effect on how the nominal problem was perceived.

At Adelaide, the nominal problem was a fire on the mother belt. There were two factors confounding a grasp of the true situation at this site. First, on the night the fire occurred, affected sections had been plagued all shift by belt stoppages. Second, recent technological developments at this mine caused the initial message to be mishandled. Several weeks prior to the fire, new sensors had been installed near the mouth of 1 Right. Maintenance people doing this work drilled holes in the tops of the sensor boxes and secured them directly to roof bolts. That action seems to have established some sort of ground potential which was keyed by signals from passing trolley motors. This ground potential in turn triggered alarms on the monitoring system outside. When the problem was fixed by rehanging the sensor boxes, another predicament appeared. Some sensors in the area were still giving false alarms. Further investigation showed that new 19 gauge wire connecting those field data stations was defective. In essence, because of technical problems, Adelaide's dispatcher had been inundated with false alarms for some time preceding the event.

The nominal problem in Brownfield's case was the burning motor located at 4 South, 6 West. A compounding factor, which no one knew at the time, was that a door had been left open in the supply chute where the motor was parked. This open door affected ventilation inby the blaze, and caused the smoke to behave in ways that the miners did not anticipate. Because of their internal state, made up in part by knowledge about how the ventilation system normally functioned, these workers were led to misapply environmental elements in making their diagnoses. The result was that many of the miners came to view the problem as far worse than it actually was. Consequently, their decisions were, in some instances, based on false assumptions and the resulting actions were not as effective as they might otherwise have been.

At Cokedale, the nominal problem was a fire that started when fallen material from the mine roof caused a trolley wire to arc. Although the person who discovered this blaze contacted Cokedale's dispatcher and reported what he was seeing, initial communications were misconstrued. The reason is that with trolley haulage "hot hangers" occur fairly often. A hanger is an insulated support bracket that suspends the trolley wire from a mine's roof. When an insulator deteriorates, the support pipe that extends into the top will heat up. If there is head coal in the mine roof, this coal may start smoking. In most circumstances, a hot hanger will be dealt with by disconnecting the power, prying down any head coal, and replacing the hanger assembly. Thus, when the dispatcher began contacting people inby the fire source and, according to several respondents, initially spoke of "a hanger burning" no one was particularly alarmed.

Thomas [1923] argued that people's actions generally depend on their definition of the situation. It has already been suggested that miners are conditioned by both their physical and social environment to define situations in certain ways. Danger is a taken-for-granted aspect of underground workplaces. It is necessary, then, for workers in such a setting to draw a distinction between routine hazards and life-threatening occurrences. In other words, any warning stimulus must make it through this sort of context filter in a manner clear enough to cause a situation to be perceived as problematic. Mallett et al. [1993] listed five characteristics of an effective warning: (1) it will be specific about what the problem is (2) the warning's validity is acknowledged, (3) it gives the nature and extent of danger to those who are threatened, (4) the warning will be verifiable, and (5) it will contain some cues to help people prepare for further action. The paragraphs that follow will discuss how initial warnings were received at the three study sites.

1 Right - Adelaide

On Adelaide's 1 Right section, the message that there was a problem came by telephone. Both shuttle car drivers were cleaning up around the feeder because their belt had been running erratically and finally went down entirely. They first heard someone on a trolley pager trying repeatedly to contact another section. Then, the 1 Right telephone began ringing:

> I said, "There's something wrong, buddy...I better answer the telephone." So I went to the telephone, I picked it up and I said, "Hello." Nobody answered. So we waited there again to about five till [eleven]; the telephone rung again. I picked it up and I said, "Hello...Who is this?" And it must have been the dispatcher because he told us, he said, "You got a fire on the belt, get the men out of the section." I said, "This is 1 Right." He said, "Go get your men out of the section. You got a fire on the belt."

The shuttle car drivers, joined by a bratticeman who had been helping them at the feeder, set out to warn those workers at the faces. The bratticeman took the left side, one driver went up the middle entries and the other took the right side to warn 1 Right's miner operator and his helper.

The bratticeman found the two bolter operators in No. 3 entry. Since the bolter was running, they had difficulty communicating:

> Well, first we shut the machine off, because we couldn't hear him, what he was saying, and then after he told us...there was a fire—or they said there was a fire on the belt; that everybody was supposed to leave...I just pulled my boom back and stopped everything, shut the power off, got my coat and bucket, and went down to the load center.

The shuttle car driver who had taken the right side first approached his boss, who was making a preshift face examination:

> I told him the dispatcher said an alarm went off and there was a fire in the mine and everybody had to get out. And he said, "Well, tell the operators." He went and kept walking along the face. I think at this time, we still didn't think it was a fire. We thought it was just an alarm.

Whether this attitude affected the manner in which the shuttle car driver approached the operators is somewhat unclear, because he recounted that "I told the operator, 'There's a fire in here, just back up and go.'" Both men on the miner, however, remember this warning somewhat differently:

> One of the buggymen come running out, and he was like three breakthroughs behind us. All he did, he just hollered up and said, "Hey...back the miner up, we're going home." I said, "What's the matter?" He says, "I don't know; all I know is we're going out."

The miner operator and his helper, oblivious to the fact that an emergency was developing, went through normal shutdown procedures and retrieved their personal articles at the load center. They then strolled to the mantrip, where everyone else was waiting impatiently to depart.

2 Northwest - Adelaide

Smoke, or the smell of smoke, arrived on 2 Northwest before the workers could be contacted. One of the shuttle car drivers, who had prior experience in fire as a mine rescue team member, was the first to sense something wrong. Like the buggy operators on 1 Right, he and his buddy were not running because the belt was down:

> [While] we cleaned around the feeder, ...the other buggyman for that night...was standing there with us talking and I told him, I says, "I smell rubber."...I looked down the belt, and I...smelled the smoke then, and I immediately went into, I think it was 4 or 5 [entry]...into the face... That's where the boss was...and I told him..."We got a fire or something went wrong with that belt again...Are you going to call?"...So he went immediately to the phone and called, and he said..."We got a fire on the belt."

Both shuttle car operators went to warn those workers still at the faces. Their boss remained by the telephone. While the miner operator remembered only that a buggyman started flagging him and said "smoke," everyone else was clear that they had been informed there was a fire on the belt. All miners were also told, they remembered, to gather fire extinguishers. Most of them did so and headed to their dinner hole. From there, they boarded their personnel carrier for an attempted trip out of the section.

3 Left - Adelaide

Workers on 3 Left reported that their section foreman was near the telephone and, when it rang, started to answer. It stopped ringing:

> Then they rang right back again and he said, "Come on, let's go." Everybody said, "Aw, we got to go down and shovel the belt..." So we were moving kind of slow and disgusted. And then he yelled again, "Come on—there's a fire on the belt—let's go!"

The boss notified all face workers and told them to back their equipment out and shut it down. Power was knocked at the load center and everyone went to their mantrip.

4 South - Brownfield

On 4 South, at Brownfield, one of the shuttle car drivers heard the pager as he was dumping a load of coal on the feeder:

> Fire boss was on the phone...He says, "...There's heavy smoke coming into the intake...get out of there as soon as you can—get those men out..." I didn't even finish unloading the buggy...I just turned around on the seat and went back up to the miner...the bolters were in there and I stopped at the bolters first and I told them that there's heavy smoke coming up the intake and we're supposed to get out of here right away—see you back at the power center—that's where the [self-contained self-rescuers] were.

When the bolters heard this warning, both of them surmised that it was only a drill. They knew that a system for sensing fires was being installed and assumed that fire drills would be planned to test the new system. The bolters further reasoned that the presence of an inspector on their section made a drill more likely: "We had that inspector in there and I thought it was like a fire drill, just to see how long it took us to go to our meeting place...get our equipment and stuff...I. wasn't that excited about it." The shuttle car driver next went to tell the miner operator and his helper, who "backed the miner back...[and] went back to the power center."

When the face workers arrived at their power center they found that the section foreman, mechanic, and a Federal inspector had already gotten there. These three were told about the fire boss's call. The section foreman had realized that there was some sort of problem. He had accompanied the Federal inspector and section mechanic to repair a scoop that was out of compliance and parked in a crosscut outby the section's transformer:

> I guess what was happening, smoke was coming up the intake and everybody didn't realize it...it was going past us...we were so far back into the crosscut...we were there working and I thought I smelled something burning...I asked everybody if they smelled it and they said yeah, they realized they did smell something...I went out to the aircourse, No. 2 aircourse, and I could see the heavy smoke was already up there, so I just told them there was a lot of smoke out there.

Thus, by the time the workers had assembled at the power center the section foreman was able to corroborate the warning everyone else had gotten through an intermediary. What was lacking was any information about the location and magnitude of the problem.

5 South - Brownfield

On 5 South also, the first warning was delivered by means of the mine page phone. The call to this section was taken by one of the shuttle car drivers:

> I heard them calling 5 South on the phone, so I went and I answered the phone...They asked if the boss was there...I said yeah...so they said tell the boss to get everybody out of the section because they had heavy smoke coming...I did get a little bit excited at first, and then I...called back [to ask] them...where it was coming from...and didn't get no answer.

The fire boss's message, already inadequate, was relayed by the shuttle car driver to his section foreman:

> The belt shut off...[the shuttle car driver] come over and said that [the fire boss] called and said there's smoke coming up the belt line...[the shuttle car driver] didn't wait...I asked him is it bad, and he said I don't know...He just said we was supposed to get out.

The roof bolter operator and his helper, deciding to take a break while the belt was down, were the next individuals to be informed: "My buddy and I...were walking back to get a cup of coffee and the buggy runner [shuttle car driver] hollered that there was smoke coming up." By the time the other shuttle car driver received word of the fire, he had already been alerted by the smell of smoke. He primarily wanted more information, which his fellow buggy runner did not have:

> We was loading in No. 2 entry...the belt went off...While [the shuttle car driver] was answering the phone...I was over at the intake, and I could smell the smoke coming in already...So then [the shuttle car driver] come through the crosscut and told us things...[The fire boss] told him there was going to be smoke coming and we better start out, but [the shuttle car driver] didn't wait and see where the fire was and all that, which he should have done.

It can be seen from these comments that the workers on 5 South, like those on the other two sections, began their evacuation without an adequate perception of the nominal problem upon which to base their diagnoses.

6 West Mains - Brownfield

On 6 West Mains section, where three people were working, the initial warning came in the form of a page phone message taken by a maintenance foreman. This individual was accompanying a mechanic and a State mine inspector on an inspection:

> "I heard the fire boss...and I recognized from his voice that he was really desperate to get somebody to answer, so I went to the phone...and he said there was a mine fire at 4 South, 6 West."

At that point, although the maintenance foreman had been told the fire's location, he had no notion about its severity. Nor had the foreman gotten a chance to reinforce the sense of desperation he detected in the fire boss's message through the medium of his own senses.

Though he was predisposed to believe there really was an emergency and to act upon that belief because of the urgency he discerned in the fire boss's voice, the maintenance foreman still "didn't really think....it was anything to...get concerned about." One reason he did not become concerned at the first warning of fire was undoubtedly because of his internal state, which had been conditioned by past experience with smoke in the mine. The foreman had seen "lots of mine fires, small mine fires...I've been in where...belts slipped and burnt halfways off the roller and stuff like that." Since smoke is fairly common in the mining environment, miners do not always interpret its presence as an indication that immediate action should be taken.

After hanging up the pager, the foreman first went to alert his mechanic. This worker, because he was involved in the complex task that had made it necessary for him to be on this section in the first place, was not paying attention to what was going on around him:

> I hollered to him from the phone and he didn't come...He said, "Wait a minute..." and I went down to where he was and says, "Come on... There's a fire in the mine down 4 South."...He said, "Just a minute."

Telling the mechanic not to wait any longer, the maintenance foreman then went into the belt entry to inform the State inspector: "He was over there at the feeder, and that's the first sign of smoke that I seen was outby the check at the belt entry." Thus having the fire boss's warning substantiated, but still not knowing very many details, the men began their evacuation.

7 Butt - Cokedale

Initial warning came indirectly to 7 Butt when a construction foreman, listening on his trolley phone, monitored talk between the lead motorman who had been bringing in empties and Cokedale's haulage foreman:

> I was sitting at old 8 Face and when he said about the trolley switch burning I turned my light in the opposite direction, because the air comes straight down...from the new intake aircourse and there was just a solid wall of smoke behind me. So I called the dispatcher and told [him] to get in contact with all the people in 8 Face Parallel and get them out because all the smoke was going in on them.

The construction foreman then went into 7 Butt to alert a fire boss, two mechanics, and four others working in the section. Because of the conversation he had overheard, the construction foreman told those with whom he spoke that a trolley switch was probably burning:

> He...thought it was a wire fire, you know, like a trolley wire. We have a lot of them down there, so you don't have to be worried about it too much...Everybody took their time. So me and the mechanics...even took the time to put the tools away.

This group, led by the construction foreman, elected to ride jeeps and a portal bus out the track entry.

8 Face Parallels

A general foreman was with two men cleaning up a roof fall. Needing some large reinforcing bolts, he had been scouting in the 8 Face area. After finding the materials he needed, the foreman sent a worker to retrieve them. In the meantime, he ate a sandwich and waited in the old section switch at 8 Face:

> There's a phone there. I saw some smoke coming up the track entry. I called the dispatcher...I said, "What we got here?...I'm getting some smoke up in here." He told me at that time, he said, "Maybe a hanger burning, or something."

The general foreman sent a worker into the 8 Face Parallels section to warn everyone there and tell them to gather near his location. While he was waiting, the foreman was joined by two motormen who were bringing a load of rails into the area. In all, eight miners rendezvoused with the general foreman. These men then attempted to walk out through their track entry.

In essence, miners in all eight groups received some sort of warning, following the discovery of fire, telling them either that "smoke" was headed their way or that they needed to leave the mine. At this point, however, most workers seemed to be acting "as if" there was a problem that required action, but were not too concerned about their chances of getting outside: "Well, at first nobody really thought too much of it, you know." It was not until their perspective was challenged by an unexpected occurrence that the miners began to diagnose their problem as a serious one.

Diagnosis

It is axiomatic that people tend to interpret events from a normal perspective as long as they can before starting to define the situation as abnormal [McHugh 1968]. This notion is illustrated by the initial misdiagnoses of those who discovered the nominal problem at each study site. Adelaide's dispatcher, for whom unreliable sensor readings had become routine, did not accord legitimacy to the first actual warning he received: "I took it as a false alarm." The fire boss at Brownfield also saw the event incorrectly when he initially encountered smoke: "I stood up and I smelled smoke. I just kind of thought it was, you know, maybe a bad roller, the belt was rubbing on the straps, or something like that because we've had that before." The haulage foreman at Cokedale seemed, to those who overheard his trolley phone exchanges, complacent about the problem he was facing: "I even heard him talk to the people [outside]. He said, "Look in my locker or by my locker and get another trolley switch."' This tendency to normalize circumstances also carried over to the way in which those inby the sources of combustion came to diagnose their situations.

1 Right - Adelaide

The crew on 1 Right had their evacuation delayed due to miscommunication between a buggyman and the operators he went to warn:

> We were just taking our good old time...There was no smoke; you couldn't smell anything...It was clear, you know...I said..."Really, what's going on?"...And [a buddy] said, "I'm telling you, the place is on fire."

Actually, it was not until the workers encountered heavy smoke that they began to realize they were in a potentially deadly situation. Group reliance upon normalcy gave way at that point to a change in the way they construed their condition [Kinston and Rosser 1980]. What had been considered a routine evacuation became disrupted:

> You could smell the coal actually, and we started pulling the self-rescuers out and passing them around...Three guys run over to the intake...and they were just—we were running, you know, here and there..."What do we do—what do we do?"

Very soon, however, the workers began to take stock of their predicament. At this point they were actively seeking information that would let them make sense of what was actually happening:

> Common sense tells me if there's a fire, chances are the fire is going to be in the belt entry. I'm also thinking if the fire is there, the fire wants to go for fresh air. It can be fueled by fresh air [in the intake]. And I didn't want to go the belt entry...Let's get into the return and find out what we have.

As the group's evacuation turned into an escape, everyone tried to fill information gaps with guesses about the fire's location and how best to proceed. The way in which they filled these gaps would have an impact on the perceived options as their escape progressed.

2 Northwest - Adelaide

There was no initial question of whether *something* might be wrong on 2 Northwest; rather, group members became concerned with the *extent* to which something was wrong. On this section, even with the smoke that was present, a few workers tended to downplay the seriousness of what their senses were telling them. This behavior, normal for the early diagnosis stage, is typified in a comment made by a bolter operator:

> I figured, well, with all the safety features that are supposed to be built in this, they got a little fire down there and the smoke coming up and they want us the heck out of here, but I figured...we're going down with fire extinguishers, I figured we'll ride down in a mantrip, come to it and—we got the fire out, if there ain't somebody already down there to get it out. It was my feelings.

The least amount of minimizing was done by the buggy driver who had voiced an alarm originally. This person was a former mine rescue team member and had experience in smoke:

> I started to get a fire extinguisher off of the miner at that time, and the smoke was getting pretty bad then. And so I said, well, to hell with the fire extinguisher. I'm going to, you know, take care of myself.

As can be seen, even where individuals had smelled rubber, seen smoke, and heard their section boss confirm they had a fire on their mother belt, there was variability in how a diagnosis was reached.

3 Left - Adelaide

Like the bolter operator quoted above, one of the workers on 3 Left also thought his crew was leaving the face to fight a manageable fire:

> They said, "We got a fire on the belt. Back the machine out and let's go." Well, I just felt we'd run down and put it out. I didn't think there was any real major [problem], they said it was just a small [fire], burning on the belt. Well, if that's all there was to it, we could have took a fire extinguisher, run down there in the mantrip [and put it out].

When the group encountered heavy smoke they became disoriented and lost their way momentarily. This added an element of uncertainty that made an accurate diagnosis of their situation all the more difficult. That, combined with the fact that they did not know where the fire was, prevented them from reaching a clear picture of what was required for everyone to reach safety.

4 South - Brownfield

On 4 South, the workers had decided to travel down their belt, which was isolated by stoppings from the intake and return entries:

> I walked over to a door in the belt entry and saw that it was clear air... There was no smoke coming up the belt...I just run that belt on the day

> prior to this and I know the stoppings were intact...So the belt entry should be clear if there was a problem in the intake.

Some of these miners expected to encounter light smoke in their belt line (because of a possible leakage through the stoppings). When this indeed appeared to happen, a diagnosis of the real nature of their problem was confounded by stress induced from having to deal with a relatively unfamiliar breathing apparatus:

> We stopped and everybody knelt down and started putting their [self-contained] self-rescuers on...when I looked over and saw the...miner operator, that's about the first time I started getting a little worried because he was shaking somewhat severely...and I just thought...we are going to have trouble because he's having a hard time even, you know, getting his self-rescuer cover off.
>
> I got the machine on and started down there and I wasn't getting the air that I thought it was going to give me...So I took the mouthpiece out... you need to breathe and you're not getting what you're supposed to.

Focusing on these perceived problems with their self-contained self-rescuers, the workers did not anticipate meeting heavy smoke during their evacuation. Therefore, when the miners did encounter dense smoke in their belt line, they were presented with an extra (and unexpected) experience.

This new occurrence, however, was one that stemmed from their environment rather than from a piece of technology. It was this second event that caused them to begin diagnosing their situation as very serious indeed: "I was thinking, I remember distinctly thinking to myself, all this smoke around...I can't even see...You couldn't even see where you were going." Choices made by these workers later in their escape, then, were based on the necessity of dealing with apparatus that did not perform as expected in conditions the miners had not foreseen.

5 South - Brownfield

The predicament of heavy smoke in areas that were supposed to be isolated was also unanticipated by the workers who escaped 5 South:

> We turned around and we were going to go down the intake and we didn't get more than 50 feet when we could see the smoke coming in towards us...one of the bratticemen said we'll get into the belt line 'cause it's neutral air...Everybody got up in there and...we only went maybe

two, three hundred feet and the smoke was in there—the belt entry... How it got in there, we don't know...We haven't figured that out yet.

This element of uncertainty stemming from a lack of information regarding the fire source was exacerbated by the workers' internal state. In essence, these individuals knew enough about the mine's environment to understand that (assuming a properly functioning ventilation system) only a large-scale fire would cause contamination of all possible escape routes: "I tell you, panic hit, believe me...'cause all the teaching and training—everything—these are all supposed to be separate splits...Well, the first thing that goes through your mind is everything's burning."

Once the miners determined there was not a smoke-free escape route, then their particular knowledge of the ventilation system led them to diagnose the problem as more serious than it actually was. Additionally, this misperception about why the smoke was behaving as it did caused some of them to consider giving up their escape attempt: "I sat down with those rock dust guys and I figured...this is it...I was just going to say goodbye to the world." The stress engendered by their inaccurate analysis of actual conditions influenced the workers' subsequent choices and actions.

6 West - Brownfield

The men on 6 West Mains began their evacuation knowing that a fire existed at 4 South and that there was some smoke already in their section. The maintenance foreman did not diagnose this as a significant occurrence, though. At the beginning, he had little concern regarding his chances of exiting the mine safely. The maintenance foreman held this notion up to the moment he experienced heavy smoke: "I've encountered smoke [in the mine before], but nothing like this." When the amount of smoke presented irrefutable evidence that things were out of the ordinary, the maintenance foreman stopped defining his situation in terms of past instances when he had seen smoke in the mine. Such a dense collection proved, in his opinion, that the present state could no longer be diagnosed as commonplace. The maintenance foreman then began to perceive the scope of the evacuation problem differently: "Once I seen that smoke, then I got pretty well shook." His subsequent choices came to be affected by that new viewpoint.

7 Butt - Cokedale

On 7 Butt, the construction foreman told all seven people in his area that "smoke was coming in" and they would have to leave. This initial warning did not disturb any worker unduly, as one of the mechanics later recounted:

> We were going to have to get out and—that was about it. We would probably be coming back in after they got the hanger, the little hanger fire put out.

The group, riding in four different vehicles, had not traveled far when they encountered thick smoke in their track entry. Three of the four vehicles, two jeeps and a tandem motor, collided because of poor visibility. The construction foreman drew upon prior experience to reach a diagnosis of what faced them:

> I set all the ventilation up down there, and I knew basically what was going on with all the smoke. The intake escapeway would have been full of smoke. So I told them we'll try to go out on power.

Everyone except three workers in the fourth vehicle, a portal bus, boarded the lead jeep and continued on. After a short distance, however, those five men in the lead collided with a parked vehicle. They and the miners following in their portal bus were forced to choose an alternative plan that would entail escaping on foot.

8 Face Parallels - Cokedale

Nine miners tried to walk out the track entry from 8 Face Parallels. When they encountered heavy smoke on the track, they decided to get into their intake escapeway. After traveling only a few hundred feet, they again found themselves in thick smoke. There was little discussion at this point:

> No, it was pretty much, you know, this is out. Let's try something else. Well, naturally the next thing would be the return. So we decided to try the designated return, at which point [the boss] did not know which was the designated return.

The group entered their left return and went a short distance before discovering they were not in their designated alternate escapeway. By this time the workers were diagnosing their problem as a serious predicament: "That's when it came into my mind...We're in bad shape." This sentiment was echoed by the other group members. The difficulty these workers had in finding their way at the start of their escape had an impact on how subsequent choices were made.

In each case, such a low level of concern exhibited by affected miners at the beginning of their evacuation was due partially to uncertainty about the true nature of the problem. This uncertainty, stemming from incomplete information, allowed the workers to define their situation initially as normal (or at least as nonthreatening). Further into the events, however, unexpected occurrences began to challenge the miners' interpretation of their predicament:

"We just [put on self-contained self-rescuers] and everybody seemed fairly calm at the time, but then...we got down to the thick stuff...and a sense of panic [set in]...we weren't told where the fire was."

As it became impossible to interpret circumstances from a normal perspective, many of the workers reacted and started to define the fire as perhaps worse than it really was:

You got one thing in mind—death—believe me...I was scared...I don't think there was a man there that would tell you that he wasn't...I really didn't think I would be here.

Essentially, as can be seen, the miners lacked adequate information to accurately assess the true nature of the problem they faced. Many workers' knowledge of the environment and of how elements were supposed to behave in it combined with their lack of information to mislead them. All of the individuals were in danger, but the real danger was from smoke inhalation—not, as some thought, because their entire mine was burning.

Options and Choices

After completing the diagnosis of a problem, a person must decide which actions, if any, must be taken. This part of the decision-making process calls for recognizing and evaluating available options and then choosing an action that is determined to be best given the circumstances. A number of variables impact a person's perception of particular choices and their appropriateness to his or her situation. Analyses of decision-making therefore must focus not only on the objective outcome of each action, but also (and perhaps more importantly) on choices that were made given the impact of elements influencing the decision-maker. The following paragraphs outline how options were viewed and choices arrived at during the three fires.

1 Right - Adelaide

When the crew from 1 Right, attempting to evacuate on a mantrip, had to stop because of poor visibility, they were faced with limited alternatives. Three miners tried to cross the belt entry to check their main intake. When they opened a door into the belt entry, these men found it to be contaminated:

And I told them, "Whoa, whoa, wait a second. If you got smoke on your track and when [you] opened the door...I seen you have smoke on your belt, you got smoke in your intake." One of the other guys on the crew, ...who was my buddy that night, says, "Why don't we go back to

> Peterson [shaft] across the bleeder and come out?"...They didn't want to go back to Peterson...I says, "If you don't want to go back to Peterson, then if you have smoke on your intake, we were always taught to get into your return, and then keep checking until you see clear intake."

The group decided their only option was to get into their left return. They found a door and had to pry it open. Before entering this return, the face boss called outside and told the dispatcher what they were planning to do. The crew then started out in air that had not yet become smoky.

As the 1 Right group traveled their return, they were faced with several other points at which decisions had to be made. First, the smoke that had been coming in their intake made its way across the faces and caught up with them near the mouth of 8 Left:

> So we put the SCSRs on. Now one guy's SCSR wouldn't work, so [one of the buggymen] gave him his spare one, and we started to come down this return. And we came to these overcasts down here; you know, one overcast we came on, it was hot and thick smoke was coming out. And after looking at it, it was the belt that was going up to 3 Left, and I mean you could feel the heat coming down it. [The buggyman's] SCSR didn't work and he told me..."I'm not going through that. Mine doesn't work."

So, the buggy runner who had earlier given a spare SCSR to a buddy, now having problems with his own, balked at crossing the overcast:

> I made the decision I couldn't go in this smoke...I was like the third, fourth one in line...and we went into that smoke and I couldn't breathe and I was gagging on that self-rescuer. I couldn't breathe anything at all. I don't know if it was psychological or what...I came back out...I did know where I was because...I'd worked in that area a lot...The other overcast that we just went over was over the intake...So I went back... I went into the door and it wasn't too bad...And I thought I'll go down this way, but then I said, no, if I don't go out with them guys, I know they're going to be looking for me. If they get out, they'll be looking for me and they'll think I'm lost. So I better go out with them guys. So I went back into the return again...I went over an overcast where the smoke was. I went over top of the overcast in the smoke and I couldn't breathe...They were already gone through there. I couldn't see—I couldn't tell where they were because you couldn't see anything over there...I can't breathe. I'm going to die here, and I don't want to die. I don't want to die here. Back into that intake again...So I went...over the stopping—over two overcasts there and got into the intake escapeway at 2 Northwest.

The rest of 1 Right crew continued out their return until they came to a door leading onto 2 Northwest track at crosscut No. 10. At this point, they discovered the shuttle car operator was not with them, and were faced with another decision:

> When we got outside that door, and it was just fresh air, and everybody wanted to take off, that's when I told them..."Hey, [the buggyman] is back there, his self-rescuer didn't work; he didn't come through that." So that's when we went back in...You're not supposed to do it...They tell you not to do that...But we felt, you know, when you work with a bunch of guys, you become close...And [the miner helper] told the boss..."Hey, I'm not leaving." Because the boss said, ..."Hey, let's go"...you know, and [the miner helper] said..."We're not leaving [the buggyman]"...and then we started going back in.

The buggyman, meanwhile, had traveled the 3 Left intake escapeway to an area outby the fire. It was some time before the crew got back together.

2 Northwest - Adelaide

Choices required of the 2 Northwest group were affected by the fact they had two experienced people with them. Their face boss knew the mine well and one of the shuttle car operators had been a mine rescue team member. When the crew entered heavy smoke on their track, a decision was made to stop the mantrip:

> The guy that was driving stated that he didn't think we'd better go any more, so that was more or less a judgment call. We could have gone down the line—you could have put your rescuers on and you could have kept going out [on] the mantrip, but the pole...would have been off...I don't know how many times, on the way out, that the poles were jumping pretty frequently going out of there...So...we stopped the mantrip and got the rescuers, took those and went back up to the section.

On the way back into their face area, the former mine rescue team member helped everyone put on a self-contained self-rescuer:

> This time we got everybody together and [the face boss] said, you take the back, I'll take the front. Don't let anybody in back of you, you know, and we'll keep everybody together.

The face boss led the group toward their intake escapeway. At the entrance to this entry, crew members took additional SCSRs that were stored there. Then, grouped together with their face boss leading and the shuttle car operator bringing up the rear, everyone proceeded out the intake escapeway. After traveling 500-600 ft, the group encountered dense smoke. The face boss then decided to enter the right return, which was a designated secondary escapeway:

> Every 3-by-3 door, [the face boss] would go check...We done this for, I counted, my calculation was 55 breakthroughs.

When the men reached the No. 3 stopping, which was outby the fire, they found the air to be clear. Finally, the face boss saw the shift foreman and notified him that everyone from his section was out.

3 Left - Adelaide

A section foreman and nine crew members were on 3 Left, which was a retreat section. The group started out on their mantrip. After traveling "four or five breakthroughs," they entered smoke. At that time they made a decision to backtrack toward the face and get into their primary escapeway. The group walked two breaks and found a door leading into their intake escapeway:

> So we went down the intake approximately, oh, I don't know, maybe seven or eight breakthroughs, it's hard to say the number right now, but it wasn't very far. And we were getting a lot of smoke in there and it was rubber smoke. You could smell it just as plain as could be; it was a belt burning.

A decision was then made to get into the alternate escapeway. The group had not gone very far in this return entry when they again encountered smoke. At this point the SCSRs were donned:

> I remember thinking to myself, I said, "This is stupid, I know better than to walk through smoke without putting that thing on because you don't know how much CO's in it." And that's when we stopped and put them on. And then, we kept on going out of the return. We got down to where our overcasts was and there was an overcast there that we couldn't cross. It was leaking so bad, and the smoke was so thick we couldn't get over it.

The face boss, deciding to get back into the intake escapeway through a door in the overcast, became disoriented temporarily:

> And then we had to have a little team meeting there. We knew there was an intake; the intake escapeway was still in that area if we could

> find the right door to get into it...The subject of barricading was brought up, but that's—what are you going to barricade if it's full of smoke everywhere?

After figuring out the proper direction of travel, the face boss led everyone over the overcast and out their intake entry. One of the roof bolter operators began having trouble, presenting the group with another decision:

> When [the roof bolter operator] went down, we was all single file and I was last...I noticed no one turned around at that point...I spit out the mouthpiece and I hollered as loud as I could...And only two people come back...It made a mean feeling in me that it was every man for himself at that point on.

Approximately three crosscuts from clear air, the group met Adelaide's shift foreman, who had been traveling the entry looking for them. He helped everyone get out from there.

4 South - Brownfield

The miners escaping from 4 South were troubled by some elements that colored their abilities to make decisions. Awareness of past mine disasters (such as a recent fire at Utah Power and Light's Wilberg Mine, in which 27 miners died) revealed to these workers how deadly a mine fire could be. Such knowledge made any uncertainty about the scope of this fire even more problematic:

> We all encountered a panic situation where we didn't know where the fire was, we didn't know the extent of it, and my personal thoughts were that it was a Wilberg disaster, and that's all that was in my mind...Where is that smoke coming from? How bad is it? Well, I panicked...I know I did, I'll admit it...Everybody, I think, did.

A complex background problem also hindered an efficient escape. Although the miners had received training on self-contained self-rescuers, few had any actual experience wearing the apparatus. During their escape, they found the device was difficult to breathe from and made communication almost impossible:

> I was with [the miner helper] and [he] was having very difficult breathing through it...He was gasping for air...[The inspector] was trying to help [him] breathe...And then with the mouthpiece in, it's real hard to communicate—you can't hear one another...Some of us took the

> mouthpiece out to try to speak and then to even breathe...It was so hard to breathe through that mouthpiece.

In addition to not knowing the location and extent of the blaze in their mine, these side issues were on the workers' minds as they attempted to determine options available and to choose the best course of action for themselves.

One miner had so much trouble that assisting him became, in itself, a background problem that had to be dealt with, as evidenced by three different perspectives:

> *Miner helper*: The smoke started getting pretty thick...You couldn't really see where you were going and I was having a lot of trouble getting enough air...I'd go a ways and I'd stop and a couple guys [stayed with me]...I was pretty shook up; I guess I panicked and a lot of stuff went through my head...Hell, you didn't know where it was coming from or anything...Finally...I just couldn't go anymore.

> *Inspector*: I couldn't get him back up again...He looked at the mechanic...I saw him look at the mechanic and he said, you guys go... You just leave me here...I can't go no more...I'm just going to stay here... I looked at the mechanic and I said I got to go...there is no sense in me staying...I can't breathe now.

> *Mechanic*: I didn't know my way out of there...I lost all orientation... I knew my way out, but I forgot...It was just a panic thing...I thought, well, [the miner helper's] not going to make it, I'm going to try and get out...I was only about a hundred foot from [the miner helper] when I came through the overcast and I opened the door and I saw No. 7 and I thought [wrongly], good, this is fresh air...I thought well I'm going back in to get [the miner helper].

Essentially, facing so much uncertainty about the fire, the miner helper gave up because he had projected a worst case scenario in which the crew would have to travel through smoke all the way out of the mine. The inspector, convinced that his self-contained self-rescuer was about to fail and forgetting that he was carrying a spare under his arm, wanted only to get out of the section. The mechanic, believing himself to be in No. 7's intake aircourse, concluded that he had left the miner helper only some 100 ft from safety, although the distance was actually much farther. Based on his incorrect estimate, the mechanic decided to go back for his buddy. In reality, all three men based their actions on assumptions that were false when, if the facts had been clear, they might have made other choices.

5 South - Brownfield

The old adage that "a little knowledge is a dangerous thing" seems to have a particular relevance when it comes to perceiving and assessing one's options at specific moments in a mine fire. Other times, however, a little knowledge can be rather beneficial. As can be seen from the following comment about the escape from 5 South, prior experience in an environment may afford a sound basis for simplifying an individual's application of some elements in the judgment and decision-making process:

> I know one thing I had going for me, when I first went up into that unit it wasn't 3 days after that I went down the return with one of the bosses...So if somebody had never went down it at all...I'm sure they're probably more uptight about the situation than I was...At least I had an idea where I was going...and then another good thing, we had bratticemen with us and they knew their way down through there, and the boss was there too.

Additionally, an ability to place the crisis cognitively in one's surroundings can, by reducing uncertainty, foster a positive attitude:

> So we went and then we run into two other guys coming down...and then they told us where the fire was at...4 South sidetrack where the motor was setting...So then we had an idea how far we had to go, so it took a little bit of pressure off 'cause we knew we was goingCwe had a pretty good chance now.

When knowledge acts to minimize sources of stress, therefore, it need not be comprehensive to have a positive function.

6 West - Brownfield

Choices made during the escape of those three workers on 6 West Mains were affected by stress along with any knowledge and skills brought by each worker to the situation. The heavy smoke they encountered created stress by impeding their ability to see and by forcing them to use relatively unfamiliar oxygen-generating breathing apparatus. This in turn led to a level of anxiety that hindered clear thinking:

> I got down to 5 South...and couldn't find my way...the door wasn't there where I knowed there was a door...but I mean, I didn't waste no time hunting...Whenever I walked past and couldn't see the door or feel it,

> I didn'tCI went back the next day and the door was there.

The miner's knowledge of his environment told him a door should be at a given location and that he ought to go through it in order to continue his escape. Because he could not find this door, the worker had to discover an alternative route. In this instance, then, prior knowledge (of the door's location) was not an element that was applied to aid the worker's evacuation.

In the maintenance foreman's opinion, cognizance of 6 West Main's designated escapeways may actually have been misapplied and consequently had a negative effect on decisions that were made during his attempt to evacuate the section along with his two coworkers:

> You try and pay as much attention in class as you can on your escape routes and stuff, and I guess I panicked a little bit when I seen the smoke in the belt line as heavy as it was...I could have went...back... and...over and...down 6 aircourse and been scot free of everything... I wouldn't have even needed to don my rescuer...But...you're trained to follow your escape routes.

Although the objective outcome of considering only designated escapeways is known (all three individuals on 6 West survived), it did limit those options available to the escaping miners. As for the possibility that these men, in adhering rigidly to their training algorithm for mine evacuation procedures, may have overlooked a better route of travel: "I know if it ever happened again, I would explore...all routes of exit before I made a real quick decision."

7 Butt - Cokedale

The decision-making on 7 Butt was done by the construction foreman, who possessed a great deal of "mine wiseness" and who took charge immediately:

> That was one of the things that I had to commend the people for. I was a foreman in charge of that area, and when I said to these people what we had to do, there was no second-guessing my decision. These people were counting on my knowledge that this was right and there was no second guessing it. I had no problem with these people as far as my decision.

The construction foreman reported that he knew evacuation would be necessary as soon as he saw the amount of smoke that was coming down their fresh air intakes. He then had to choose between going into 7 Butt or 8 Face Parallels to warn workers that they were in danger:

> And I made the decision to go into 7 Butt to get these people because they were far enough away from communications that somebody would have to go and recover these people and being that I was there, I was the one to go and get these people and get them out...But the dispatcher could get in contact with [the 8 Face Parallel] people and tell them that they had to evacuate because of the amount of smoke that was coming in.

As mentioned previously, the construction foreman attempted to get everyone out in vehicles. Looking back on that choice, he reported he would have taken a different option if he could do it over:

> As I brought these people out, we would have stopped when we got to the smoke, and at that time everybody had their SCSRs on and then we would have walked...I don't know if I told the dispatcher or not that I was going out the return escapeway to Crystal. But I would have been a little bit more organized the next time as far as my...communications... to the surface, my travel, and how many people I had with me.

One reason the construction foreman made some decisions at the smoke that he later second guessed himself on was because of a significant background factor:

> I was anticipating the trolley switch burning out. There's quite a bit of smoke with it...and I was assuming that if the trolley switch was burning, from what I heard...that would be the main concentration and... we would go through here. And it was like second-guessing instead of coming to the smoke area, getting together, and then walking out.

Once the group got into their return escapeway, the construction foreman began checking mandoors leading to the track entry. He did this in order to determine when they had reached clear air. Upon getting outby the fire, the construction foreman called outside and arranged for his crew to be picked up and transported to the surface.

8 Face Parallels - Cokedale

Lack of knowledge was an important factor in perceived options and choices that confronted the group from 8 Face Parallels. Initially, the nine miners there tried to walk out their track entry. In a short time, however, they hit smoke and had to make another choice. A general foreman who was with this crew decided the next option should be to go out their intake escapeway: "You're always trained intake, track, intake, return. I tried track, that was no good, tried intake."

The problem was that this intake did not extend to the shaft bottom. The only person who seemed aware of this fact at the time was a trackman who had been delivering a load of rails to the area. He was unfamiliar with that part of the mine, however:

> I was like the most greenhorn out of the group, so ICI pretty much kept to myself what my thoughts were. The game plan [was] that they were going to walk out the intake. Now at that point, I can't say how I knew this, I obviously heard it from somebody at some point and it stuck with me, but I was told that...the intake went out onto the track. According to the old laws...they didn't have to [take] it to the shaft...And that stuck with me, and when they decided they were going to walk the intake, I specifically said to [the general foreman], "We can't go out the intake. That's just gonna take us right under the smoke." No, we'll walk the intake. Well, you know anarchy can't reign.

The group proceeded about six breaks in their intake and encountered heavy smoke again. At that time they decided to return to the face and try to go out their secondary escapeway. At the section loading point, another mistake was made. Because of stress and unfamiliarity with the section, the men entered the wrong return. After traveling a few breaks, someone realized there were no reflectors indicating that this entry was an escapeway. The group was forced to backtrack in order to reach the correct entry.

On their way out in the alternate escapeway, group members faced other choice points. When they reached their section regulator, it was decided to stop briefly. A general inside laborer, who had once been a maintenance foreman, suggested to the general foreman that the two of them investigate conditions ahead. Leaving everyone else at the regulator, these individuals went a few hundred feet on. When the smoke became worse, the general foreman expressed reservations about continuing that way:

> He said, "We can't lose the smoke this way." I said, "I know...we have to go through this—go out the return. Smoke, no smoke, or whatever, we can't keep changing our minds—we'll be here forever." So he agreed.

The general inside laborer then went back to get those workers waiting by the regulator. Some of them were already discussing whether to put on their filter self-rescuers (FSRs) or don their SCSRs. The general inside laborer and a mechanic donned self-contained self-rescuers. Everyone else put on their filter devices:

> We were always trained [that] at the first sign of smoke you should [put on your SCSR]. At the first sign of smoke I didn't put it on because, you know, they were saying fairly confidently that it was probably just a hanger burning...[Later] the instances that I pointed out...led me to believe that this man wasn't going to get us out of there in a safe period of time...You have an hour with that SCSR. Not knowing where I was, that's the reason I didn't put it on immediately.

The group traveled for some time until the filter self-rescuers became hot. At that point, the men knelt in a circle and donned their SCSRs. They then proceeded outby in the return, checking through mandoors for fresh air.

It seems from the preceding comments there were two factors that had a disproportionate impact on the choices miners made. The first was their internal state, specifically their knowledge (or lack thereof) regarding how elements in the environment were supposed to fit together. While all of the workers generally understood what it means to have the haulage belt on a neutral split of air, for instance, few seem to have considered the possibility that something as simple as an open door, rather than a raging blaze, could explain the contamination of this air. In the same vein, although the miners had internalized an awareness of what their self-contained self-rescuers were supposed to do, not many were prepared for the actual experience of breathing with one. The second factor influencing the miners' choices concerns the amount of uncertainty stemming from a lack of adequate information. Those workers who did not know the fire's location, or its source, were inclined to believe the worst. Their choices tended to be based on a perceived need to travel some miles with close to zero visibility before the oxygen in their apparatus ran out. For the few miners who had been told where the smoke was coming from and what was causing it, the goal was simply to get outby some point inside their mine.

Actions

Once a choice is made it then can be executed. Any action taken by an individual or group therefore has real consequences that are frequently used by others as a basis for an analysis of the quality of this choice. The actual decision-maker, however, aware of all those factors that affected the process, may evaluate his or her choice using different criteria. Those who escaped from the three fires discussed options they exercised and reflected on the quality of their actions.

1 Right - Adelaide

The first action taken on 1 Right was a delayed one: "The phone was ringing but we never answered it, you know, because usually the boss would take care of that." This delay, combined with the holdup caused by a subsequent miscommunication between the buggyman and miner operators, could have had severe repercussions:

> Another 5 minutes and we wouldn't have been able to come out the way we did because that overcast did go and collapse. We'd have had to find another route out of there. And it was already 45 minutes...I only had 15 more minutes on that self-rescuer because they said it only lasts an hour. And we were just fortunate.

A second significant action was when the crew abandoned their mantrip. The miner operator discussed an option that occurred to most of the groups but was not executed successfully by any of them:

> If we had known, we probably could have put the self-rescuer on [and ridden] out in the mantrip. But then we thought about that, and when you have a mine fire, you're [liberating] other gases too, and the pole on this [mantrip] always jumps off. And what we were afraid of is [the pole] jumping and a spark and having an explosion. You know, we were a little concerned about that.

In view of these concerns, therefore, the group explored their possible choices and decided the best course of action was to go out their left-side return airway.

A heroic but ill-advised action was undertaken when the crew reached fresh air and found one of the buggymen missing. A bolter operator, the miner helper, and a bratticeman volunteered to go back and look for him. The miner helper borrowed the face boss's light so he could tie it to a water line that ran in the left return. This light was to indicate the point at which the three men should make a left turn to find the door they had come through. Leaving the bolter operator at the water line, the miner helper and bratticeman continued on to the overcast where the buggyman had separated from the group:

> When I got to that overcast, as soon as I was going up on the approachway, you could just feel something collapse. I mean, the smoke, you couldn't even see your hand in front of you.

When the overcast blew out, the bratticeman, who had been holding onto the miner helper's belt, drew him away from the approach. The two men then retreated back along the water line, running over the bolter operator in the dense smoke. All three individuals then crawled until they saw the light they had tied to the water line. They turned left into the break and went back through the mandoor to fresh air.

2 Northwest - Adelaide

Perhaps the most significant action on 2 Northwest took place at the beginning of the miners' escape. The face boss quickly assigned the former mine rescue team member to bring up the rear as everyone traveled out. The boss stayed near the front and tried to keep the men from walking too fast—a tactic that was appreciated by the utilityman:

> No, he was like in back of me there and we just—we all stuck together real well. You know, if I got too far or [the bratticeman who] was with me, he'd get out in front of me and if we got out too far, the boss or somebody just said, "Take a break." And the one guy was having trouble and he said...that he needed to rest some, and we just stopped and rested with him.

Because the face boss did not know the fire's exact location, he would open each door in the stopping as the group progressed. This offered the workers another opportunity to stop and catch their breath. Overall, as the data show clearly, 2 Northwest had the most orderly escape of any of the eight groups in this study.

3 Left - Adelaide

It was mentioned earlier that some of the 3 Left crew balked at crossing the overcast at 3 Left junction. The face boss decided to get back into their intake escapeway through a door in the overcast. At that point, according to the miner helper:

> We got confused and we started going back into the section till we run into the first door, and we just made a complete circle and come right back to that main overcast again...He made a right instead of a left the first time.

The boss, coming through the door again, knew which way to go the second time because he stopped a moment to feel the air current on his face. "Once we made the left, we were in good shape."

4 South - Brownfield

On 4 South the seven miners and one Federal inspector started their escape by going down the section's belt entry: "[The boss] had noticed there was some smoke already coming up [the intake] and they figured the return would be filled up too, so we couldn't go down [that] way...So they figured the belt would be the best way to go." At the beginning of this evacuation, all eight individuals were hurrying along the belt. Not all of these workers, however, had the ability to keep up this rapid pace. Therefore, two groups were formed. The section foreman went ahead in order to keep up with three workers who were moving rapidly, leaving the inspector with slower members of the crew. This second group was also divided as one person in it continued at a slow but steady pace, essentially escaping alone. Those left behind were the miner helper who had been having difficulty, along with the mechanic and inspector who were trying to help him. Finally, these two individuals left the miner operator as well.

As was indicated previously, the mechanic, believing that he had entered 4 South's intake aircourse only a short distance from where he had abandoned the miner helper, went back after him. The mechanic and section foreman, who had by this time also returned, assisted the miner helper to the track entry. All members of the crew then continued outby the burning motor.

The interview data show widely divergent opinions about the appropriateness of 4 South workers' actions during their escape:

> The one thing we did wrong, it come out that we was two different groups of four...We kind of split up and got ahead of each other.
>
> I didn't want them splitting up...I was glad that the inspector was there because I felt he's going to watch [the slower] people and I'm going to watch the other group.
>
> It's nice if we could have stayed together...but nobody knew where the fire was and everybody was trying to get out as best they could...It didn't bother me that I was left behind.
>
> Actually, [having the whole crew stay back with the slowest person] might have been worse...Everybody fumbling around...[The others] weren't able to see this man in, I guess what you'd call a panic state and maybe that's good for them.

It is interesting that the first statement, implicitly critical of some miners leaving others, was made by a worker in the first group out. The last two quotes, which suggest that leaving was at least understandable, were taken from miners in the slowest group. During their interviews, most of the individuals from this section reflected at length on their personal decisions to leave (or not to leave) others behind. Obviously, the choices made by each miner were arrived at within a context of extreme stress:

> It did cross my mind a couple of times that we should be sticking together and come out as one group...We had one man that sat down and didn't want to go any further and there was four of us ahead...There could have been four extra guys to at least help the guy, something... You never know what you're going to do until you get in a situation...but definitely we should have stayed together.

> I didn't want to go to the head of the pack—I wanted to stay and know where my people are...That was my first concern...I just didn't like the idea, but I didn't want [the faster group] taking off the way they were... I can't sit on them all...So long as [the inspector] would go with that group, I'd go with the faster group.

> I'm back here with this guy and he's having all this trouble breathing and now I'm having trouble breathing...there's no sense in me staying...I can't breathe now...I know where I'm at...I can send somebody back...I'll go out and get somebody...If it's only to the main track, there will be somebody, I hope, out there...I can send them back and I know exactly where you're at.

As can be seen from their accounts, the trip off 4 South was very problematic for these workers. Even though everyone lived through the experience, there was little consensus as to whether or not the best choices had been made.

5 South - Brownfield

Like the miners on 4 South, those in 5 South crew began their evacuation down the belt entry: "We said we couldn't go down the intake because that's where the smoke was coming from...So everybody decided to go down the belt line." These workers, who stayed close together throughout their escape, continued along the belt line until they hit heavy smoke and then crossed into the return aircourse. They traveled down the return entry, checking through doors for clear air as they went. At one point they finally detected fresh air, crawled through this door, and it led them out onto the track.

An official investigation was conducted after the blaze. In this inquiry there was some criticism of the workers' choice of escape routes. The belt entries traveled by those miners from 4 South and 5 South had not been designated as either primary or secondary escapeways. The Federal inspector who escaped the fire addressed this criticism during his interview:

> It had been suggested through the course of the investigation...that we... didn't...follow the proper escape procedures because we didn't utilize the return aircourse as an alternate escapeway...I promptly informed this person...you had smoke coming up the intake, there's only one way for that smoke to go and that's back down the return...the first thing I did was check the belt...and the belt was clear...So I know the belt entry had permanent stoppings...I had no reason to believe that that belt entry should have been contaminated.

While the correctness of these miners' actions can be questioned, the inspector was sure that, given his situation, the best escape route had been taken.

As was also suggested during the investigation, there may have been an escape route for 5 South that was objectively better than the one they chose:

> From what we were told...instead of going down the return, we could have went up...Being [the fire was in] 6 West Mains (which we didn't know at the time), we probably would have been better off going up the hill to 6 West Mains and across.

This miner agreed that, with the advantage of hindsight, a better route of escape might have been chosen. He went on to note that decisions being made by the miners on 5 South during their escape were executed with incomplete information about the fire and the condition of the mine. So, without the luxury of prescience, the workers used their best judgment.

6 West - Brownfield

After picking up their self-contained self-rescuers, the two miners and State mine inspector who were working in 6 West Mains began their evacuation: "I was going to ride the jitney out of there, but [the inspector] wouldn't let us, so we went on foot." The men started down 5 South's intake aircourse, walked approximately 50 ft and hit thick smoke: "When I turned around and said we got to go back, [the inspector] says no, and I says you can do what you want to do, I'm going back." All three did backtrack, entered the return, and continued their retreat out of the section until they came to an overcast where the miners from 5 South were encountered: "then I was relieved a little bit because I knowed that boss coming with that crew was real familiar with the mine." After crossing this overcast, the miners began hunting for a door that would take them into the intake aircourse. One miner from 5 South called and said that they had just passed a door. Everyone returned to that door, went through it, and eventually got into clear air.

During their interviews many of the miners speculated about the State inspector's decision not to permit use of the jitney in the evacuation of 6 West Mains section. Even though the inspector based his actions on the knowledge that a mine fire can liberate potentially explosive gases and that these gases might be ignited by an electrical motor, there was still extensive debate centered upon whether or not the people on that section should have ridden out.

One of the miners who had been on 6 West Mains and who had complied with the inspector's directive not to ride out, thought that the decision was nevertheless a poor one: "I know one thing, if it ever happens again and there's something to ride, I don't give a damn who—they can do with me what they want when they get me outside, but I'm riding." Later in their escape, when the three men hit heavy smoke, this miner refused to regard the inspector's initial refusal to backtrack and enter the return aircourse: "I said, 'You can follow me or do what you want.' At that point I didn't give a damn who followed me or who didn't, I was getting out of a heavy concentration."

Even though it meant retracing their steps, the worker considered going back in order to enter the return an appropriate choice:

> When I encountered the really heavy smoke...We could have probably made it down through there...I'd have probably made it just as quick or quicker...because I [backtracked] and then we went further down [past] 4 South to come out [into fresh air] than I would have if I [had stayed in] the intake...But I'm glad I went the way I did because we might have went down further and encountered smoke...you wouldn't have knowed where you was at...you might have went in circles.

While analyzing his actions, the miner pointed out that because of uncertainty about the true condition of his intake aircourse, he had to assume that smoke in this supposedly smoke-free entry meant there was possibly fire as well. The thought that they very well might "run right into the fire" is what made this worker seek alternative escape routes once he and his companions encountered smoke in their primary escapeway.

7 Butt - Cokedale

The group from 7 Butt intended to ride out in vehicles. A mechanic, who was in the lead, stopped his jeep as soon as he encountered heavy smoke and began putting on his self-contained self-rescuer. The construction foreman, who was following, collided with the stopped jeep. This caused the wireman who was riding with him to lose his cap, cap lamp, and battery. A general inside laborer, who was operating a tandem motor carrying himself and a trackman, ran into the foreman's jeep. After retrieving the wireman's cap and other gear, all five men boarded the mechanic's jeep and continued. They had not gone far, though, when they collided with an abandoned locomotive. This time, the wireman lost his cap, cap lamp, and battery for good. He then had to be helped by the others. This is the point at which these members of the group got into their return. They then waited for three people who had not followed them into the smoke.

The remaining three workers in this group were traveling in a portal bus. A mechanic and a general inside laborer had stayed on the section briefly to rendezvous with a fire boss who was conducting his preshift examination. When they encountered smoke, the fire boss, who was driving, backed the portal bus out into clear air. They heard, over the mantrip's speaker phone, conversations that ensued from the collisions up ahead. The three men decided to take another route out:

> So we put our self-rescuers on. We looked into the intake escapeway; it was filled with smoke. So we crossed over to the return and there was just starting to get smoke in there. And we started out there and we went out the return and we tied back in with [the construction foreman] and our group that left right before us 'cause we waited for the fire boss.

The eight workers proceeded out their return. Two individuals stayed close to the wireman who had lost his cap and light, reassuring him and helping him along until they came to the set of double doors through which everyone exited.

8 Face Parallels - Cokedale

Execution of decisions was a problem on 8 Face Parallels because the group's familiarity with the area did not extend to their escapeways. The general foreman addressed this issue in regard to his choice of their primary escapeway even though the fire was in a track entry:

> And it's my fault that I didn't know the...escapeway was dumping on the track. Of course, I didn't know where the fire was at either.

Once the group reached their section regulator and the general foreman, accompanied by a general inside laborer, explored ahead and saw more dense smoke, they were faced with another decision to execute:

> And we put [the filter self-rescuers] on at that point in time when the guys came up to me and I signaled everybody. I already had mine on

> and my clips on; everybody put them on...It was an old return that I'd walked and we put those on and we may have made about a thousand feet. We didn't make it anywhere near the mandoor to Steiner. And boy, they were cooking. They were cooking and we all knelt down and put the [SCSRs] on...We knelt in teams...helping each other and checking everything. Maybe 3, 4 minutes. It's hard to tell.

This group proceeded on out under air from that location, eventually joining up with the miners who had escaped out of 7 Butt.

Discussion and Analysis of a Particular Case

The interview data show that everyone who escaped from the three mine fires experienced numerous episodes of problem recognition, evaluation, decision-making, and action while being influenced by their internal state and the environment. In order to understand the decision-making that was done by these workers during their escapes, background variables were identified and included in a model. This heuristic device was then used as a starting point for analyzing the characteristics of decisions made during the emergency.

The escaping miners were continually processing information and acting upon their perceptions of the mine environment. Though some of the workers spoke of being in a state of "panic," they do not tell of any points at which they were not actively evaluating their situation and attempting to continue to safety. Even those miners who had the most difficulty and, in fact, could not escape without assistance, were thinking through their available options. This can be seen in the attempt by the 4 South mechanic to switch from a self-contained self-rescuer to a filter self-rescuer just before the others came back to help him. In this extremely dangerous situation, the will and the ability to make decisions was not lost. It is likely that the decision-making process will exist in all contexts and, given the right techniques, will be available for study.

The authors of this chapter are not experts in either disaster management or mine rescue. A group of mine rescue experts were, however, brought together to review the reported actions of those miners on 4 South. They then worked with a cognitive psychologist to develop a simulation problem based on the event [Cole 1989]. This problem unfolds over time and only offers information and alternatives that would have been present in the environment at a particular choice point. From the simulation, then, it is possible to arrive at some insight into what these experts agreed on that would be either a good decision or a poor one in the context within which it occurred.

Perhaps the worst decision, in terms of any attempt to allay stress during these workers' escape, was made by the shuttle car driver on 4 South. It will be remembered that this individual hung up the page phone and went to warn his buddies rather than stay on for another moment and try to get more information about the fire's location and magnitude. Put simply, whether the fire boss actually knew any more details than he was able to communicate is immaterial: the shuttle car driver saved a minute—2 at most. Even coal mines do not burn up in that space of time.

Interestingly enough, those experts who constructed the mine fire simulation agreed with the Federal inspector that 4 South's belt line was the one good escape route available. This inspector could not know that it would become filled with smoke, nor could he foresee those difficulties encountered by a crew member (which were made worse by cramped conditions along the belt). A poor decision was to undertake travel down this entry without first calling outside to inform someone that the workers would not be using either of their designated escapeways.

Another bad decision was to move into the belt line without first donning self-contained self-rescuers. Even smoke-free air can be contaminated by carbon monoxide. In fact, since brattices tend to leak, there could have been more CO in the "neutral" air along their belt than in the smoke-filled but rapidly moving air of 4 South's intake entry. A good choice was to check through the mandoors leading into the primary escapeway periodically, thus enabling crew members to get into fresh air as soon as possible, since they were having problems with their self-rescuers.

Regarding use of their emergency breathing apparatus, expert opinion was that the crew members made some decision errors that could have killed them had carbon monoxide levels been high. For one thing, they waited too long to don their apparatus. Secondly, almost all of the workers "cheated" by taking the mouthpiece out to breathe in areas where smoke was not so dense. This was done despite the fact they had no way to check for carbon monoxide in their atmosphere. Finally, two individuals used their devices to assist the miner helper (these apparatus are approved for self-rescue only), when a better course of action for them would have been to remain outby the fire and wait for a mine rescue team to arrive. While there was some debate among the mine rescue experts as to how filter self-rescuers and self-contained self-rescuers may be employed optimally, they were in agreement about the notion of "self" rescue. This led them to conclude that those four workers who left their slower-moving comrades behind and continued outby the fire made a good decision. Their reasoning was that since the self-contained self-rescuer has a finite supply of oxygen (about an hour) and 4 South's crew had no idea where the fire was located, to stay with the miner helper might well have spelled everyone's doom. Furthermore, someone should have gone on outby in order to inform mine rescue personnel where to look for those who could not make it (since they were not in either the primary or secondary escapeway).

In summary, even though the assessments of decision-making quality discussed above result from a consensus of experts, there is still room for debate. The point here is that research that focuses on judgment must include scrutiny not only of decisions that are made, but also of real-world variables that influence them. The quality of any decision may have little or no direct relationship to the eventual outcome of its execution in a given situation. This is because a decision-maker is constrained not only by the stress of the situation or personal knowledge and attitudes, but also because he or she can only weigh information that is available. Acknowledging the complex context of concrete decision-making environments is a first step to understanding the skill of decision-making and learning to evaluate the abilities of decision-makers.

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CHAPTER 6.—FIRE WARNINGS AND INFORMATION UNCERTAINTY

The first steps in the process of mine evacuation are the recognition of a problem and an attempt to communicate the problem to miners who may be affected. This chapter will focus on the way that a problem, fire, came to the attention of mine personnel and the messages that were sent to miners in the affected areas. The concept of information uncertainty, which was introduced in chapter 4, will be discussed as it influences problem perception and diagnosis. Sociotechnical and interpersonal communications will be explored and suggestions for improving these systems will be offered.

It might seem that the first indication of a dangerous fire would motivate individuals to take self-protective action, to evacuate the affected area or structure, and to provide clear warning to others who are in danger. Research has actually shown that in most situations this does not occur. Instead, time is taken to gather more information, confirm information that is provided, and consider possible alternative explanations that could account for the given circumstances [Canter 1990; Scanlon 1979; Bickman et al. 1977]. This process of confirmation can lead to the loss of critical time. Canter [1990] summarizes the problem in his book, which reports studies of a number of fire events: "As discussed throughout this book, ambiguity and confusion, incoherent instructions and time-wasting actions, lack of appropriate instructions and misunderstanding of the nature of the event that is unfolding, are all hallmarks of fires and emergencies that kill people." In this chapter, the detection of each mine fire and the communication of warning to endangered miners will be reviewed with an emphasis on how those processes were affected by the availability and use of information.

Information can become available through a variety of mechanisms during an emergency situation. First, cues may be taken directly from the environment. Smoke is an obvious example. Secondly, mechanical devices, such as smoke detectors, may provide warning messages. A third source of information is interpersonal communications. These can occur face-to-face or through some mechanical device such as a telephone. With all three methods there is a possibility of miscommunication, misunderstanding, and misinterpretation. All of these means of communication were used with varying degrees of success in the three mine fires analyzed here.

A fire, like any nonroutine situation, engenders uncertainty about a diagnosis and understanding of the problem [Mead 1938]. This uncertainty leads to delays in realization of the seriousness of the situation and therefore in the proper response to it. Delay in action is an important concern in any fire setting, but is even more at issue in underground coal mine fires. Mine fires are qualitatively different from structural blazes: workers' escapeways may be miles long; the seam height at many operations is so low that it is 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]. In these difficult circumstances, 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 detection and clear communication of warning.

When transmitted warnings or direct stimuli from the environment convince people that danger exists and they perceive that options are available, they are likely to take action. According to Nigg [1987], the tendency to believe a warning and take action is influenced by the credibility of the source of the warning and the content of the message. The content will, however, be interpreted in terms of what people expect to happen [Auf der Heide 1989]. Since fires or other potential disasters are nonroutine events, the predisposition is to disbelieve messages that could be interpreted as signs of such danger. Coupled with the tendency toward disbelief is the 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 the situation whenever possible and decide that response is unnecessary [Perry 1987]. Therefore, the more credible a source and the more unambiguous the message, the more disposed individuals will be to switch their frame of reference and believe that a nonroutine event is occurring [Mileti and Fitzpatrick 1991]. Even when the message appears to be clear, however, interpretation is a subjective phenomenon that will vary by individual and context because of personal and social history [Duchon 1986]. Therefore, warning messages must be as timely and unambiguous as possible. Regardless of the warning provided, though, it must be anticipated that some people will respond more quickly and more appropriately than others.

Use of Information in Mine Fire Detection

Like structure fires, underground mine fires can be detected by environmental cues, verbal warnings, or alarms from detection systems. Research conducted in the area of response to fire warnings shows that warnings given by any of these means are not always effective. Canter [1990], for instance, explained that in many fire settings environmental cues are not recognized as warnings:

> "In every disaster that has been examined in this book, it has been found that, in the early stages of fire growth, people have ignored or misunderstood the early cues indicating that a dangerous fire was developing."

Canter [1990] then provided three reasons that traditional audible alarms are also often ineffective:

1. A failure of people to differentiate fire alarms from other types of alarm.
2. A failure of people to regard fire alarms as authentic warnings of a genuine fire.
3. A failure of fire alarms to present information that will assist fire victims in their attempts to deal with fire.

It is evident that these findings may be readily generalizable to the fire detection and warning systems in a mine setting.

The following sections will describe how the fires were discovered at the three mines. The means of detection differed at the three sites. In one location, the fire was discovered when a resulting situation created a problem with continuing routine work and the miners went in search of the cause of that problem. In other words, the fire was not detected by a system designed for that purpose, but instead was happened upon by personnel during the course of their work. Systems for detecting dangerous conditions did come into play at the other two sites. At one site, a mine examiner discovered the problem during a routine check for hazards. The third site had installed a mine-wide monitoring system that provided their initial warning. The stories of fire detection can therefore be seen to range from the casual finding of smoke during routine tasks to the use of sophisticated warning equipment. Details of each event will be discussed in the following sections in order of increasing use of formal warning systems. Each account is given from the perspective of the individuals who first determined that a serious situation did exist.

Fire Detection at Cokedale Mine

The workday began to vary from routine at Cokedale Mine when workers driving motors noticed fluctuations in power supplies to their vehicles:

> When I went to put the power on, there was none, and I asked my buddy if he had lost power, and he says, yeah, but it came back on. And then I hit my controller and the power was back on again, and then I heard [the haulage foreman] say, "Well, my power's on down here, but it's real weak...My lights are real dim...I've got this thing on full power, and it's hardly moving."

The two motormen and the foreman driving the affected vehicles then began to search for the source of electrical power fluctuations that were impeding routine work. First the dispatcher was called and asked to check the above-ground substation. The dispatcher found that the automatic system had locked out the power and called back to report this information. Meanwhile, one of the motormen saw "about an inch of smoke along the roof." His initial diagnosis was that a switch had burned out. The dispatcher explained why this diagnosis was made: "I heard [the foreman] telling [the motormen] to check No. 1, which we had a switch burned up once before down there. It was about the same way." The motormen put the smoke into a framework that had been created by a past event (which gave similar environmental cues) and went to the area of the earlier problem to search for confirmation.

> About half the entry was filled with smoke. I ducked down and tried to look around the corner and I wanted to see if that trolley switch was burning, which was probably maybe 6 to 8 feet in...I couldn't really see so I took a step into it, and it was just—black. I mean, everything right now was black. It was nothing, and I couldn't even, I turned around and I couldn't see anything.

At that point, the motorman determined that this situation was not a repeat of the prior one, as he had been expecting. He called the dispatcher and reported what he had found.

> We got a problem down here...Something's burning and I don't know what. I said, I don't think it's a trolley switch, there's too much.

The dispatcher realized the seriousness of the situation from this verbal communication and called to tell miners working inby the fire to evacuate the mine.

Fire Detection at Brownfield Mine

Detection of the fire at Brownfield Mine consisted of a process that involved the experience of one individual. On the day of the fire, a mine examiner was performing a preshift examination. A mine examiner's job is to routinely check the mine for hazardous situations before and during shifts. He was walking a beltline when he went through a door and then smelled smoke. Like the motorman at Cokedale, this miner assumed the smoke was the result of a situation that occurred in the past: "I just kind of thought it was, you know, maybe a bad roller. The belt was rubbing on the straps, or something like that." He continued his examination, specifically checking the rollers to see if one of them was the source of the smoke. As he walked on, the smell of smoke grew stronger, but there was still no sign of the source of the problem. He began to hurry toward an overcast because that was the location of a past problem. When he got to a section belthead, "the smoke just seemed—it was there. I mean, all of a sudden it was there." Even though the amount of smoke provided undeniable warning that this was an abnormal situation, the mine examiner still wanted to confirm exactly what was happening. Therefore, he started running through the entries searching for the source of the smoke and for a safe passageway. He heard a rumbling, which sounded to him like a welding torch. Again trying to understand his surroundings within a routine framework, he thought that maybe someone was welding and a problem had resulted. "I yelled for [the welder]. I yelled about two or three times for him and there was no answer or anything." At this point, the mine examiner began having problems maneuvering through the smoke.

> When I got in there, the smoke was real thick in there, too, and I couldn't see, ...I was coughing around and it really burned my chest at this time, so I probably stayed there a couple minutes to get my bearings again.

The mine examiner still had not reported the situation to anyone. He chose instead to continue to search for the welder who he thought might be in jeopardy in the smoke-filled area of the mine. He also was attempting to determine the exact source of the problem so that he could take action in response to the threat.

> I crawled up along the rib, 'cause I still thought [the welder] was in there and had a fire or something had happened. I thought there was a man in there. I went up along the rib and I got my head around the corner and I looked in and I yelled for [the welder] a couple more times and I could see the flames...coming off the top of the motor. I went back and I knew that there was a cutout...in the high spot, but in the smoke I couldn't see it, so I wasn't about to try and find that cutout, so...I run back down to 6 Left and pulled the cutout blade.

When the mine examiner saw the flames coming off the motor, he knew that this fire was a major problem. He determined that he could not find the welder, so after he had taken the only response action that he felt was available to him, cutting the power to the trolley wire, he called to report the fire to miners at inby locations and to the shift foreman.

Fire Detection at Adelaide Mine

Warning of the fire at Adelaide Mine was given by a carbon monoxide (CO) monitoring system. Adelaide's dispatcher was alerted by a CO warning of 10.5 ppm, which cleared from his computer screen almost immediately. A few seconds later, the same sensor registered a warning of 11.5 ppm, but cleared in less than 30 seconds.

> 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.

An element in how this particular warning got diagnosed was the fact that past false alarms had strongly conditioned Adelaide's dispatcher to question the legitimacy of each alarm. Due to his mistrust of readings provided by the monitoring system, the dispatcher did not follow a normal protocol for responding to this first CO warning of the shift. Instead, he continued his ordinary routine until he received an alarm that was more likely to be a true reading of an abnormally high CO level. At that time the dispatcher looked for more information about the situation:

> [The monitor reading] went 18, 20, 22. It just started going straight up. I got on the phone and called the dumper's shanty...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 5, 6 minutes later, he called me back and said I better get some fire extinguishers up there fast, that there was a lot of smoke.

Upon confirmation of a serious blaze from the miners at the dumper shanty, the dispatcher determined that miners in three areas of the mine were in danger and must be evacuated.

Discussion of Fire Detection at the Three Mines

To those unfamiliar with the mining environment, it may be difficult to understand how seeing unexpected smoke could be interpreted as normal. During a study in which 214 miners from 8 mines were asked about mine fire related experiences, however, 65% reported that they see or smell smoke in the mines where they work at least once per month [Vaught et al., 1996]. Furthermore, 15% said that they had been surprised or caught off guard by the smell or sight of smoke within the past month. There are a number of potential sources for smoke underground that do not usually lead to large fires.

In all three cases, the miners who discovered the fires initially attempted to interpret the messages they were receiving within a framework of normal mine operation. In the first two mine fires discussed above, the miners who initially discovered smoke attempted to attribute it to such sources. Like the miners in the Vaught et al. [1996] study, they had past experience with smoke in the mine that had not led to major fires. The suggested causes—a burned-out switch, a hot belt roller, or a welding torch—would not necessarily create major problems. In these first two cases, however, the environmental cues provided, the amount of smoke, and/or a view of the flames, could not be explained within the miners' normal frameworks. When they reached that conclusion, the initial warning was received successfully.

In the third mine, initial detection came from a mechanical device instead of directly from the environment. As discussed in the introduction to this section, for fire alarm systems to be effective they must be viewed as "authentic warnings of a genuine fire" [Canter 1990]. Unfortunately, the dispatcher at Adelaide had background filters that predisposed him to not take heed of the CO monitor's warning. The system had in the past given multiple false alarms and had thereby made false CO warnings a normal frame of reference:

> 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.

The system had been put into service while still being finished. Unfortunately, some of the monitors were attached to roof bolt plates, causing a short circuit. The resulting false alarms seem to have lulled the dispatchers into complacency. These false alarms were particularly problematic because of the way the system was implemented at the mine. Adelaide's dispatchers had been placed in charge of the monitoring terminal, but no analysis was performed to determine if this job was complementary with their primary tasks—to "direct traffic and move coal." The dispatcher occupied a key role: being able to recognize and communicate potential danger from readings of increased CO levels, but did not view that as an important part of the job.

Another implementation problem was the lack of adequate training. The system manufacturer's representatives conducted two formal training classes that 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." Mine management had allocated resources to the implementation of a sophisticated system which, if working properly, should provide early warning of fire. However, the same attention was not given to the human-machine interaction that was a vital link in the system. When the dispatcher decided that this time the warning might be real, he still asked for confirmation from miners who had to go and look for the alarm's source before he determined that miners inby the fire were in jeopardy.

Communication of danger was delayed in all three mines because individuals tried to place the abnormal cues into normal unthreatening frameworks. Miners caught inby the fires could have begun their escapes earlier if those who discovered the problems had risked making errors on the conservative side and reported the potential danger as soon as the first cues were received. In the first two cases, the environmental cues could have been somewhat ambiguous. One way to improve that situation would be to use mechanical devices that could remotely provide more explicit information and clearer warnings. While this could have helped in the interpretation of conditions in the first two examples, the third case shows that implementation of technology without careful consideration of how its messages will be interpreted will not be successful.

Warning Information Communicated to Miners Inby

Regardless of the means used to detect a fire, after it has been discovered any workers in the affected areas must be warned about the potential danger. They must be given messages that will allow and encourage them to act appropriately and escape efficiently. In these cases, eight separate groups of miners were forced to escape from inby the three fires. In some cases, the information they received assisted them with an effective egress from the section. In other cases, little information was conveyed to the miners at risk. Communication of the initial warnings will be discussed in the following sections.

Warning Miners Inby at Cokedale

When the dispatcher at Cokedale heard confirmation of the fire from the miners who discovered it, he attempted to communicate a warning to workers who might be in danger. Miners were working or traveling in two areas that could be blocked by smoke from a safe exit. In both sections, however, the dispatcher's message was not the first cue they had that something was not normal. The miners who started looking for the reason for the power fluctuations discussed previously were communicating on an open channel. Individuals on the sections, therefore, could overhear the conversations regarding the problem and the speculations about a trolley switch burning. Miners in the inby sections got another cue as they began to smell and/or see smoke. They began to think that something unusual might be happening and looked for confirmation of that fear. The dispatcher provided confirmation through phone calls in which he relayed the information that a fire was burning underground and that they should evacuate the mine. Each section started evacuation after that message was received. They began the trip, which would take them through thick smoke, knowing that a fire was burning. The other information at their disposal was more vague, however. From the overheard conversations, they had some notion of where the miners were who had discovered the fire. They therefore could make a reasonable guess about the fire's location, but had no information about its severity.

Warning Miners Inby at Brownfield

The fire boss who discovered the fire at Brownfield called miners working on the three sections at risk. The message given to two of the sections, 4 South and 5 South, was that there was a belt fire and that they should evacuate the mine. The fire boss, with the vision of hindsight, discussed what was lacking in the warnings received by those miners.

> So I called them and told them there was smoke coming out, they better get out of there. But the one mistake I did make is, well, the man that I talked to in both cases never—he never give me the opportunity to tell them where the fire was at. It made it kind of a bad situation for those guys coming out, cause they really didn't know where the fire was, which was one thing I learned from the whole situation.

The stories of the miners who took the fire boss' calls confirm that, as the fire boss reported, they did not wait for additional information after hearing that the mine was burning. In both cases the miners were forced to make decisions about their evacuation without knowing the fire's location. The third section, 6 West, had more information available as they decided which way to go. The foreman who took the call from the fire boss explained why: "I was the only one of all the guys [who escaped] that knowed where the fire was. And the reason for that is I took and asked [the fire boss] where the fire was." This miner had asked for and received exact information about the fire's location and used it to make decisions about evacuation.

Warning Miners Inby at Adelaide

As discussed in the section about detection above, the dispatcher at Adelaide received warning of high carbon monoxide levels and sent the dumper to explore the situation. When the dumper reported back that a fire was burning, the two workers split the task of contacting miners inby. There were three sections affected and all three were told, either by the dispatcher or the dumper, that there was a fire on the belt and that the mine should be evacuated. No information about location or severity of the fire was provided and no further details were requested by the miners who answered the calls. All of the miners inby the Adelaide fire evacuated without knowing where the fire was and, therefore, how far they had to travel.

Discussion of Communication of Warning at the Three Mines

Most of the miners who evacuated from the three mines did not have information that would allow them to make decisions about efficient escapes.

The communication breakdown came from two directions: the individuals providing the warning did not offer details about the situations even though some details were known, and the individuals who received the warnings did not ask for clarification of the situation. As discussed in chapter 4, this lack of information allowed miners to continue attempting to place cues into normal frameworks after they should have evaluated the situation as abnormal and threatening. When the environment left no doubt that this was not a routine exit from the mine, it was too late to gather more information because there was no form of communication to the surface in those locations. Most decisions about appropriate travel directions had to be made without the miners knowing where the fire was, and therefore where the smoke was likely to be. Equally important, the miners did not know whether they must face the extreme conditions for a hundred yards or 5 miles. In the case of Cokedale, miners could guess where the problem was from monitoring the radio calls. They could not be absolutely certain of its source, however, and they had no indication of its severity. As shown in figure 5.1, uncertainty created by a lack of information increased stress on the escaping miners and influenced their decision-making (and therefore their actions).

Improving Fire Warning Systems in Underground Coal Mines

Data from the three fires studied show information that could have been used to help with evacuation decision-making had it been provided to the miners who were most in jeopardy. In all three cases, delays in activating the warning communication system happened because the individuals who first determined that an abnormal situation existed sought additional confirmation before communicating the cues they had received. Further delays occurred when the miners inby also sought confirmation before evacuating, and often, even then, did not believe that an emergency was in progress. The lack of reliable detection methods and standard protocols for emergency communication caused those miners who were put in danger by the fires to delay their self-rescue attempts, and often to act without needed information. The following sections will suggest methods that could be used to address some of the causes of faulty communication that occurred during these mine fire evacuations. First, technological advances in fire detection will be discussed. Then, human interaction with technology and human reaction to warning and risk communication will be explored. The last section of this chapter will summarize issues that should be considered in the design of a fire warning system.

Fire Warning With Smoke Detectors

The fire at Adelaide was detected initially by a mechanical device. Having any mechanical device installed to provide early warning of a fire may allow miners inby more time to escape. The CO detector system used at Adelaide, however, may not be the best choice. Instead, a smoke detection system might provide even more time for evacuation decision-making and actions before the mine atmosphere becomes irrespirable. Data from fire testing indicate that a fire will generate smoke reaching levels that will force evacuation, and make travel difficult, significantly earlier than it will generate a toxic environment due to its product gases [Litton et al. 1991]. This is significant because it implies that for even moderate levels of smoke, the air is still breathable and life-supporting. It is only when the levels of smoke begin to totally obscure visibility that the toxicity of the combustion products begins to play a role in the question of escape and survivability.

As shown in chapter 7, smoke from a fire is a significant obstacle to escape. The rapid detection of smoke at very low levels can increase the time miners will have to escape before smoke obscures visibility completely. Such rapid detection is possible because smoke is produced much earlier than other fire signatures during the stages of fire growth and development, and smoke sensors are extremely sensitive devices. Smoke sensors can respond to smoke levels that are barely visible to the human eye. Furthermore, smoke sensors will alarm while CO levels are often still near the ambient threshold of CO alarm sensors. Since smoke may be the greatest impediment to survivability during a mine fire escape, its early detection can optimize the chances of surviving.

Smoke Detection

In the United States, both Underwriters Laboratories, Inc., and Factory Mutual Research Corp. use standard tests for approving smoke sensors to be used as early-warning fire sensors. Abroad, similar standard tests are employed for approving smoke sensors (such as EN-54, used by the European community). These standards are based on the optical density of the smoke. In very general terms, a smoke detector passes the sensitivity tests if it alarms before the smoke optical density reaches a value of 0.058 m^{-1}. Many approved smoke sensors typically alarm at optical densities of one-third to one-fourth of this value.

It has been proposed [Litton et al. 1991] that smoke sensors approved for use in underground coal mines be classified more rigorously by defining two classes. Class 1 smoke sensors are those which always alarm at smoke optical densities less than 0.022 m^{-1}. Class 2 smoke sensors are those which always alarm at optical densities less than 0.044 m^{-1}. Any smoke sensor that alarms at optical densities greater than 0.044 m^{-1} would not be approved for use in underground coal mines. For a class 1 smoke sensor, the range of visibility would exceed 40 m.

In determining which type of alarm system should be installed in underground mines, it is appropriate to compare the approximate levels of CO that would be present at the alarm thresholds of class 1 and 2 smoke sensors. This comparison is shown in table 6.1 (flaming). For a class 2 smoke sensor, the average CO levels at smoke alarm are 5.7 ppm for flaming fires. For a class 1 smoke sensor, the CO levels at smoke alarm are 2.9 ppm. These numbers are clear indications of the superiority of smoke sensors over CO sensors in providing early warning of fire.

Table 6.1.—Approximate CO levels present at alarm threshold for flaming fires

Combustible	ppm CO at smoke alarms	
	Class 1	Class 2
Wood	5.5	11.0
Coal	1.7	3.4
SBR conveyor belt	1.9	3.8
PVC conveyor belt	4.1	8.2
Neoprene conveyor belt	3.2	6.4

The earlier the warning given to miners who will be required to travel through smoke, the better their chances of making a successful escape. Assuming the maximum time available for escape is that point at which visibility in an escapeway becomes critical, it is possible to determine how much of this time is available to miners warned by different types of sensors. In detection of a fire in the belt entry, a reasonable time before smoke obscures visibility is about 38 minutes. It is possible to determine when, during that time span, various types of sensors would alarm and therefore how much evacuation time would be made available. For smoke sensors, 30 minutes (79% of the total time) are estimated to be available; for 5-ppm CO sensors, 23 minutes (61%); for 10-ppm CO sensors, 19 minutes (50%); and for thermal sensors, 3 minutes (8%). Such an analysis clearly shows that smoke sensors can provide earlier warning than CO monitors.

Smoke Sensor Classifications

Smoke sensor classification systems are based on various criteria. Smoke sensors are often classified according to their principle of operation. Smoke sensors are either ionization-type, photoelectric-type, or some combination of the two. An ionization-type smoke sensor is one that uses a small source of radioactive material (usually americium 241) to produce molecular ions in the air space between two electrodes. When a small voltage is applied to these electrodes, the ions produce a current. Smoke particles that enter the air space between the electrodes serve to deplete the ions correspondingly by reducing the flow of current. When the current loss is 10% to 20% of the total current, an alarm is given.

Photoelectric-type smoke sensors, which are based on measurement of light, may be divided into two subcategories. The first subcategory contains sensors that measure the light that is scattered from smoke particles. This type of detector is located to the side of a beam of light at some fixed angle (usually around 45E from the forward direction). In the absence of smoke particles, this detector receives no signal. When smoke enters the projected beam of light, some of the light is reflected (scattered) into the detector producing a measurable signal. When the detector signal reaches some preset level, an alarm is given. The second subcategory contains sensors that measure the transmission of light through a cloud of smoke. A light beam is projected into a detector, producing a steady-state signal level. When smoke enters this light beam, it reduces the detector signal level and produces an alarm.

Smoke sensors may also be classified according to their use. Deployment can be fixed-station, sampling, or open area. The most common sensor deployment method is called fixed-station sensors. These sensors are mounted on or near the roof and are fixed into place. Another type of smoke sensor is a sampling-type smoke detector. The sampling-type smoke detector usually employs a small axial-vane fan to convey a sample of air from some desired point back to the sensor via plastic tubes. Very often, this type of smoke sensor draws samples from several different monitoring locations (usually about 10 per detector). This allows 1 sensor to essentially replace 10 fixed-station smoke sensors, but also means that the 1 sampling-type detector must be more sensitive, since smoke from any one location can be diluted by a factor of 10. As with fixed-station use, either ionization-type or photoelectric-type can be employed in sampling.

The final type of smoke sensor to be discussed here is the open area (or projected-beam) detector. It requires the use of a photoelectric-type system. For this system, a light source is located remotely from a light detector. The light detector measures the transmission of the light beam through a cloud of smoke particles. This type of smoke sensor can function at separations between light source and light detector up to 90 m. It is intended for use in structures that are relatively open on the inside, such as warehouses.

Use of Smoke Sensors in Underground Mines

Most smoke sensors that have been approved by a recognized testing laboratory should perform reliably in an underground coal mine. The major obstacle to their effective use is dust. Both coal dust and rock dust are present, often at elevated levels, in underground coal mines. Two problems can be created by this condition. First, false alarms can be given when dust enters the smoke sensors. Because dust is similar to smoke except that the dust particles are larger, dust can cause smoke sensors to alarm. Second, dust may contaminate a smoke sensor causing the sensor to become more sensitive over time. This is particularly true for ionization-type smoke sensors and those photoelectric-type smoke sensors that use light attenuation as the means for detecting the smoke. Increased sensitivity due to dust buildup eventually results in an increasing frequency of random false alarms. For photoelectric-type smoke sensors that use light-scattering to detect the smoke, dust accumulation can eventually render them totally insensitive.

There is one fixed-station smoke sensor that is impervious to dust—the Becon Mark IV ionization-type smoke sensor, manufactured by Anglo-American Electronics, Inc., of the Republic of South Africa. It achieves this result by using a radioactive source (Kr-85) that emits β-particles rather than the α-particles produced from americium 241. This radioactive source has an activity level greater than the exemption level specified by the Nuclear Regulatory Commission, and special licensing requirements are needed by a United States distributor before it could be used extensively in underground mines in the United States.

Other than the Becon smoke sensor, sampling type smoke sensors offer the greatest potential for reducing or eliminating the problems of dust in underground coal mine use. They use a forced flow to bring the sample of the mine atmosphere to the detector for measurement. Dust particles are much larger than smoke particles. Techniques exist for selectively filtering out these larger dust particles from the flow and allowing only the much smaller smoke particles to be transmitted to the detector for measurement. With current readily available technology, the sampling type of detector seems to provide the best solution to problems created by coal and rock dust.

Communication of Fire Warnings

Timely detection of fire is only one step in the fire warning process. As shown by the activities that took place after the CO monitor alarmed at Adelaide, proper response to mechanical detection devices is required for the warning system to be activated. If the individual responsible for monitoring the alarm system trusts that the sensors are reliable and valid, and if that person has been trained in the proper actions to take when an alarm sounds, the warning system is likely to be activated immediately upon receiving the first alarm. If, however, the system has given multiple false alarms or the sensors are set inappropriately and alarm to low levels of smoke, such as from welding, or to dust, then the person monitoring the detector is likely to look for confirmation of a serious problem before providing warning. Even when the alarm is believed or the situation confirmed, if the individual has not been trained in the proper way to relay warning, vital information is likely to be forgotten.

A person who is responsible for communicating warning information will be doing so under stress. That individual is in the position of telling others that their lives may be in jeopardy. In that situation, the person providing warning must have a detailed protocol for relaying information that has been explained, discussed, and practiced *before* the emergency occurs. At a minimum, the protocol should include elements such as (1) identification of the individual providing the warning, (2) the location of the situation, (3) definition of the type of problem occurring, (4) severity of the problem if known, and (5) instructions for those at risk. Information about changes to the environment or response to protocol that have occurred because of the emergency should also be communicated. As discussed previously, none of the individuals who communicated a message to evacuate the miners in this study relayed all of the pertinent information available. In the worst cases, the miners inby were not told the location of the fire and therefore lacked information vital to planning an appropriate escape route.

For a warning system to be successful, the communicated message must also be received appropriately. This requires that everyone underground be trained in the proper way to gather information during a warning communication. In many instances, workers who received warnings of the fires did not ask any questions of the person telling them to evacuate the mine. In the worst case, one person simply ran from the phone as soon as the beginning of the message was relayed. Miners must be prepared to control their stress levels as they hear about the potential threat and obtain as much information as possible so that later decision-making can be done in an informed manner. At a minimum, they should be trained to ask (1) the nature of the problem, (2) the location of the problem, (3) the severity of situation, (4) which actions should be taken, and (5) any details of the situation that would be relevant specifically to the people in that area. If the person providing the warning and the person receiving it are both trained in emergency communication protocols, the potential for an effective warning system can be greatly enhanced.

Recommendations for an Effective Warning System

When an individual is warned of danger, that person will act if (1) he or she believes the danger is real and (2) feels that there are options. A warning system should be designed to provide the most information possible to comply with those two needs. The detection of a problem, whether by mechanical or other means, must be trusted so that warning can begin immediately upon discovery of the problem, as opposed to waiting for confirmation. After discovery, warning must be provided to everyone who is in danger. Secondarily, warning must be provided to those who will be called on to respond to the emergency, and in such a way that it allows informed decisions to be made about what actions should be taken. Training is needed for both giving and receiving warning messages properly. Developing an effective warning communication system should include—

1. Installing proper detection devices as appropriate to the situation.
2. Training personnel who will be monitoring the detection system and its functioning.
3. Developing a warning message protocol to be used to provide warning.
4. Training personnel who will be monitoring the detection system in proper protocol for providing warning when the system alarms.
5. Developing a receiving warning message protocol to be used when receiving warning.
6. Training all personnel in the proper methods for use of the receiving protocol to gather information when receiving a warning.
7. Incorporating this system within a general mine emergency response plan.

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CHAPTER 7.—SMOKE AS AN ESCAPE AND BEHAVIORAL ENVIRONMENT

This chapter focuses on smoke as it relates to escape from underground mine fires. Among the topics discussed are the measurement of visibility in smoke; smoke-related hazards such as the production of CO, hydrochloric acid (HCl), or other byproducts of combustion; and miners' personal experiences while escaping through smoke.

Smoke Measurement and Visibility

In general, smoke consists of hundreds of thousands of very small particles. These particles have some "size," usually expressed in terms of their diameters, and they have some concentrations, usually expressed either in the number of these particles per unit volume or the total mass of the particles per unit volume.

Humans cannot see individual smoke particles because they are too small. Similarly, "umber concentrations" and "mass concentrations" of smoke particles do not have much meaning to people unless they are trained technically. Still, individuals know that they can see smoke, independent of all the technical jargon used to describe it. Also, they know that when the smoke level gets too high, it is no longer visible. In fact, nothing is visible because the smoke absorbs all of the light in its surroundings.

The eye is only sensitive to light in the wavelength region from about 400 nm to about 700 nm. The maximum sensitivity of the human eye is to light that has a wavelength of about 555 nm. It is important to know how the eye responds to light because if its response is known, it is possible to use a light detector that has almost the same response as the eye. Such a detector can then be used to quantify the visible characteristics of smoke because it responds in the same manner as the human eye.

Smoke is visible because it either scatters or attenuates (diminishes) light. In some instances, smoke is visible because the smoke particles reflect light which is then detected by the eye. The eye actually "sees" an intensity of light that has been reflected from a cloud of smoke particles. Imagine shining a flashlight into a cloud of smoke. Someone off to the side can actually "see" the beam of light as it traverses the smoke cloud. This is called scattering. Smoke is also visible because it attenuates light. Imagine having someone shine a flashlight into your eyes. As smoke begins to build up along the beam of the flashlight, the light begins to dim. The smoke is visible because it is now reducing the intensity of light that falls upon the eye. As the smoke level increases, it is said to obscure our visibility. When the beam is no longer visible, the smoke obscuration is said to be 100%. In other words, none of the light energy from the flashlight makes its way through the cloud of smoke. Another way of saying that the obscuration is 100% is to say that the transmission of light through the cloud is zero.

Although it is possible to measure the light that is scattered by smoke, most studies usually measure the amount of light that is transmitted through a cloud of smoke. There are three basic reasons for measuring light transmissions rather than the amount of light that is scattered. First, the intensity of scattered light depends on many factors, such as the size of the smoke particles, the angle at which one measures the scattered light relative to the direction of the light beam, and also the attenuation of the scattered light in the space between the beam and the light detector. Second, the amount that smoke obscures light is a direct measure of a visibility hazard. Obscuration by smoke is one hazard that is clearly evident in mines. Imagine a 100-watt lightbulb 3 m away. If the smoke is dense enough so that the effective power of the bulb is only 1 watt, then the obscuration would be 99%. If the cloud of smoke is so dense that obscuration is total, then it becomes impossible to see. Smoke from an unwanted fire that reaches this level of obscuration represents a critical, life-threatening situation because it becomes impossible to use one's eyes to escape. Finally, the measurement of light transmission allows for characterization of smoke by a single parameter. This parameter is called the "optical density" and is derived from the amount of light that is transmitted (T), at a given intensity, through a smoke cloud over some path length (L):

$$D = \frac{1}{L} \log \left(\frac{1}{T} \right)$$

Optical density is used to assess hazards of smoke and levels of detectability. It is important to remember that this transmission is measured using a light detector that matches the response of the human eye.

Smoke Hazards, Visibility in Smoke, and Human Response in Smoke

The chemical composition of smoke particles depends, in part, on the material that is burning. Some materials may produce gas, or gases that attach to smoke particles, which can cause the eye to tear, even at moderate levels of obscuration. Smoke from a fire is also breathed into the lungs, where some of the smoke is deposited before it can be exhaled. The smoke and its chemical composition can irritate the respiratory system and also contain elevated levels of toxic gases or compounds that attach to the smoke particles. All of these effects are difficult, if not impossible, to quantify because of the many combustibles that can burn and produce adverse effects.

Several studies have been conducted to assess the effect of smoke on humans, especially with regard to ability to escape from smoke-filled environments. Jin [1981] reported the results of a series of studies that investigated emotional instability of individuals in smoke from fires. Using human subjects, Jin measured both physiological and psychological response to smoke produced from smoldering wood that was uniformly introduced and dispersed throughout a test room. For the experiments, individuals were seated one at a time at a table in a test room with a floor area of 5 by 4 m (16.4 by 13.1 ft), with no windows and one door. At the table, each person was asked to manipulate a steadiness tester which consisted of a metal plate with four holes of graduated sizes, and a metal stylus. Both of these devices were connected to recording instruments. Each person was told to thrust the stylus into the holes in a specific order, but trying not to touch the sides of the holes with the stylus. The smaller the diameter of the hole, the harder the subject had to concentrate to avoid contacting the sides of the hole. After completing one cycle of operating the steadiness tester, which required about 30 seconds, each person stood up from the chair, walked to the other side of the room, pushed a button switch located on another table, and then walked back to the table on which the steadiness tester was located. The button switch ensured that test subjects walked to the other end of the room after each cycle. Each person walked a total distance of approximately 10 m (33 ft).

In the experiment, Jin divided subjects into two groups. The first group, composed largely of fellow researchers, received a pretest briefing in which individuals were made familiar with the layout of the test room and were also informed that the smoke being used was harmless. The second group, which constituted subjects from the general public, was placed in the test room without being familiarized with the area or informed of the smoke's nontoxicity. For both groups, few individuals had previous experience with exposure to smoke from fire.

Jin noted that as the smoke density increased, fear of the smoke coupled with irritations of the eyes and throat impeded individuals' ability to concentrate on the task of operating the steadiness tester. This resulted in increased frequency of contacts between the stylus and edges of the holes. Human response levels were correlated with the optical density of the smoke produced by assessing the number of stylus contacts on the steadiness tester.

Results indicated that, for the general public, most individuals began to experience emotional effects when the smoke optical density reached 0.044 m^{-1}. In contrast, most subjects in the group of researchers began to show emotional fluctuation at smoke densities of 0.15 to 0.24 m^{-1}. It is interesting to note that, while all individuals were told they would be advised when they could leave the test room, 15 people out of the general population group fled the room to escape the smoke before their test run was completed and prior to the smoke density reaching 0.22 m^{-1}.

Following these experiments, some of the participants were interviewed regarding their experience. Jin generalized the comments for the general public test subjects as follows:

> Smoke itself didn't scare me much when it was thin...irritation to the eyes and throat made me nervous, and when I thought of the smoke getting still thicker...I was suddenly scared of what's going to happen next.

Jin concluded that the data from these individuals could be treated as being equal to data that would be obtained from a group of people who are unfamiliar with the internal layout of a building.

Among subjects from the group of researchers, most individuals became more anxious about physiological factors such as throat and eye irritation rather than the psychological element. As mentioned by one participant, "When I got the signal to end the test, irritation and suffocation were near the limit I could physiologically stand." Jin concluded that—

1. For a person unfamiliar with the escapeways and exits of a building, that individual's ability to escape safely from a fire within that building is severely reduced when the smoke optical density exceeds 0.066 m^{-1}.
2. If an individual is familiar with the escapeways and exits of a building, that person's ability to escape safely is severely reduced when the smoke optical density exceeds 0.22 m^{-1}.

During these tests, the levels of CO were continuously measured, reaching a peak value of 50 ppm at the end of each test (D . 0.305 m^{-1}), which equates to an optical density/CO ratio (D/CO) of 6.10×10^{-3} $(ppm \cdot m)^{-1}$. At these levels of optical density, smoke obscuration is severe enough to reduce visibility to near zero levels. For instance, at $D = 0.066$ m^{-1}, the range of visibility is about 13 m (42.5 ft) while at $D = 0.22$ m^{-1}, it is approximately 4 m (13 ft). Because of this, Jin referred to these optical densities as critical values at which the smoke becomes untenable due to the total impact of the smoke on the human response, which includes reduction in visibility and other physiological and psychological effects.

Other studies have chiefly focused on visibility in an effort to determine critical limits for optical density in smoke. Rasbash [1975] conducted experiments in which subjects, wearing breathing apparatus, focused headlamps that were held waist-high on a target. The target was a black letter "C" on a white background. As smoke was introduced, visibility values were recorded based on individuals' ability to see the target. Rasbash concluded that the visibility limit in smoke occurs at an optical density value of 0.08 m^{-1}, which corresponds to a distance of about 10 m (33 ft). Babrauskas [1979] studied escape from rooms containing burning furniture. Because of the short travel distance used in these experiments, Babrauskas used an optical density of 0.5 m^{-1} as an obscurity criterion for escape. Heyn [1977] obtained similar results when measuring the relation between smoke density and visibility at the Tremonia Experimental Mine in Germany. For these experiments, Heyn conducted tests using small conveyor belt fires which resulted in visibilities of only a few decimeters.

Miners' Emotional and Physiological Experiences in Smoke

Miners who escaped the three mine fires experienced psychological and physiological effects similar to those noted by Jin [1981], as well as visibility problems like those noted by Heyn [1977] and others. One analysis of the data revealed that a number of workers experienced trouble wearing their SCSRs [Brnich et al. 1992]. Twenty-nine of the miners who escaped these fires (63%) reported having difficulty breathing with their SCSRs, largely because they were unfamiliar with how an SCSR worked. As a result, 27 of the 29 said they either took the mouthpiece out to catch a breath or "breathed around" the mouthpiece in smoke.

Many of the miners interviewed at each of the three mines had some prior experience in dealing with fires underground. Often, though, these fires were small ones, such as equipment cable fires, hot belt rollers, or hot trolley wire hangers along the haulage. These types of fires generate heavy smoke in some cases, but rarely result in the need for miners to escape through smoke-filled entries. Consequently, many of the miners who were caught inby the three fires had never escaped through smoke.

Most of the miners who escaped the fires at Adelaide and Cokedale Mines were unfamiliar with the escapeways leading from their working sections. About 3 weeks before the fire at Adelaide, the company realigned section crews in an attempt to boost morale and improve productivity. Many miners were assigned to sections they had never worked on before. As a result, a number of these reassigned workers had not been given an opportunity to walk the escapeways from 1 Right, 2 Northwest, and 3 Left sections in order to become familiar with them.

Personnel caught inby the fire at Cokedale Mine worked on a maintenance shift and were not assigned to any particular section. On the night of this fire, these miners were in the process of setting up a new production section in 8 Face Parallels or doing maintenance work in 7 Butt. All individuals were working in an area of the mine with which most were unfamiliar, and, like miners at Adelaide, many of them were not familiar with the escapeways leading from this area of the mine. Unlike workers at the other two mines, miners who escaped the Brownfield Mine fire were working on their regular sections and knew their escapeways, but chose alternative routes in an attempt to elude heavy smoke.

As mentioned earlier, Jin [1981] concluded that a person's ability to escape by an unfamiliar route is severely reduced when the smoke optical density equates to a sight distance of about 42 ft. Persons familiar with escapeways have their ability hampered when the smoke optical density equates to about 13 ft of visibility. Based on Jin's findings, it is reasonable to expect that miners who were not familiar with their escapeways would have been at a disadvantage compared to those who knew the travel routes. However, individuals who escaped the mine fires reported visibility distances that were often far below those calculated from Jin's results. Consequently, familiarity with escapeways did not necessarily help miners navigate, due to the overall poor visibility. Visibility distances estimated by workers ranged from less than 2 ft in primary escapeways, track and belt entries (mean 7.3 ft) to as much as 60 ft in return airways (mean 47.5 ft). In addition, some miners did not expect the smoke they encountered to be as thick as it was. A wireman, who was moving a power center in 7 Butt at Cokedale Mine when the fire occurred, described his experience:

> I didn't expect it to be that thick...they show you movies, you can get down on your hands and knees and crawl out. I don't think you could do that...you could see it coming right off the runaround.

Miners characterized smoke in various ways by both its color and thickness. In areas where the smoke was lighter, a worker described it as having a bluish-gray color and being "like...more just like a filtering smoke." Another miner, traveling with his crew through a return airway, said he could see about 30 to 40 ft and that walking through the smoke was like walking through a light fog. Other workers, however, encountered thick, heavy smoke as they escaped. Two miners described the thickness of the smoke they encountered. A utilityman from Adelaide Mine said:

> You couldn't see...it was just like, I'll tell you what it reminded you of... like riding in behind...a bulk duster for rock dusting.

Another utilityman, also from Adelaide Mine, was traveling with his buddies through the secondary escapeway located in the right-side return aircourse of 3 Left. When they reached an overcast where the return crossed the intake, the group encountered heavy smoke:

> I walked up there to the overcast and I stepped right into it. And it was like a black wall. It was like burning 50 tires and trying to walk through it...and I said, "We can't go that way." So we walked out and there was some—I know there was doors in those overcasts. I said, "The intake's here someplace. All we've got to do is find it." And you'd open up the door and it'd just billow out; and you'd open another door and it would

> billow out...we opened up [one] door, it looked like it was a black river running by. That's how thick it was.

A miner from Brownfield Mine could not find the mandoor in a stopping because of the thick smoke:

> The [stopping] was probably on the other side of these props, but I couldn't see it. I couldn't even see the door, that's how thick it was. I put my hands out...and I couldn't see the end of my fingers.

For miners escaping in heavy smoke, navigating through the mine was difficult because of the poor visibility. At Brownfield Mine, the smoke was so heavy that a foreman actually walked into the belt structure while attempting to make his way to the other side of 6 West mains to check for fresh air in the No. 7 intake:

> So I went out through this door, and I'll tell you the smoke's so thick right here I walked into the belt. I couldn't see it.

Regardless of whether they followed designated escapeways or not, miners used various (and in some cases highly creative) means to keep themselves together to prevent becoming separated and to navigate through the smoke. Workers escaping from the 7 Butt section at Cokedale Mine held on to one another as they attempted to stay together while crossing through the track entry to get into the return:

> Smoke was coming on the tracks, we reentered on the tracks there by the spray pump, smoke was real bad we had to hang on to each, one another like a bunch of elephants.

To guide themselves, miners escaping through smoke followed objects they encountered in the mine entries, such as stopping lines, rows of props, old track, and water lines. At Adelaide, the 1 Right crew was led out by a utilityman who was a former fire boss. He led his buddies down the left return airway of old 8 Left to the 2 Northwest left return and then continued outby. For the entire distance, the utilityman followed the stopping line located between the intake and return entries knowing that, by keeping the stoppings on the left, his crew would be less likely to make a wrong turn. A maintenance foreman and mechanic, working in the 6 West section of Brownfield Mine, were following the primary escapeway from the section. Hoping that there would be lighter smoke in the secondary escapeway, the two miners, along with a State electrical inspector, went through a door into the left-side return aircourse. Although the group encountered moderate to heavy smoke in the return, the foreman knew that the return airway would lead them directly past the fire area. The foreman, therefore, decided to continue traveling in the return, since he could follow a row of posts in this entry to guide himself. "I mean, the return is double-timbered. I just stayed between the props and went." The crew from the 5 South section at Brownfield Mine also traveled through the 6 West left return and used the props to guide themselves:

> We just stayed—we knew that the return went straight down because we'd walked it before. So we just stayed in the 6-foot walkway between the posts, and more or less we were walking from overcast to overcast.

A group of miners who were escaping from the 8 Face Parallels at Cokedale used a unique method to help them find their way. The crew, being led by a general inside laborer (GIL), made their way to the secondary escapeway located in the right return aircourse of 8 Face. Because the escapeway followed entries that were mined more than 35 years earlier, the passageways had deteriorated. Miners had to cross over roof falls and contend with low clearances due to floor heave and low crossbars. Although the escapeway was marked with reflective signs, miners reported that it was difficult to see them due to the heavy smoke and the fact they had to bend over to walk. To more easily navigate through the escapeway in the smoke, the GIL who led his buddies from the 8 Face Parallels area did not try to follow the reflective markings in the escapeway. He instead followed the footprints left by fire bosses who had conducted prior hazard examinations of the area, knowing that the footprints would lead him out of the mine:

> As you're walkin', you're not walkin' on a—you're goin' up and down crawlin' [over falls] this and that—people were, you hear people goin' "ow, ow" hit their head...And I just kept lookin' at the ground and lookin' at footprints and I did catch I did see footprints. Reason I say I was lookin' at footprints and not the signs was why keep bangin' your head needlessly. If you can't see 2 feet, how are you gonna possibly see that sign—I don't care whether it is red or green, you can't see it. The footprint is the closest thing to you that also meant to me—these [returns] have to be walked periodically. When I see footprints, I felt better. Somebody was through there already there is only one set goin' out. So chances are that if there was a return set of footprints, I would think somebody had to turn around because it's blocked. Being there was only one set, there's got to be an opening up ahead somewhere.

While some miners had the "luxury" of being able to follow markers or other objects to guide themselves out of the mine, the smoke was so thick in some cases that miners could not follow objects visually. Instead, they had to feel their way along in places in order to find their way out. Miners felt their way along water lines, posts, the mine's ribs, and other features in order to make their way to safety. At Brownfield Mine, a Federal mine inspector was escaping with the crew from 4 South and was part of a group of four miners making their way off the section by traveling the belt entry. During their escape, the group began to break up after a miner from the crew started having trouble walking. At this point, fearing he would run out of oxygen in his SCSR, the inspector left the group and continued on his own. When he reached the mouth of the section, the inspector decided to go through a door in an overcast and check the intake escapeway for smoke. Upon seeing that it was still filled with heavy smoke, he came back into the belt entry, which also contained heavy smoke, and attempted to continue his escape. Unable to see, the inspector felt his way along a machine guard on the belt drive:

> The belt drive is entirely guarded with chain link fence...as I come out of the overcast area, it seemed like the first thing, I reached up as I came out and the chain link fence was there. I really couldn't see but I just hand over hand followed the chain link fence so I wouldn't trip on anything.

In his experiments, Jin [1981] noted that as smoke density increased, individuals began to fear the smoke and experienced physical irritation as well as an elevated apprehension that severely hampered their concentration. Miners who escaped the three mine fires reported psychological and physiological effects similar to, and in some cases more dramatic than, those experienced by participants in Jin's experiments. Of the 48 miners interviewed, nearly one-half of them (48%) reported experiencing some level of emotional instability as they made their way through the smoke-filled escapeways.

Several miners said that they became frightened when they first encountered smoke. In some cases, fear of smoke severely hampered miners' ability to concentrate and perform motors tasks such as those associated with donning an SCSR. The wireman, who had been in the 7 Butt section of Cokedale Mine, was riding in a jeep with the section boss when they encountered smoke in the 8 Face track entry:

> We were in the jeep, and we hit smoke. I got all scared you know, all, what the hell we going to do, you know, all this smoke...And I was on the jeep, and [the boss] said, "Get your SCSRs on." And I...opened mine up and I was like shakin' like a leaf, couldn't get the damn thing

> open. And [the boss]...said, "Here, pop this, stick this in your mouth..." I mean, I couldn't get the damned thing, I was so damned scared I didn't know what else, I didn't know what the hell to do, you know.

Other miners said they began to fear the smoke when it became thick and heavy. Apprehension about the smoke caused one of the shuttle car operators at Adelaide Mine to experience difficulty breathing, even though he was wearing an SCSR and was protected from the smoke. When his crew encountered heavy smoke billowing from an overcast that they had to cross at the intersection of 3 Left and 2 Northwest Mains, this miner experienced tremendous anxiety:

> We went into that smoke and I couldn't breathe and was gagging on that self-rescuer. I couldn't breathe any at all...I couldn't go in [that smoke]. I guess it may be psychological or something about being in that smoke or something. I couldn't breathe at all. In [the smoke] I was gagging but as soon as I would come out of there, it seemed like I was breathing better, a little bit better.

Because of his experience, the shuttle car operator chose not to follow his buddies into the heavy smoke at the overcast. Instead, recognizing where he was, he decided to follow another route that led him across 2 Northwest Mains and down the right-side return escapeway to a point outby the fire. This decision is significant because several of the miner's buddies, believing him to be lost, risked their lives by going back to the overcast to look for him after everyone had reached safety.

While some miners became afraid in the smoke, others became confused and disoriented. This inhibited some miners' ability to think clearly and respond functionally to the situation. The Federal mine inspector, who escaped from 4 South at Brownfield Mine, had conducted numerous inspections in the sections off 6 West Mains and was moderately familiar with the layout of that portion of the mine. Nevertheless, he reported becoming disoriented and confused in the heavy smoke, especially toward the end of his ordeal as he made his way from the belt entry to the track:

> As soon as I found the crosscut, I went in because I didn't want to miss it and I went to the end of the crosscut and run into a permanent stopping. Well, I started looking for the door and it seemed like I was lost. I wasn't lost but it seemed like I was lost because I got sort of that feeling, well, I know that door is here but I just couldn't find it.

After getting into the track entry and traveling another crosscut, the inspector reported seeing lights ahead of him, but he was not sure of their significance

"I could see lights ahead of me. I could see these lights...[but] the lights really didn't mean anything to me."

The 4 South section mechanic was in the same escape group as the Federal inspector. After the escape group broke up, the mechanic continued traveling outby along the beltline. Even though the belt entry led directly out of the section to 6 West mains, the mechanic became confused and disoriented in the smoke:

> I didn't know my way out of there. I lost all orientation how to get out of there. I knew my way out, but I forgot. It was just a panic thing.

Jin [1981] noted in interviews with test subjects that, as the smoke became thicker, some individuals became apprehensive as they wondered what would happen next. Based on these findings from a controlled experiment, it is not surprising that miners who escaped the fires experienced similar mental anguish when thoughts of what lay ahead entered their minds. Miners who experienced emotional instability reported thinking about many different things as they made their way through the mine. The foreman of the crew escaping from 8 Face Parallels said, "Your heart's thumping and all kinds of goofy crap's going through your head." Some miners thoughts turned to their families. A brattice-man who escaped with the crew from 3 Left at Adelaide Mine said he thought about never seeing his family again: "I kept thinking, I want to get out. I don't want to die in here, I want to see my wife and kids."

Other miners experienced thoughts of not escaping the fire and dying in the mine. The shuttle car operator, who left his crew at the overcast to explore another escape route, said, "I thought I was going to die right there in that smoke." Several miners said they thought about the Wilberg Mine disaster and wondered to themselves if they were going to meet the same fate as their fellow miners did in December 1984:

> But what was in everybody's mind was the thing that happened at Wilberg. Myself, I thought we wasn't going to go, to get out.

> And my personal thoughts were that it was a Wilberg disaster, and that's all that was in my mind.

While some miners only thought about the possibility that they were going to die in the smoke-filled entries, others had virtually given up hope. After checking the left-side intake of 6 West Mains at Brownfield Mine and seeing that it was full of smoke, a roof bolter operator from 5 South made his way back to where several other miners were waiting:

> And there was a couple of rock dust guys right there. I sat down with those rock dust guys and I figured this is where I bunk—this is it. I was just going to say goodbye to the world. I couldn't see anything.

In another instance, the miner operator from 4 South at Brownfield Mine reported being also ready to die. He had been evacuating with the section mechanic, the Federal inspector, and another miner. While traveling along the 4 South belt entry, the miner operator experienced great difficulty. He was having problems breathing with his SCSR, became disoriented and unable to see in the smoke, and kept falling down in the mud. After falling down for one last time, and after his buddies had left him, the miner operator gave up:

> So I was there by myself and I was down in the mud. I remember just stopping a couple of times and just, you know, wishing it would get over with, almost wishing I'd die or something, just to get it over with. It was a horrible feeling.

It is evident from these accounts that miners experienced great emotional trauma while escaping through the smoke-filled passageways. In some cases, miners' ability to concentrate, make informed choices, and take appropriate actions during their escape was severely hampered by the need to deal with emotional effects of the smoke.

Besides having to cope with the psychological effects of smoke in their escape environment, many miners had to contend with physiological elements as well. Smoke clouds carry CO as well as sensory irritants, both of which are byproducts of combustion. As mentioned earlier, Jin [1981] measured CO levels and calculated the ratio of CO to optical density as D/CO. It is worth noting that the ratio observed by Jin ($D/CO = 6.10 \times 10^{-3}\ (ppm \cdot m)^{-1}$) is identical to the value quoted by Litton [1989] for smoldering wood. Therefore, depending on a person's familiarity with his or her surroundings during a fire, the levels of CO that are present when smoke visibility reaches its critical level lies somewhere between 10 and 35 ppm.

Relationship Between Critical Levels of Smoke and CO

In Jin's experiment, these critical levels of optical density were measured for wood smoke. Depending on the actual material burning and the resultant characteristics (both physical and chemical) of the smoke produced, these critical values could increase or decrease. Clearly, a critical level of optical density at which the range of visibility is reduced to •1 m represents an upper limit. The range of visibility is defined as the distance at which the light obscuration exceeds 86% (or, the transmission is less than 0.14). At a 1-m visibility range, the critical level of optical density is 0.92 m^{-1}. This value should be considered as an absolute maximum value based solely on reduced visibility.

Using the data of Litton for the ratio of CO to smoke optical density, it is interesting to compare the expected levels of CO that would be present at the values of optical density equal to 0.22 m^{-1} (the maximum critical level reported by Jin) and 0.92 m^{-1} (the absolute maximum), discussed above. These levels are shown in table 7.1 for smoldering fires and in table 7.2 for flaming fires.

Data have been acquired in full-scale tests at Lake Lynn Laboratory which demonstrate the levels of visibility that occur as a function of the CO level. In these tests (see figure 7.1), placards were placed at fixed distances from a camera and irradiated by a white light. As time progressed during these tests, the smoke level increased, eventually obscuring the placards. As these placards disappeared in the smoke, the levels of CO at the times of their disappearance were measured.

Figure 7.2 indicates the visibility (in meters) measured as a function of the CO level (in parts per million). The solid line indicates the level of visibility predicted from smoldering coal fires, while the dashed line indicates the level of visibility predicted from flaming coal and styrene-butadiene (SBR) belt fires. It is important to note that during the large-scale experiments, the initial levels of CO and smoke come from a smoldering coal fire while the later levels come from a flaming coal and conveyor belt fire. In figure 7.2, the level of CO at which the coal fire ceases to smolder and begins to flame is indicated by the arrow. The importance of these data is apparent: significant reductions in visibility occur at relatively low levels of CO (10-20 ppm).

Table 7.1.—Visibility as a function of CO level in smoldering fires

Combustible	ppm CO at $D = 0.22\ m^{-1}$	ppm CO at $D = 0.92\ m^{-1}$
Wood	36.0	150.0
Coal	9.0	38.0
SBR conveyor belt	2.5	10.5
PVC conveyor belt	3.0	12.5
Neoprene conveyor belt	7.0	29.0
PVC line brattice	11.0	46.0

Table 7.2.—Visibility as a function of CO level in flaming fires

Combustible	ppm CO at $D = 0.22\ m^{-1}$	ppm CO at $D = 0.92\ m^{-1}$
Wood	56	234
Coal	17	71
SBR conveyor belt	19	79
PVC conveyor belt	42	176
Neoprene conveyor belt	32	143
Transformer fluid	7.5	31

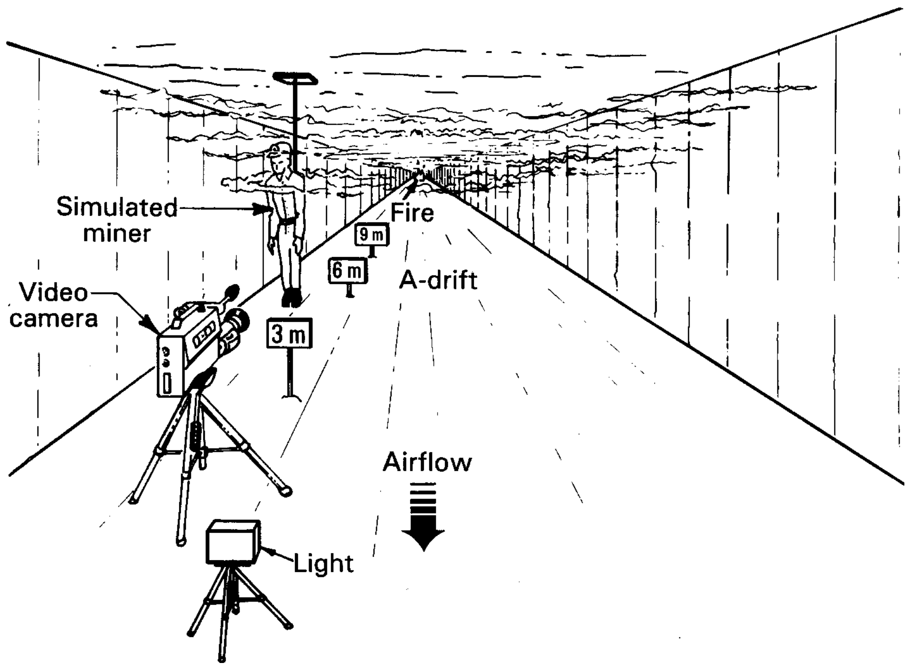

Figure 7.1.—Depiction of experimental setup in A-drift at Lake Lynn Laboratory.

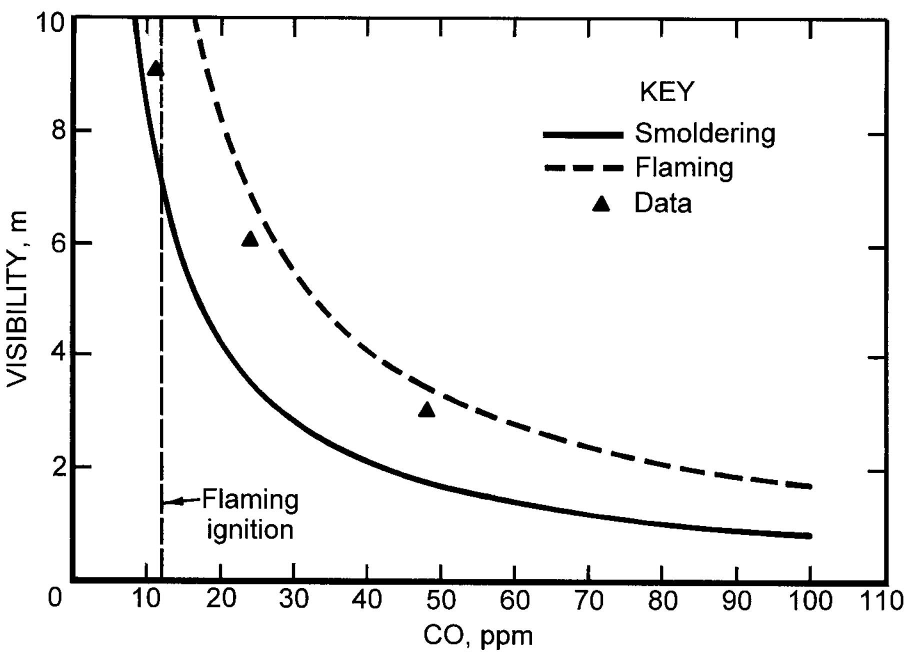

Figure 7.2.—Visibility measured as a function of CO level.

Depending on the material burning, other toxic and irritating elements can be produced. For conveyor belts, in particular, the generation of HCl vapor due to chlorine in the belt, as either a component of the base polymer or as an additive to make the belt more flame-resistant, is an example of such an irritant and also represents a potential toxic hazard in addition to the CO produced. Smith and Kuchta [1973] have measured the levels of HCl and CO produced from flaming SBR and polyvinyl chloride (PVC) conveyor belts. They found that the ppm of HCl is equal to 0.105 times the ppm of CO for SBR belts and 0.205 times the ppm of CO for PVC belts. Similarly, for smoldering conveyor belts, Egan [1992] finds that the ppm of HCl is 0.30 times the ppm of CO for SBR belts; 0.40 for PVC belts; and 1.0 for neoprene belts.

For CO, the level quoted as being immediately dangerous to life and health (IDLH) is 1,500 ppm; for HCl, 100 ppm [Mackinson et al. 1980]. If one uses these numbers as critical values and assumes them to be additive, then a toxic environment is produced downstream of a fire when the following condition is satisfied:

$$TOX = \frac{\text{ppm CO}}{1{,}500} + \frac{\text{ppm HCl}}{100} \geq 1.0$$

Using the levels of HCl produced relative to the CO, tables 7.1 and 7.2 can be used to generate values of TOX at the indicated levels of smoke optical density. These are shown in tables 7.3 and 7.4.

Table 7.3.—Values of toxicity at indicated levels of optical density in smoldering fires

Combustible	TOX at $D = 0.22\ m^{-1}$	TOX at $D = 0.92\ m^{-1}$
Wood	0.024	0.100
Coal	0.006	0.025
SBR conveyor belt	0.009	0.038
PVC conveyor belt	0.014	0.059
Neoprene conveyor belt	0.075	0.313

Table 7.4.—Values of toxicity at indicated levels of optical density in flaming fires

Combustible	TOX at $D = 0.22\ m^{-1}$	TOX at $D = 0.92\ m^{-1}$
Wood	0.037	0.155
Coal	0.011	0.046
SBR conveyor belt	0.033	0.138
PVC conveyor belt	0.114	0.476
Transformer fluid	0.005	0.021

Only a flaming PVC conveyor belt produces toxic products of CO and HCl to such an extent that the combustion products begin to pose a severe toxic hazard. This occurs at the maximum allowable level of optical density. It is clear from tables 7.3 and 7.4 that the presence of smoke poses a more severe impediment to survivability and eventual escape from fire than the toxicity of the gases produced.

It is interesting to note several subjective observations regarding smoke irritation made by Kissell and Litton [1992] during a conveyor belt fire test. In levels up to 40 ppm CO, test subjects experienced some labored breathing and mild eye irritation. When CO levels reached 80 ppm, individuals experienced hard breathing and stinging of the eyes. At 160 ppm CO, subjects found it very difficult to breathe and reported severe eye irritation. Participants also stated that they could barely see. These results indicate that severe sensory irritation can occur at CO levels below those that would cause carboxyhemoglobin danger.

Experiencing Smoke Density and Physical Discomforts

The studies reported here indicate that smoke density and the physical irritants produced pose a greater threat to escaping miners than the levels of CO and other gases, which do not reach toxic levels when the critical optical density is reached. In the three mine fires, however, some miners could have been in danger had CO levels been high enough. The reason is that most of the miners who escaped did not really understand the dangers that combustion products can pose. Miners were asked if they thought about the presence of CO during their escape. One miner provided his thoughts:

> Well, the way I was thinking, we was on the intake side...and was just starting to get some smoke. When we went in the return, it wasn't even heavy as that, so why worry—you know what I mean—as long as you can't see the smoke.

Although research has shown that the levels of CO and HCl do not appear to always reach toxic levels in thick smoke, a number of miners reported experiencing moderate to severe physiological effects, particularly sensory irritation. Slightly more than one-third (34.8%) of the miners who escaped said they experienced various problems such as choking, coughing, and eye irritation. Some miners said that they traveled barefaced through smoke before donning their SCSR and subsequently inhaled smoke. A mechanic at Cokedale, escaping with his buddies from 8 Face Parallels, described his experience with smoke inhalation:

> The section was really starting to fill with smoke, I had never had such a dry mouth or throat; it's almost like you could spit dust. I mean it's so

> dry, that's the one thing I remember vividly. And at that point, the smoke had started to uh, to overcome me. I was choking, coughing, and gagging and at that point, I took it upon myself to use my small [filter self-] rescuer.

Some miners experienced eye irritation from particulates in the smoke. A trackman who escaped from 7 Face at Cokedale said, "My eyes were affected somewhat. They were extremely red when I got outside."

It is understandable why miners experienced emotional instability during their escape through smoke from these fires. However, one might question why more than one-third experienced physiological problems since miners would have been offered respiratory protection from either their SCSR or FSR and eye protection from the goggles contained in their SCSR. These problems are easily explained: besides removing the mouthpiece to breathe, as mentioned earlier, nearly 48% of the miners who escaped also took the mouthpiece out in smoke to talk. Subsequently, miners inhaled smoke and various contaminants which caused them to experience breathing discomfort. The interviews also revealed that few miners wore the goggles supplied with their SCSR to protect their eyes. Many of the miners said that the goggles fogged quickly and hampered their vision. As a result, more than 63% of the escaping miners said they did not wear the goggles for that reason.

One of the most interesting problems that affected miners' emotional stability during escape was the unanticipated presence of smoke in certain areas of the mine. Ventilation systems can be extremely complex and made up of four or more air shafts, tens of miles of aircourses, and hundreds of stoppings and overcasts. This is especially true in large, older mines such as Adelaide, Brownfield, and Cokedale, where air must travel several miles from an intake shaft through intake entries to the working sections and back to the shaft via return aircourses. Where air must traverse such considerable distances through older aircourses, excessive air loss is common. Depending on the mine, it is not unusual to lose between 30% and 50% of the air before it ever reaches the working sections [Mosgrove 1981; Stefanko 1983].

Air loss is due to a variety of reasons, including frictional resistance in the aircourses and leakage across stoppings and overcasts. In a mine fire, air leakage across ventilation devices can result in significant amounts of smoke making its way into escapeways and other entries. To demonstrate, a U.S. Bureau of Mines investigation by Litton et al. [1991] studied the detection of conveyor fires. For this experiment, researchers placed a pile of coal beneath a section of SBR belt. Air velocity in the test tunnel, designed to simulate a single mine entry, was 10 m/sec (200 fpm), while the air quantity was 7.6 m^3/sec (16,000 cfm). Researchers then monitored combustion products in the air 20 m (65 ft) downstream as the pile of coal smoldered, burst into flame, and then set the SBR belt on fire. Data obtained from this study were then used to calculate contaminant and visibility levels, resulting from air leakage across stoppings, in a hypothetical escapeway that might be located adjacent to an entry containing a fire [Kissell and Litton 1992]. These calculations reflect conditions 60 minutes into the fire. The concentration of contaminants in the escapeway (C_e) was determined using the dilution equation:

$$C_e = C_f \left(\frac{Q_L}{Q_e + Q_L} \right),$$

where C_f is the contaminant concentration in the fire entry, Q_L is the quantity of air leakage, and Q_e is the quantity of air in the adjacent escapeway. Assuming a Q_e of 9.4 m^3/sec (20,000 cfm) in the escapeway, a CO concentration (C_f) of 2,700 ppm in the fire entry, and a Q_L of 0.94 m^3/sec (2,000 cfm) across the stopping line, a CO concentration of 245 ppm was calculated for the escapeway. A similar calculation was performed to determine the optical density in the adjacent escapeway. Using the optical density value, a visibility of 0.3 m (1 ft) was calculated. These results indicate that visibility reaches minimum acceptable limits at relatively low leakage levels.

The reason an unanticipated presence of smoke helped elevate workers' apprehensiveness is that miners tended to have certain predisposed beliefs about how the ventilation system should function and, consequently, where the smoke should be encountered under "normal" conditions. In a normal situation, fresh air comes into the mine via the intake air shaft, traverses the mine entries to the section, sweeps the faces, and then makes its way back to the upcast air shaft via the return aircourses. Ideally, air flow should occur with no air leakage across stoppings and overcasts, provided all ventilation devices are intact and mandoors are closed. However, minimal leakage is inevitable in any ventilation circuit regardless of how well stoppings and overcasts are sealed. Typically, a certain amount of air leakage will occur across mandoors, especially if they are left ajar. As calculations reported by Kissell and Litton [1992] show, smoke will make its way across ventilation devices into escapeways and other entries as a result of leakage.

About 37% of the miners who escaped the fires at the three mines apparently never considered the fact that air would leak across ventilation devices and introduce smoke into entries that they assumed should be clear. Surprisingly, some miners had misconceptions of how the smoke from the fires would travel. As a result, some groups of workers decided not to continue their escape in the smoke-filled intake escapeways or track entries and chose instead to move into the return aircourses, believing that the smoke there would be lighter or non-existent, since it would have to make its way to the faces before reaching the return entries. A continuous miner operator at Adelaide Mine, who was escaping with his crew from 1 Right section, elaborated on his crews' decision:

> Then if you have smoke in your intake, we were always taught to get into your return, and then keep checking until you see clear intake. So we got in our left return. There was no smoke because it hadn't reached up to the face and come back down the return.

At least one miner thought that by getting into the return, he and his crew would be safe, again because of a belief that any smoke in the intake must travel to the faces:

> We started in the intake escapeway, yeah. And whoever's decision it was, I don't know, because when we hit smoke, we decided it was time to get in the return because we figured all the smoke would have to go up to the unit or the face and come down behind us. So we're clear and out of all danger.

When miners encountered smoke in areas where they did not expect it, they began wondering how the smoke got there. A bolter operator described his thoughts:

> I think that was the thing that threw a lot of us off was when we came to the return, we hit the smoke on the haulage, we went over and we hit smoke in the belt entry, we got over into the return and it was still pretty clear. Because we went down 10 or more blocks, 15 blocks, whatever. That's when we starting hitting smoke [again]. Now, we got smoke in all, all the escapeways, you know. What is wrong?

In some cases, miners who became emotionally distressed assumed the worst when they encountered unexplained smoke. A utilityman quickly surmised that the fire had burned completely across the section when his crew hit smoke in the return:

> We were in the return by then and it was filled up with smoke and I knew we were in serious trouble then, we had a long way to go and we were already full of smoke...At that time, I couldn't get through my mind how we had smoke in the return escapeway that quick. I said, what did it do, burn all the way across and we don't have any way out now?

In fact, there were plausible explanations why smoke was being found unexpectedly in various locations at the three mines. As mentioned in an earlier chapter, a large quantity of air was being used to ventilate the 2 Northwest belt entry at Adelaide. Because this was a high-pressure entry, vast quantities of air quickly leaked across ventilation devices into adjacent intake and track entries, especially between the fire location and the mouth of 3 Left. As a result, significant amounts of smoke bled into these adjacent entries and eventually into the returns. This explains why the crews escaping encountered heavy smoke in all entries including the returns.

Several crews who escaped the fire at Brownfield Mine experienced similar situations, encountering smoke unexpectedly. Knowing that the beltline was on a separate split of intake air, miners escaping from the 5 South section decided to follow the belt, believing they would have clear air all the way out. When they encountered smoke in the belt entry, however, miners became concerned:

> We started down the belt because we figured the belt should have been neutral, really, but by the time we got there, the smoke was already on the belt line...we still can't figure out how the smoke got on the belt. Nobody—our boss can't figure out how the smoke got on the belt line. We should have been able to go down and get out the belt.

Misunderstandings about where smoke should be was not confined to rank-and-file miners. The mine inspector who escaped with the 4 South crew at Brownfield had a similar misconception. Knowing that smoke was already in the intake escapeway, the inspector checked the belt entry and found it to be clear. The section foreman, after conferring with the inspector, decided to take his crew down the beltline. All the while, the inspector thought the belt entry would be clear for the entire distance: "I really believed that the belt entry would be clear the entire way."

Some individuals, though, did think about why they were encountering smoke in certain locations and reasoned what was causing the problem. The mine inspector who escaped from 4 South at Brownfield Mine hypothesized later that a mandoor had to have been left open for there to be thick smoke in the belt entry:

> To this day we really didn't conclusively come up with an answer why that belt got contaminated. We checked the [stoppings]. I understand [stoppings] do leak somewhat but not to go from no smoke to thick heavy smoke in a matter of minutes. [Stoppings] don't leak that much. Someone left the doors open into that belt, also. I believe it.

At least one miner at Brownfield Mine was thinking clearly about why there was so much smoke in the belt entry. He was traveling with his buddies from 5 South:

> Thick smoke was in the belt lines before it was in the return...somebody goofed and opened something and left that air in. My opinion is that somebody opened the doors right across [4 South] ramp.

Finally, some miners at Cokedale Mine were perplexed by the way smoke "behaved" in the mine air courses, especially the return escapeways. Miners escaping from 8 Face Parallels were traveling in the return escapeway that led to Crystal air shaft. The workers noticed that there were points where the heavy smoke they were traveling in would suddenly lift and the air would become moderately clear. The miners might then travel several crosscuts in this clearer air until they encountered heavy smoke once again. A mechanic who was in the group escaping from 8 Face Parallels describes this occurrence:

> We headed out the return and we had gotten so far and it cleared a little bit, and we were kinda relieved, but then for some reason we hit the thick smoke again. It didn't clear completely but it looked like it was gonna clear, but then we went a few more blocks and it got real thick again. Why it was clear in that area I'm not really sure.

Because the smoke behaved in this manner, miners experienced a false sense of security when they reached the clearer air, only to find that the heavy smoke would return as they continued their egress. This undoubtedly helped to increase workers' anxiety as they escaped from the mine.

Discussion

Research on human behavior in smoke has shown that (1) people not familiar with escapeways tend to experience higher levels of emotional instability, and their ability to escape from a fire is severely reduced when the visibility falls below 13 m and (2) subjects familiar with escapeways experience relatively more problems with physiological effects of smoke, and their escape ability becomes hampered when the visibility falls below 4 m. Fire research data indicate that smoke reaches levels of untenability significantly earlier than it takes the fire to generate a toxic environment due to its product gases. It is only when the levels of smoke begin to totally obscure visibility that the toxicity of the combustion products begins to play a role in the question of escape and survivability.

Most of the miners who were caught inby the fires discussed here had never escaped through smoke. As a result, a number of workers experienced emotional instability that resulted from the need to cope with smoke in their escapeways. The psychological effects of smoke, in some instances, inhibited workers' ability to think clearly, make correct choices, and take proper action during their escape. In addition to suffering emotional upset during their escape, a number of miners also experienced some physiological effects of smoke, including smoke inhalation and eye irritation. In short, miners' ordeals in smoke when escaping mine fires confirm the findings of the research.

While underground miners must receive retraining annually on topics including mine ventilation, escapeways, emergency evacuation, and the use of SCSRs, it is evident that workers who escaped these three mine fires still were not adequately prepared to escape through smoke. In the future, mine operators may wish to consider offering smoke training to their workers as part of their annual retraining regime. Miners could don an SCSR training apparatus and then traverse a manmade network of corridors filled with nontoxic smoke. This type of training would allow miners to practice escaping through a smoke-filled environment, plus experience breathing through an SCSR.

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CHAPTER 8.—WAYFINDING AND ESCAPE BEHAVIOR

The notion of wayfinding, as conceptualized by planners, geographers, and psychologists, denotes the ability of an individual to move from one point to another through physical space. In order to achieve this movement, a person relies on a cognitive map of spatial representations [Passini 1984]. Which features of this cognitive mapping will be stressed depend, in part, on the researcher's perspective. A planner, for instance, would tend to emphasize the effect of physical structures on mobility. A psychologist, on the other hand, might focus on individual differences in how human minds encompass and represent physical space [Evans et al. 1984]. There is yet another dimension to wayfinding that needs consideration, and it rests upon the idea that reality, as experienced by human beings, is mediated: "[People] have preselected and preinterpreted this world by a series of commonsense constructs...which help them find their bearings in their natural and socio-cultural environment and to come to terms with it" [Schutz 1967].

These "common sense constructs" are arrived at socially and constitute the agreed-upon schemas that guide people's everyday activities. According to this principle, cognition is governed by some nonlogical factors that reflect not only individual procedures but collective ones as well. These group strategies, which are shaped by shared rules and values, influence "the information gathered, the ways it is processed, the inferences that are drawn, the options that are being considered, and those that are finally chosen" [Etzioni 1992]. From this perspective, cognitive maps, rather than being individual-centered templates of environmental images [Rovine and Weisman 1989] or representations of spatial relationships [Evans 1980], are partially group-centered schematic processes. As such, they are subject to reinterpretation, revision, and outside intervention [Kaplan and Kaplan 1982].

As intermediaries between the environment and behavior, cognitive maps serve as bases for decision-making. Traditionally, it has been assumed that good maps facilitate correct decisions, which in turn leads to optimal performance during wayfinding [Hunt 1984]. Given the argument that there is a social (non-cognitive) facet to cognitive mapping, however, this image of a cognitive map as some sort of static reference construct that motivates individual action is too narrow and mechanistic. If cognition involves less a knowledge of the environment than it does the process of "giving it meaning through imposing an order on it" [Rapoport 1976], then wayfinding behavior is not just a function of setting and individual differences, but is also a function of one's "normative-affective" structure [Etzioni 1992].

Rapoport [1976] used such an assumption as the base for a set of hypotheses about the connection between "external demands" and "organismic factors." One significant assertion deriving from Rapoport's ideas is that environmental knowing, the way people order their spatial world and act within it, is partially dependent on "cultural habit." Camic [1992], citing the 19th century French sociologist Emile Durkheim, underscored this function of cultural habit by noting that as long as an equilibrium exists between the environment and individual dispositions, action takes place without much reflection. That is because humans behave habitually. Furthermore, these habits are external to the individual since they are a product of socialization, and constrain people by imposing customary practices upon them.

An interesting implication becomes apparent at this point. Just as there are supposed to be individual characteristics of spatial representations, there ought to be cultural ones as well. In other words, every social group will share some distinct cognitive categories that help its members order the world conceptually. While these "noticeable differences" [Rapoport 1976] may be more pronounced between a simple society and an industrial nation, it is logical to assume that a certain amount of taxonomic differentiation will also exist within a populace. Even researchers who do not engage in cross-cultural comparisons can still contribute to a greater understanding of wayfinding behavior by focusing on the immediate cultural context within which spatial problems are defined and solved. This chapter intends to make such a contribution, while examining escape activities during the three underground coal mine fires that are the subject of this book.

The Mine as an Ecological System

In effect, coal miners spend their working days encapsulated in a gigantic maze that may lie a thousand feet below the Earth's surface. The floor of this maze is composed of fire clay, its walls are unmined coal, and the ceiling is made up of slate or shale. The height of a particular coal seam determines if workers must crawl from place to place or whether they will be able to stand upright and move around freely. Seam heights vary from less than 3 ft at one operation to 12 ft (or more) at another. In either instance, workers' environs are well-defined and rigidly bounded. This section contains a discussion of how the process of extracting coal and the culture miners have created helps them make sense of this environment.

Because underground coal mines are dangerous, rules have been promulgated to help support and protect workers. For instance, Federal regulations (30 CFR 75) require that a routine communication system be installed in each mine. This system must include a telephone (or some other two-way device) connecting the surface with each working section. The regulations also mandate installation of automatic fire warning devices on each underground belt conveyor. These devices must furnish audible and visual signals at either of two locations: (1) all work areas where miners may be endangered or (2) a staffed location at which personnel have an assigned post and there is telephone or similar communication with all workers underground who may be endangered. Finally, the Federal code stipulates that underground operations have to maintain separate and distinct passages, to be designated as escapeways, which are properly marked by reflective signs and symbols. There must be at least two of these travelable escapeways, one of which is to be ventilated with intake air, extending from each working section to the mine's opening.

While formal rules are critical, the most immediate source of support and protection miners have is their workplace culture. Social scientists recognized early that work groups share some sort of informal structure, but have agreed on neither its coherence nor overall importance [Roethlisberger and Dickson 1947; Roy 1953; Stoddard 1968; Bryant 1972; Schwartzman 1986]. It has been argued by those studying dangerous occupations, however, that a rather cohesive body of beliefs, values, and behavioral norms exists in risky work settings. Furthermore, these cultural elements function to increase certainty of action by subordinating individual will in order to realize larger group objectives [Hayner 1945; Janis 1968; Fitzpatrick 1974; McCarl 1976; Vaught and Smith 1980; Smith and Vaught 1988]. These arguments are supported by the work of Kaplan and Kaplan [1982], who pointed out that any culture, in order to be viable, must be a mechanism for coping. The three avenues through which culture should provide a template for individual cognition, according to Kaplan and Kaplan, are (1) relating people to ecological constraints in their environment, (2) guiding interpersonal behavior by enabling one to anticipate his or her cohort's likely actions in a particular situation, and (3) orienting members to the larger world that they might be expected to deal with.

The ecology of an underground coal mine is one in which humans are busily creating a void beneath the Earth's surface. This act produces dust that is unhealthy, because some of it is respirable and dangerous. Explosive gases are liberated during the mining process and water may seep in from disturbed aquifers. Additionally, massive forces brought to bear upon the newly exposed mine roof and coal pillars present the possibility of cave-ins or floor upheavals. Men and women work routinely in the face of these hazards, because they can draw upon a stock of accumulated knowledge intended to help them control such situations. Mine workers believe that they will be able to grasp both obvious and subtle cues about changing conditions and take action in time to prevent mishap, which gives miners a feeling of mastery over their work environment [Althouse 1974].

Workers underground recognize, of course, that nonroutine events do occur. This is a major reason why they expend so much effort achieving mastery over the social domain. An elaborate unwritten normative structure has evolved to ensure group cooperation and individual predictability in the mine setting. The details of miners' preoccupation with rules of interpersonal behavior and the ritualistic sanctioning mechanisms they invoke to enforce these norms have been discussed in other publications [Lucas 1969; Althouse 1974; Fitzpatrick 1976; Douglass and Krieger 1983; Smith and Vaught 1988]. The point to be made here is that in this environment, as in others where group survival is problematic, there is little tolerance for personal aggrandizement. Rather, a lot of concern is focused on the ideals of shared expectations and coordination of efforts.

The resulting consensus, based on workplace norms, implies that everyone has approximately the same cognitive map of their underground world. According to Kaplan and Kaplan [1982], such uniformity is of benefit to the members of any culture because, as they put it, "Sharing and affirmation...lead to conviction, which in turn reduces...the confusing." This type of arrangement is especially functional in coal mining, where section crews must labor as cohesive units in order to perform their tasks safely [Vaught and Smith 1980]. Cohesion does not, however, imply rigidity. It should be obvious that no cognitive structure which did not provide a great deal of flexibility could serve as a coping mechanism in the underground environment. Thus there exists, on an individual level, a tension between control and complaisance. As will be seen in the analysis, this contradiction is apparent when miners must draw upon cognitive templates to devise escape strategies during emergencies.

How Workers' Ability Will Be Analyzed

It was stated in the section above that workers have roughly the same cognitive map of their mine environment. That is to say, each miner carries an internalized representation of direction, distance and material structures, which allows him or her to interact and work cohesively with others in the setting. In an elaboration of this notion that coherency is a requisite of crew functioning, workers' environmental cognition was depicted as orientation not only in natural space, but in a nonphysical or social one as well. The process of wayfinding, then, may be characterized as "purposeful mobility" [Passini 1984] during which spatial problems are solved on the basis of systemic images. Results will hence be discussed in terms of how ecological constraints, interpersonal behavior, and conceptual content affected information gathering, item processing, inferences drawn, options considered, and choices made during the escapes under investigation.

Ecological Constraints

Ordinarily, the question of how to exit a familiar setting will have a straightforward solution based on environmental information recalled from past experience [Passini 1984]. In all three mines, the normal means of exit would be travel by portal bus to the shaft bottom. The fires, however, presented an unusual factor:

> We had power on the mantrip, so we figured we can get out with the mantrip. We started out in the mantrip, got out so far, and we hit... smoke.

Upon finding they could not evacuate along their normal course of travel, workers were faced with the necessity of generating alternative escape routes. It was this exigency that changed the behavior at all of these sites from a more or less automatic series of responses to the known (or expected) into actual spatial problem-solving activities.

Adelaide

A physical characteristic of the affected sections at Adelaide that had wayfinding implications was the ventilation setup. Because working sections were being advanced farther from the main fan and there were a limited number of intake aircourses going into the 2 Northwest area, it was decided to ventilate active working places with belt air. The operator requested and was granted permission by the MSHA District Manager to make these modifications. Requirements contained in the approved request were made a part of Adelaide's existing ventilation, methane and dust control plan. One of the requirements was that management would install a carbon monoxide monitoring system and locate the sensors in belt entries at distances of 1,000 to 2,000 ft (depending on air velocity). A second aspect of the plan allowed suspension of the requirement to separate the belt and track entries with stoppings. In actuality, this had only been done on 3 Left.

At the beginning of 2 Northwest, it was the belt and track entries that carried most of the air. The belt was a high-resistence entry, however, and lost its air rapidly. Most of this air went into the track and an adjacent intake entry. The result was that perhaps as much as 60,000 cfm of air passed over the belt at the fire site. Also, the belt entry at that point contained a velocity of more than 1,000 fpm. The fire therefore had enough oxygen to propagate rapidly, while the smoke-filled air started dumping into the intakes within a few breaks. Thus, when workers inby the source of combustion began evacuating, they found that not only their track but all intake entries had been contaminated with smoke.

One of the crew members from 1 Right found a novel use for some of the lids that were discarded when everyone put on their SCSRs in the smoke:

> And when we first started out I was picking up the lids...Every time we would turn I would drop one of those orange lids. Because I figure if we get down there and we can't get out, because we didn't know where the fire was, exactly...and we got to backtrack, I wanted to know where I came from. And if I find one of them lids, I know that I had been there

> and...follow my way back...I was saving them like Hansel and Gretl—drop the little bread trail.

Another individual, the miner helper, made use of physical characteristics with which he was familiar because he had worked as a fire boss for several years:

> There was guys walking up this bleeder—the old bleeder...[There] are reflectors in there. They were following the reflectors. I told them, ignore the reflectors, because you're going to get lost. I said, "Keep the stoppings to your left."

By using the stoppings to maintain their orientation, the group was able to travel their left return to an area outby the fire.

The 2 Northwest crew had comparatively little trouble finding their way, since their face boss was very familiar with the area. Because they did not know the fire's location and were in such thick smoke, however, there were times when they had problems. The former mine rescue team member recounted the effect this smoke had on even one as experienced as he:

> But from my experience...I thought...we were walking right into this fire...I started to get a little upset, a little tight...And in our returns we have reflectors...And it's a good idea if there's no smoke but...you ought to have something in there to grasp a hold of [to] tell you...if you're going the right direction. You fall down and you get up and you get turned around, you know, if somebody doesn't know where you're going, you could be crawling around down there.

Some of the group, being new to the section, had not walked their escapeways and were dependent on either being able to see the reflectors or having someone to help them: "I wasn't up on that section [very long] but I know that big man, the boss, knew how to go and I figured I'm sticking with him." It was the face boss who kept everyone together and led the group out.

3 Left, as mentioned previously, did not have belt stoppings all the way up. As the crew was on its way out, they "just hit a wall of smoke" and had to stop the mantrip. The group first went into their intake escapeway and, when they encountered smoke after traveling only a few breaks, got into their return:

> When we got to the return, why someone just took off, you know, never waited on anybody...They panicked and got scared...That's the worst thing in the world to do...Everybody should stick together and then there's everybody in one place...They know where you're at; they know if you're strangled out there.

The men who "just took off" were four buddies who had worked on that section for several years and, as a result, knew the area well:

> We were all...together because we're all real familiar with that escapeway...So we were more or less in the front, leading the way and the foreman was back with some of the other people and I'm not sure who was in—at dead rear...We were the ones that were picking the escapeway out.

Those who had gone ahead were also the ones who balked at crossing the overcast located at 3 Left junction, according to the face boss:

> I could see lights coming back at me and they said they couldn't make it over those overcasts; there was too much smoke. So we started back because I noticed the 3-by-3 door in the return. So I wanted to get back into the intake. Well, I couldn't find that 3-by-3 door and I knew I didn't want to start running around in circles. So I sort of collected myself and we started up over an overcast in the return and in the...sidewall of the overcast there was a 3-by-3 door and one of my men opened it up and said, "This is the intake escapeway." So everybody went out into the intake escapeway...We started walking and we were in the intake escapeway but something didn't look right to me...Around vacation time they had dug the sump and you had a path—as you come out your intake escapeway, the slate's on your left side and the path's on the right side and...I'm walking along and I started thinking something's wrong because that damned slate should be on my left side, not on my right.

When he realized his crew was headed back into 3 Left section, the face boss decided to get back in the return. The crew discussed their next move, then traveled to the overcast once again, where, upon opening the mandoor into their intake this time, the boss felt air movement on his face and was able to determine which direction the group should go from there.

Brownfield

A physical factor that affected group escapes from locations inby the fire at Brownfield was a double set of doors in the 4 South supply chute. A door in the second set was open to a width of approximately 6 ft. A locomotive parked in the chute had been left with its controller set on first point. When the motor overheated, smoke passed through the open door into the intake aircourse of 6 West Mains. In a short time, the intakes of 4 South and 5 South were contaminated as well. This forced all miners inby the source of combustion to evacuate through moderate to heavy "white smoke."

When smoke was discovered coming up the intake into 4 South, a Federal inspector who was on this section quickly checked the belt entry. The inspector and face boss decided to go out that way, because the belt was clear. Within a few hundred feet, however, the group encountered smoke on the belt. After donning their self-contained self-rescuers, the crew continued on down the belt line. The face boss began looking for a way out of the heavy smoke:

> I knew there was a crosscut—on 5 South it cut down into our belt line, and I knew there was a wall there with a door. I thought, well, maybe if we got to that door and went through it, maybe it would be clear in there. That was just a future longwall face area; [there wouldn't] be much smoke in it...So it got to the point where you had to feel the rib, you couldn't see. You might see water line. I was feeling the rib just to find out where that crosscut was and finally found the crosscut. We went up through the brattice door.

The face boss and three men who were with him paused to get their breath and formulate a plan for exiting the mine:

> I told them since the smoke was in the belt line...and track, we were going to have to get over into 7 aircourse [of 6 West] Main on the other side...Maybe that one was clear. That's where I told them we would probably be heading...And [the smoke] was all heavy, so we continued across the main and we got out into the track area and it was the same out there...There was no door to go over into...the intake on the other side.

Unable to get into 6 West right intake, the face boss and his companions decided to travel outby in the track entry. After going four or five blocks, they found themselves past the burning locomotive:

> I'm kind of glad there wasn't a door at 7, 'cause...I guess they opened the door on that right side to help clear the smoke out...I would have been worried if I had gone to 7 and saw smoke on that side, too, 'cause then I would have known [mistakenly] we'd have a long way to go to get out.

In the next several minutes, the face boss was joined by others from 4 South and learned that his miner operator was down up the belt line. He then went back after this individual.

Although the 5 South group started to evacuate by way of their intake escapeway, they only traveled a hundred feet before deciding to enter the belt entry. Unlike the crew from 4 South, however, they did not stay there. After proceeding approximately 400 ft with the smoke increasing in density, the group came to a steel door: "I don't know his name, the bratticeman, he was first. He went into the return." The smoke was lighter here, so everyone continued down their return until they reached a regulator at 6 West left-side return. At this point the miners donned their self-contained self-rescuers. According to the face boss, his crew was somewhat strung out by the time they had gotten outby to the 5 South intake overcast:

> A couple guys had already come out and went over this way trying to get to this door. 'Cause this is the belt line, track entry, then [6 West right] intake. In my opinion, they did the right thing, you know, trying this way. But then they got out to this intersection here, they couldn't see...anything, so they turned around and come back to the door.

The face boss then decided to make an attempt to reach the 6 West right-side intake himself. Telling those with him to wait, he opened the door and went into the belt entry. The smoke was so thick he ran into the belt. The face boss crossed it and came to a second door:

> I opened this door and the power center's setting here. I couldn't even see that from the door...Right then, I tell you, panic hit, believe me. 'Cause all the teaching and training, everything, these are all supposed to be separate splits. Well, the first thing that goes through your mind is everything's burning. In my opinion, there was no sense even trying to get [to the right-side intake], so I come back. There's a bleeder pipe that goes from this overcast over to the power centers and that's how I found my way back over here. They waited for me. They made up their minds that they was going to wait 10 minutes for me and then go. When I come back, the smoke was getting a little bit heavier in the return...I said, "You guys want to try to make it over there" and before I said much more...the bratticeman said, "We're ahead of the smoke! Let's go!" Well, right then—well, everybody seen the smoke here. That's when there was not much control, you know, and everybody started just going.

One of the masons, who thought his SCSR was not working properly, took it off and threw it away. The face boss helped him don his filter self-rescuer. The group, with "everybody stringing out pretty good [by] then," passed across the overcasts at 4 South, the face boss checking doors as they went. He came to a door outby the fire area, opened it, and found fresh air. The boss called everyone back and they went through that door onto the track.

A maintenance foreman working on 6 West took the fire boss's call. He then gave himself an advantage over members of the other two groups by discovering the fire's location:

> And I knowed I had to go down past 4 South here...I was the only one out of all the guys that knowed where the fire was...And the reason for that is I took and asked [the fire boss] where the fire was.

The maintenance foreman, a mechanic, and a State mine inspector met at the beginning of the intake escapeway. The three men donned their SCSRs at that time because they could see light smoke coming up the intake. The group traveled down to 8 Left aircourse, where they encountered heavy smoke. About 50 ft past that point, unable to see, the maintenance foreman decided to backtrack:

> The smoke was so heavy you couldn't even find the mandoor at the overcast. But I knowed if I went up one more crosscut and I went up along the rib pretty close and went into the left and then come back a crosscut [I'd get] into the return.

The men did this and went through a door into 6 West main return, which was their alternate escapeway. They proceeded outby in that entry:

> And we was probably halfway between 5 South and 4 South whenever I heard the 5 South crew coming. I heard them coming over the overcast, and then I was relieved a little bit because I knowed that boss coming with that crew was real familiar with the mine.

Knowing that the fire was at the 4 South supply chute, the maintenance foreman continued in the lead. He passed up a mandoor that would have brought his group into clear air outby the chute, however, and was called back by the 5 South face boss. The 5 South and 6 West groups then entered the intake and from there proceeded out onto the track.

Cokedale

One particular physical characteristic of that area of the Cokedale Mine where both affected crews were located proved to have a significant impact on everyone's wayfinding behavior. The primary (intake) escapeway, which in most mines would have extended "separate and distinct" to an air shaft or portal, led instead onto Cokedale's main haulage track. Since the source of combustion was on this track, that meant the escapeway could rather quickly become smoke-filled. If anyone possessed a clear picture of the layout and was able to communicate this fact to his group, no time would be wasted on attempts to evacuate down the intake entry. Without knowledge of the source of combustion, however, this primary escapeway should be the first choice. Thus, what might have been a minor component of even the most comprehensive cognitive map became critical in this case.

After encountering smoke on their section track, the group from 8 Face Parallels held "a small discussion as to where we were going to go, what we were going to do." A trackman, who had just delivered a load of rails to the area but who was unfamiliar with that part of the mine, recounted his reaction when those supposedly more cognizant of their immediate surroundings began to consider going out the intake escapeway:

> According to the old laws they didn't have to [route] it to the shaft and this fell under [the old laws] since it was an old established section... And that stuck with me, and when they decided they were going to walk the intake, I specifically said to [the general foreman], "We can't go out the intake."

Regardless of this warning, the accounts show that "it was the consensus of everybody [to] head for the intake." Additionally, the decision seems to have been based not on any stock-taking but on a generalized training protocol that suggests miners should always travel their primary escapeway if possible.

A problem arose immediately because "nobody seemed to know how to get into the intake escapeway from where we were out at the mouth of the section." The general foreman mentioned above, who had been leading this group initially, decided to "go back [and] get into the intake from the face." The workers then returned to the section in order to enter their primary escapeway. Everyone walked across the face area, got into the designated intake entry, and proceeded down it until "we came to an overcast and as we walked over top of the...steps, you could see on the other side the smoke was coming in the intake." At about this time "the guys started...making the decisions on what to do," although there was still little discussion taking place. Since there was only one way out of the smoke—back up the entry to the face—the miners, led now by a trackman, retreated in that direction.

Once again on 8 Face Parallels section, the group was faced with yet another decision. Given the general instructions miners receive in training classes, "naturally the next thing would be...the return [secondary escapeway]." Their choice was made fairly quickly, and, while appropriate under the circumstances, did not get translated into proper action. In fact, a procedural error was committed, further compounding the crew's earlier decision error:

> So we decided to try the designated return, at which point [the general foreman] did not know which was the designated return.

> We headed out...on the right side and...went five or six blocks and...one of the guys up front noticed there's no arrows; we're in the wrong return. We're not in the return escapeway. So then the bratticeman from the

> section, he said, "Oh, yeah—that's on the other side of the section." So then we turned around.

For the second time, then, an important item in at least one person's cognitive map was disregarded, causing the men to travel an additional thousand feet before ending up back where they had started from.

Regrouping in the face area, several workers decided to gather information before beginning the next attempt to find their way out. An individual remembered the section map, which had been hanging in their dinner hole:

> I stopped and got the map, read the map, and two other guys...they stopped and was reading the map with me and...what we wanted to do was see where it brought us out...and once we...saw where it brought us out...we knew the smoke was coming down there so we knew...the fire had to be fairly close.

Reassured by this knowledge, the miners entered their designated return escapeway and, led by a general inside laborer who had once been a foreman, finally started their ultimately successful exit from the section.

Those on 7 Butt had a somewhat different experience. According to a general foreman who was with this group, "we all started out at the same time...and we ran into that wall of smoke [on the track]." When they ran into the smoke they also collided with a stopped vehicle. As a result, one person lost his hard hat and cap lamp. He was assisted by his buddies as the general foreman gathered everyone and planned their next step:

> I [had] set all the ventilation up down there and I knew basically what was going on with all the smoke. The intake escapeway would have been full of smoke.

Informed by his cognitive map of the area, this individual was able to depict for these miners some of the features that would be affecting their intended escape. He first told crew members the location of a mandoor they should go through to get into one of their return entries. Next, the general foreman assured everyone that they would encounter less smoke by taking his course of action. Finally, he provided a preview of their route:

> The return that we started going out was not a return escapeway; it was just a return airway. I told them...we go through the mandoor, follow [the return entry], ...cross over the overcast, check the doors up there... get into the return escapeway and follow it up to [the portal].

Thus, the workers all had at least a limited notion of where they were going and how long it would take to get there. As the crew walked, the general foreman was able to keep them updated:

> Everybody was asking me where we were...what direction we were headed. And with the information that I had...I knew first-hand...what direction we were headed, ...where the mandoors were, ...[our] location [in reference to] the motor road...and where I was gonna bring 'em out.

With these reassurances, the miners from 7 Butt were able to stay together and exit their section in an orderly manner.

Interpersonal Behavior

Overall group performance largely depends on how well group members can play their assigned roles. In nonroutine situations, difficulties may arise if someone who normally holds a leadership position is not prepared. The same may be said of a person who, because of his or her experience or expertise, is considered to be "mine wise" but who does not use that wisdom. Workers still look to these people for guidance. This complication stems from the fact that roles which people enact during an emergency, instead of being expressly different from their typical roles, are existing ones that have been carried over and tailored to unusual circumstances [Best 1977; Johnston and Johnson 1988]. Worker accounts reveal clear differences in behavioral patterns within and among the eight groups under discussion here. This section addresses some of the ways these and other social phenomena began to have a bearing upon individuals' use of cognitive maps and their subsequent wayfinding activities.

Adelaide

The section foreman on 1 Right had been recalled only recently to Adelaide. While this might not have been too detrimental to his performance of duties at the face, he encountered difficulty when he had to extend his leadership role into emergency circumstances. The miner operator explained his attitude toward the boss's performance:

> The boss; I can't blame that boss...This was the first time he was on the section in 5 years; he'd been laid off...He...didn't actually know just where to go, but [the utilityman] was a fire boss at one time, so more or less...took the lead.

The utilityman, who was working as 1 Right's miner helper that night, initially wanted to lead this group through the bleeder system to Peterson shaft:

> I told them if we get [back] in the mantrip and...go back to 35 stopping or 36 stopping, there's a door in a left return. I said, "You can walk across the bleeders to Peterson shaft." I said, "Let's all get in the mantrip, we'll go back, and we'll get out of the mantrip, we'll call and tell them that we're getting out and we're walking to Peterson; they'll have a mantrip waiting for us at Peterson."...We was standing by the mantrip, but they wouldn't get in it.

Having failed to convince his coworkers to backtrack, the utilityman then began acting as advisor to the face boss and crew: "I don't know...They say I [took charge] but I don't think so...I just knew where to go...that's all." Regardless, the accounts show that this person's recognized "mine wiseness" and relationships with other crew members played a significant part in how his group found its way out of the mine:

> And when we walked down through here, you had to watch because if you followed the reflectors, you'd end up in this bleeder here or in the gobs, because they had reflectors. And [the utilityman] kept telling them, "Hey! Keep the stoppings on your left. If you veer off, you're going to end up in a bleeder or gob." So twice he had to say, "Hey! No, no! You're going the wrong way."

Thus, the utilityman apparently used his fire bossing experience to compensate for the face boss's lack of familiarity with the area while refraining, in his view, from actually assuming control.

On 2 Northwest, the section foreman moved quickly to control the situation, drawing upon the experience of one of his buggy operators, who had been a mine rescue team member:

> We got everybody together and [the boss] said, "You take the back, I'll take the front...we're going in single file...Don't let anybody in back of you...and we'll keep everybody together." The boss took control...He told them, "This is what we're going to do." There was no, well, I think we ought to go here; I think we ought to go—we knew what we were going to do...where we were going...I had confidence in him; everybody did...And he had confidence in...me...being from mine rescue.

The behaviors of both individuals were consistent with their roles. 2 Northwest's face boss was familiar with the area and continued to direct his crew. The buggy operator performed according to certain expectations of his mine rescue role. This group escaped without undue complications.

Leadership roles on 3 Left shifted during the course of their escape, with individuals making suggestions or taking the lead at different moments:

> I was the first one in line going over the second overcast and when I seen that smoke coming up out of there, it was so bad, I told everybody in line, "There ain't no way in hell I'm going...I'd rather have it coming in my face [than] at my back." And we got back into our intake escape-way and had the smoke coming in our face.

Some of the miners attributed the vaguely defined leadership in this group to panic. Another, and perhaps better, explanation stems from the fact that 3 Left was a "split crew." Some of the miners were buddies who had been on the section for several years and knew the escapeways well. Others had been there only a few days or weeks and were unfamiliar with the section. They were left behind by those who could more readily find their way. Unlike the foreman on 2 Northwest, who was able to take the head of the line because of help from a person well-versed in mine rescue procedures, the foreman of 3 Left found it necessary to stay with the workers who were having trouble. His ability to control the escape was therefore hampered.

Brownfield

There were two individuals on 4 South who possessed not only a certain degree of "mine wiseness," but who were also in authority positions: the face boss and a Federal inspector. As the group proceeded down their belt line, some members began to get ahead of others. The inspector broached this problem to the face boss:

> I said, "Those guys are getting ahead and I don't think we can slow them down. Someone better travel with those guys." There was never any discussion on who was going to go with them. I said, "Why don't you go down there and go with those guys and run them ahead and I'll stay with these guys." I knew the mine quite well so I didn't have a problem with where we were going or where the aircourses...[were].

Later in the escape, however, the inspector encountered difficulties of a different sort. One of the two workers he was with (the miner operator) became unable to continue. The inspector's knowledge of the mine, combined with his lack of information about the fire's location, presented him with a predicament. Should he continue his helping role or leave the victim behind in order to save himself?

> I knew we were in the belt entry, but I didn't know where we were as far as getting out to the main but here again, not knowing where the fire was, I didn't know how far we had to go once we got to the main. Once we got to the main...if we had to travel in smoke, I knew it would be at least another hour to get to the portal. So it started to concern me, the time element and getting out of this section.

The inspector did not immediately make a decision to depart. Rather, he kept trying to assist until the victim himself suggested the others leave:

> He looked at the mechanic. I saw him look at the mechanic and he said, "You guys go. You just leave me here. I can't go no more. I'm just going to stay here." I looked at the mechanic and I said, "I got to go. There is no sense in me staying...I can't breathe now...I can send somebody back. I'll go out and get somebody. If it's only out to the main track, there will be somebody, I hope, out there. I can send them back and I know exactly where you're at..." Even when I told this man I thought I was out of air, I got to go get help, I was still carrying an extra self-rescuer and I guess I had taken enough smoke...I didn't realize I had it.

The mechanic, left alone with the miner operator, soon became convinced there was nothing further he could do:

> I didn't know my way out of there. I lost all orientation how to get out of there. I knew my way out, but I forgot. It was just a panic thing...so anyway, I thought, "Well, [the miner operator's] not going to make it; I'm going to try and get out. So I started out and I was only about a hundred foot from [the miner operator] when I came through the overcast and I opened the door and I saw No. 7 and I thought, "Good. This is fresh air...the way out." I thought I was out to the track, but I was only into No. 4 aircourse. So I thought, "Well, I'm going back in and get [the miner operator]. I'm this close, we're going to get out of here."

Buoyed by his mistaken belief that the victim was only a hundred feet from fresh air, the mechanic went back to renew his rescue efforts. He was soon joined by the face boss, who brought two replacement self-contained self-rescuers. The face boss informed both men that fresh air was just 500 ft away. The mechanic and face boss then got the miner operator on his feet and supported him as all three made their way outby the burning motor.

The workers on 5 South stayed close together during the first part of their escape. When asked how much planning was done before they left the face area, the section foreman replied:

> Actually, there was no real planning until we got down to this regulator. We put our self-rescuers on, then we got down and couldn't get out here [into 6 West right intake]—then everybody knew they was going down the return. Everybody knew where they were then...and there is no turns. Everything's straight in that return.

The section foreman finally came to a "void" in the smoke where he spotted the door that led into fresh air. He then shouted for those group members who had gotten ahead and the crew all exited into the intake and from there into the track entry outby the fire source.

The maintenance foreman who took the mine examiner's warning call on 6 West asked him where the fire was located:

> Well, he told me there was a fire at 7 Left ramp. He didn't know what was burning, because he couldn't get in to it. But I knowed how far I was from 7 Left and I traveled as fast as I could to beat it. Only you don't beat those things. I found that out real quick.

The maintenance foreman reported that he walked ahead of the mechanic and State mine inspector who were with him, looking back frequently to make sure they were keeping up. There was little discussion among the three, because the maintenance foreman was familiar with the area and knew what point the group needed to reach in order to be outby the fire.

Cokedale

One early problem for 8 Face Parallels (8FP) stemmed from the fact that Cokedale's dispatcher, whose functions may be envisioned as somewhat akin to those of an air traffic controller, did not inform everyone of the fire's location:

> He was trying to call the other section right away. So...I can understand...what he has to go through trying to call everybody and try to get them out, call the DER [State enforcement agency] and everything else. He got his hands full.

Worker accounts indicate that the resulting uncertainty heightened this crew's confusion and indecisiveness. Where they would ordinarily look to management for direction, the miners had a general foreman who was as confused as they were. Additionally, given Cokedale's authority structure and work rules, an alternative leadership mechanism was not in place—one had to emerge. This emergence was a process negotiated over an extended period of time, seemingly at the expense of efficient wayfinding behavior.

It has already been stated that by the time 8FP began its final attempt to exit the section, the workers were being led by a general inside laborer who had once been a foreman. Researchers reached this conclusion by weighing various responses to questions about who was actually making decisions at certain points during the escape. While there was much agreement in everyone else's accounts, the general inside laborer himself had a slightly different interpretation:

> At that point in time me and [the boss] was close together—there was nobody right there that could hear what I was saying. I say, "I didn't bring the map, [but] we have to go out this return." Being as [the boss] knows me, it was more a mutual agreement...He respects my knowledge from mining and I respect his so...that he understood more or less what I was talking about—that...we were running out of time. That wasn't the time for no argument.

Thus, this worker cast himself in the role of advisor, deferring as much as possible to his general foreman's authority and legitimate leadership position. Also, the general inside laborer presented himself much the same way during interactions with his buddies: "I was not in a foreman capacity, but I could see things going on that was wrong...so I would say, 'I sure wouldn't [do that].'"

Eventually, the crew traveled outby to their section air regulator and stopped. At this point the general foreman decided to explore ahead. The general inside laborer chose to accompany him, so both men went through the regulator and proceeded some 100 ft farther outby:

> You could see 50 feet and then you couldn't see 2 feet...[I thought] there was a stopping blew out [or something] because [the air was] all mixed up no matter which way you turned...[The boss] said, "We can't lose the smoke this way." I said, "We have to go through this—go out the return. Smoke or no smoke...we can't keep changing our minds...else we'll be here forever."

After regrouping, the miners did continue out their return through smoke that kept varying in density. This phenomenon concerned the general inside laborer as he tried to orient himself, because "if something happened at one point [and] you walk six, seven, eight hundred feet, then you could be in a better situation or a worse situation—but that wasn't happening." The smoke's behavior confused everyone, and, as one motorman observed, caused a few individuals to waste time looking for ways out of it where there obviously were not any:

> We would come to places in the return where the bleeders were and people would actually go and look over the wall at the bleeder—for what purpose, I don't know...maybe they weren't familiar at all with what the return looked like or whatever an old bleeder would be.

It was this person's opinion that the aimless search for alternative routes as they traveled could have been curtailed by more forceful leadership.

Even though the men were wearing emergency breathing apparatus and were not supposed to remove their mouthpieces, they did so in order to communicate. As the general inside laborer's comments suggest, crew members seem to have kept up a running commentary regarding their location:

> Somebody mentioned..."We're going parallel to the track..." I'm thinking, "Boy, that's a bright deduction after we walked all this way—whoever said that's really thinking. If we ain't parallel to the track, we're in a lot of trouble...what the hell's wrong with these people?"

What was wrong, in the motorman's opinion, involved a circumstance of past experience and perspective:

> Now I found...out after[ward] that the older fellow had worked in those returns off and on [setting timbers] and things like that...But...one old entry looks like another one...as far as I'm concerned.

The men therefore drew upon each other for support and continued to speculate about their progress, since "we still didn't have the slightest idea where we were or how long [we had been walking]."

The general inside laborer checked behind mandoors as the group came to them. He eventually located one that opened into fresh air on the loaded track. The miners crawled through onto this track and began to get their bearings:

> My buddy immediately recognized where we were. He said, "We're between 18 and 19 crossover." Because he'd run motors out there for so many years...he could recognize where we were...We gathered ourselves. The elation was just unbelievable.

After resting a few moments the crew members made their way over to the empty track and up it to 19 crossover, at which point they joined with workers escaping from 7 Butt.

It has already been stated that the people from 7 Butt did not have as many problems finding their way as did those from 8FP; nor did they waste time trying to go out their intake escapeway, because the general foreman with this group knew where that entry led. The workers still encountered some difficulties, however. At one point, according to several accounts, the pace quickened almost to a run. This proved particularly stressful for that individual who had lost his hat and lamp in the vehicle collision and was depending on his buddies to lead him:

> My buddy in front...I held onto his belt all the way out...I followed their lights plus held onto his belt...I lost him a couple of times. I kept yelling...'cause everybody was running—everybody was in a hurry.

Aside from aiding their coworker, who began to "get excited," these miners' biggest concern was staying together and keeping themselves oriented. Although there was little talking reported among this crew in comparison to the miners from 8FP, several still queried the general foreman about their location as they traveled.

The group proceeded out their main return, with the general foreman checking through mandoors to see if they had yet reached a point where there was fresh air in the track entry:

> Every time he would check a door he had us stop to cut our breathing down a little bit, which was nice—everybody kinda got a little rational... I think we had to check maybe two or three.

The workers came finally to a set of double doors situated between 18 Face and 19 Face: "It...probably took about an hour, but...you weren't doing anything or really thinking 'cause it was just basically following the leader at the time." The general foreman led them through these doors into clear air, across the loaded track entry, and into their intake. The men walked outby to 19 crossover, where they met 8FP crew. Following a head count and brief telephone report to the outside, these combined groups continued toward 20 Face, where mine management had arranged mantrip buses to take everyone to a portal as yet unaffected by smoke.

Conceptual Content

As Kaplan and Kaplan [1982] observed, "humans are inclined to be painfully distressed by confusion and by helplessness." When they experience this anguish, people most commonly resort to authority, either social or cultural. Social authority involves the positions held by individuals and their expertise in playing roles incumbent to a certain position. Cultural authority is derivative, following from widely shared beliefs and values. An essential function of authority, in whatever form it takes, is to convey certainty in an uncertain world. Thus, a great deal of human effort is spent interacting with others for the purpose of evoking authority in an attempt to achieve clarity and agreement upon matters that would otherwise be disturbing or even disruptive. Such was the circumstance at the three sites under study here. This section presents a brief overview of various ways in which the miners strove to reach a consistency of perspective.

Adelaide

It was stated earlier that the utilityman on 1 Right suggested the crew, once they encountered smoke on their track, retreat to 35 or 36 stopping and walk across the bleeders to Peterson shaft. Evidently, he did not argue his point; at least, this is what one of the roof bolter operators remembered: "Well, he kind of mentioned it, see, then he just left it go." A missing piece of information, and one that, in the opinion of the bolter operator, would have predisposed the group to follow the utilityman's suggestion, was the fact that 2 Northwest had been forced to abandon their mantrip near the mouth of 1 Right:

> When they got into the intake...they called the dispatcher and told him, "Hey, we're going in the intake. The smoke is too heavy at the mouth of 1 Right." So when we called the dispatcher and told him we're going in the return, he should have told us that 2 Northwest stopped down at the mouth...the smoke may be too thick down there.

Instead, the 1 Right group, thinking they might soon be out of the worst of the smoke, entered their return and traveled in increasingly worsening conditions.

According to one of the shuttle car drivers, the group engaged in some discussion of where the fire was probably located:

> We were going to try...getting to Peterson, but we didn't know exactly where the fire was. We thought that the fire was at 3 Left. No. 2 transfer, the low spot, there's always a bad place the belts fall in and everything else. So that was our idea...I wished we knew where the fire was for one thing. It's like you're going into the unknown; you don't know exactly where you're going.

Near the end of the crew's escape, this individual, recognizing his location from a series of overcasts he had helped construct, left the group.

After the members of the group from 2 Northwest abandoned their mantrip, they walked back into the face area in order to reach their intake escapeway:

> The boss, he said, "We'll be all right." He said, "Everything'll be fine as soon as we get up into the fresh air." So we was scooting along pretty good and went back up the track, went over to the intake...It was smoke. There wasn't any fresh air there. So that was the point there where we all put on our rescuers.

The crew proceeded down their intake for a short distance and then decided to get into the right return. According to one of the roof bolter operators there was not a lot of conversation, although group members engaged in stock taking during rest stops:

> Yeah, we stopped different times—one guy fell down. I pulled him back up. He fell down. He was a little red and hysterical there a little bit of the time. And we stopped and the boss talked to him and calmed him down. We stopped periodically if anybody was having problems. We'd stop and check. Not long, but long enough to talk and see where to go and calm down.

The right return was designated an alternate escapeway, so all that was required of the 2 Northwest crew was that they stay in that entry until they were outby the fire. Because group members did not know the fire's location, the face boss, who was leading, would feel and open each mandoor they came to. At last he opened the door in No. 3 stopping and encountered fresh air. The bolter operator quoted above was one of the first through:

> I know I went through it and hit that fresh air and I was hollering at the other ones, because they was kneeling down there taking a little break. I told them to get...over here and get out of there. We appreciated that air more than you ever did.

After contacting the shift foreman and notifying him that everyone had gotten off 2 Northwest, the face boss was given instructions to take his crew to the surface.

The crew from 3 Left contained some members who had not been on the section for very long. One of these was the bratticeman who, because he was new, had been selected recently to walk the escapeways:

> I walked that the first day I was there, 3 weeks before. My boss wanted—he comes to me and says, "I want you to walk out with me and I want to get a couple of other volunteers to walk out. So you'll know in case something happens." But it's kind of—when you're walking out and you know there's nothing wrong, you're just strolling through because you have to do it. You know the reflectors are up there so you really don't pay attention to the markings or anything other than the reflectors and what door you go through; you know, where you go out.

At one point the group became disoriented and was actually headed back into their section. The bratticeman recounted how this confusion raised the miners' anxiety level:

> We went down this breakthrough and we couldn't go through and we come back, we come back like around the block and we got confused and we sort of all just grouped together in one place trying to decide what would be the best way to go out...We were walking down—we ran into our shift foreman who said at six more breakthroughs, five or six, make a right and you'll be out of this. That's when the two guys that always seemed to be ahead really took off.

One individual who was having problems received help from the utilityman, a shuttle car driver, and the shift foreman who had been looking for them. The crew finally reassembled outby the fire and found transportation to take them out of the mine.

Brownfield

4 South's face boss was able to take advantage of the Federal inspector's presence during that group's escape:

> So we started down the belt line and there was three guys that wanted to take off. They ran like deer...I was trying to stay in the back being the last one to make sure everybody was ahead of me. And it got to the point where I could see these guys were going too quick. The Federal inspector was back there with me, too, and I finally told him, I said that if he would stay with the slower three guys or four guys, I was going to go ahead with those faster guys, 'cause I didn't want them to walk into something that they weren't ready for. I walk that belt line every day... I didn't know what we had down there.

Near the mouth of 4 South the face boss led those workers who were with him into a future longwall face area. His intention was to get them out of the worst of the smoke and give everyone a chance to catch their breath. At this point he outlined the route they would take to try to get into the right-hand aircourse of 6 West:

> So everybody got settled again and we went back out and worked our way down the belt line. It was a slow process. The smoke was so heavy you just couldn't see.

The group members eventually arrived at 6 West track but were unable to find a door that would let them into the intake entry they were trying to reach. At that point, one miner left the others:

> My supplyman, he had gotten ahead. He took off again. He was the quickest one of the bunch, so when we got out into the high track,

> I called for him 'cause I didn't know—he could have took a left, took a right, fell down, I wouldn't have seen him. So I yelled—that's when the people down below the fire yelled that there was fresh air down that way.

After getting his small group outby 4 South supply chute, the face boss learned that his miner operator had not made it out. He then went back into the smoke in search of this individual.

A rapid pace was set by the bratticeman, who was leading initially as 5 South crew made its escape. One of the roof bolter operators recounted how this put stress on everyone else:

> To the best of my recollection, the bratticeman just took off running. He says, "Come on—we got to get out this way." And he took off. Well, he took off and he was leading the pack, okay. When we got down to where the regulator was at and put the self-rescuers on, that's when [the boss] took over. One of the things I told him later on, I says, "You're the boss—one thing you got to do if this ever happens again, you should have a man that's in charge that's going to take his time and walk out of there slow and easy with his self-rescuer on."...[You go] six, seven, eight hundred feet before you even try to put one of them things on, you're winded. [Then], it's like trying to suck through a straw.

A shuttle car operator also discussed the difficulties group members were having getting enough oxygen from their apparatus. Added to this concern was the fact no one knew the fire's location at first:

> So we went and then we run onto three other guys coming down from 6 West, too, which was the maintenance foreman and an inspector—and a mechanic. Yeah. And then they told us where the fire was at. But we was still up away from where it was at a good bit. But they told us it was down at—what was it—4 South—4 South sidetrack where the motor was sitting. But we had to go down below that, so then we had an idea how far we had to go, so it took a little bit of the pressure off 'cause we knew we was going—we had a pretty good chance now.

5 South crew, together with the three individuals from 6 West, eventually came out onto the track one door down from the burning locomotive.

The maintenance foreman on 6 West intended originally to ride out in his three-wheeled jitney. He was dissuaded from doing so, however, by the State mine inspector accompanying him:

> Well, it could cause an explosion, he said, for one thing. I mean, I was on the damn thing and so was [the mechanic] when he says no. I know one thing—if it ever happens again and there's something to ride...I'm riding.

The fact that he knew how far his group must travel in order to get outby the fire influenced this person's approach to their escape. During their walk out, the maintenance foreman kept an eye on his two companions and made sure all three stayed together.

Cokedale

The workers from 8 Face Parallels apparently kept up an almost constant stream of communication. At first, conversations were directed toward assuring each other that nothing much was out of the ordinary:

> The dispatcher started calling us, and...said that they had detected some smoke and that we should come out. Well, this isn't real uncommon because...belts or something might burn off a pump or...you can get a hot hanger once in a while. So at that point we really weren't all that concerned.

People's tendency to treat a nonroutine situation as normal until it is no longer possible to do so is a well-documented phenomenon [McHugh 1968]. This fits well with the notion that human beings have a predisposition to impose order on their world as a way to minimize uncertainty. However, in events needing a quick response, critical time may be lost. This is especially true in cases where there is an effort to reach group consensus before action is taken.

As the escape off 8FP progressed, miners' talk shifted from efforts to normalize their situation and focused instead on a need for cohesive performance:

> The older man...said, "Why don't you guys stay right here, and [we] will take a walk up through and just see if...it looks passable." So those two proceeded to walk—I couldn't tell you how long they were gone...And they came back and they said, "This is definitely the return, and I think we can get through, so we should try it."

To bolster this endeavor, which the workers were unsure would be successful, they used various interpretive strategies [Kaplan and Kaplan 1982]. Chiefly, the men seemed to seek information about their location and progress, even though these actions did not always appear to make sense. A couple of cases in point are the motorman's account of people looking over into old bleeders and the general inside laborer's bemused reaction to an observation that his group was walking parallel to the track. Additionally, however, some individuals imputed expertise they did not have to someone else. For this group, their authority became the general inside laborer, who had once been a boss and who had "worked in those returns off and on."

7 Butt personnel were less distressed during their escape because there was a convergence of formal authority and expertise in the general foreman who led this group out. These workers seemingly devoted more effort to dealing internally with their predicament than in information seeking:

> I felt pretty confident...because I knew [the general foreman] had been up there for a long time walking returns and this and that and he was real familiar with this area.

Having someone in control, as they did, enabled group members to pose alternative scenarios based on properties of individual cognitive maps:

> If I would have been left to my own devices, I knew that I could have made it out following the track.

This activity undoubtedly had a calming effect on the person, but may also have helped each worker establish a better grounding in relation to his environment and how it could be negotiated.

Both groups, in essence, utilized strategies that differed according to their circumstances. The 8 FP group focused more on information exchange and a search for authority; the 7 Butt group tended to deal "intrapsychically" [Kaplan and Kaplan 1982] with the situation that confronted them, getting their heads straight by talking to themselves. In this event, the effects of social dynamics can be seen in those coping mechanisms used. It is thus arguable, given these divergent patterns of interaction and reaction, that individuals' conceptual content was shaped by their shared experience. Such a notion takes cognitive mapping and wayfinding beyond the psychological domain and situates it within a broader social science perspective. Also, this paradigm focuses on group effects rather than positing personal differences as a variable of interest.

Discussion

What can be gained from introducing a diverse level of analysis to the problem of wayfinding? First, it opens up a new realm of possible questions and answers. As Simmel [1971] pointed out, each level of the social world provides valid insights, but can only be understood in terms of its own unique rules of evidence. Second, since the escape behavior discussed above clearly took place in a group context, an individual differences approach would lack explanatory power when applied to wayfinding in that situation. Clearly, broader analysis is needed in relation to these mine fires. By considering the cultural and social milieu of cognitive mapping and wayfinding behavior, social scientists will be able to more readily explain how people in crisis go about deciding what to do next when more than one person is likely to have input into the decision.

Several key points about wayfinding and cognitive mapping have been raised in this chapter. First, the way human beings make sense of their environment is, according to some theorists, socially mediated. In other words, people's definition of even the most taken-for-granted elements, such as time or distance, is a result of group consensus. Thus, mental maps are not wholly idiosyncratic constructs. Second, cognitive mapping is a dynamic process. The map one has in his or her mind can be acted upon by forces both internal and external to the individual. As a wayfinding tool, then, a cognitive map acts mutably rather than in some mechanistic fashion. Personal decisions about a best course of action are therefore more problematic than they have sometimes been portrayed as being. Third, it has been suggested that some settings in modern society may be characterized by a sameness of cognitive maps. This would help to ensure predictability in situations calling for close coordination of action. Finally, wayfinding is a spatial problem-solving activity in which factors external to the individual (such as ecology and interpersonal relations) have a significant impact upon outcomes.

The purpose of applying certain theoretical notions to real-world problems is to attempt a better understanding of some empirical phenomenon or phenomena. In the present case, the issue to be understood is how workers go about moving from one point to another in a mine fire. The approach used here should be highly generalizable, however. It is hoped that in the future, more attention will be paid to those intersubjective factors once thought to have little bearing on such "intrapsychic" processes as cognitive mapping. Social scientists may benefit from new avenues of inquiry. In addition, planners and engineers would almost certainly gain by having a deeper understanding of what variables motivate the behavior of those who inhabit their structures.

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CHAPTER 9.—LEADERSHIP IN ESCAPE FROM UNDERGROUND MINE FIRES

This chapter explores leadership behavior in a life-threatening situation—fire in a coal mine. Previous chapters have discussed the database of interviews with miners who escaped from underground fires. Researchers raised questions such as: (1) Who led the miners out of the mine? (2) Did leadership make a difference in the escapes? (3) Was the escape leader the hierarchal leader? (4) What, if any, characteristics did the escape leaders possess? Subsequently, researchers analyzed the mine fire database from a group interaction perspective to address the leadership questions posed.

Leadership has been one of the most researched topics of human behavior in the twentieth century. Studies have ranged from individual characteristics of leaders, to situational leadership, to interaction of leader and follower, suggesting different leadership techniques for different followers. The question that emerges here is: Are there different types of leadership that "fit" different kinds of situations? In a crisis situation like that examined in the present study, such information about leadership may significantly improve the chances of escape.

To address these issues, the study team looked at the formal authority structure before each fire, considered leadership behavior or lack of leadership during the escapes, and examined those conditions associated with the emergence of leadership. According to Bardo [1978], "Emergent behaviors are those forms of action, and the norms, values and beliefs governing those actions, that rise out of the disaster situation." This chapter discusses previous studies in the area of crisis leadership and examines the emergent behaviors of leaders under duress during the mine fire escapes.

Previous Studies

The research on leadership during emergency situations has consisted mainly of simulation and field studies, with the principal concern being escape from building fires. During the 1980s, Hayashi [1988] created a computer simulation model to evaluate leader behavior in a fire. Although his purpose was to aid in planning for disaster prevention, his findings are relevant because they address the issue of situational leadership in crisis—where a leader changes his or her behavior to fit the situation. Essentially, his simulation model was designed to judge the actions and thinking of leaders. The simulation was tried by 101 subject/leaders 4 times each. The simulation consisted of a maze containing the leader, an informal leader, and 50 evacuees. Interestingly, the results indicated that the leader's actions were *not* dictated by circumstances. Any differences in behavior were attributed to the *individual characteristics* of each leader. The study also showed that the worse the situation became, the less individual differences emerged. Hayashi thus concluded that an evacuation plan should not be based or rely on circumstance, but should consider the anticipated behavior patterns of leaders.

Sugiman [1984] and Misumi [1988] conducted field tests comparing two evacuation methods: the Follow-Direction Method and the Follow-Me Method. The studies took place in an underground shopping mall with volunteer escapees and confederate leaders. In the first method, the leader indicated the direction of the exit in a loud voice and by bodily gesture as he moved toward the exit. In the second, the Follow-Me Method, the leader told a few evacuees to follow him and then actually proceeded to the exit. To make the evacuation more complicated, two exits were set up, one not visible from where the evacuees were located. In addition, the lights were turned off and a siren sounded for 20 seconds before evacuation.

In the first study, the researchers found that the Follow-Me Method evacuated people more quickly than the Follow-Direction Method, because a multiple number of small groups formed around each leader. A followup study focused on leader-evacuee ratio, presuming that the formation of groups would be different if there were fewer leaders. It was concluded that when each leader had a small number of evacuees (a 1:4 ratio), the Follow-Me Method was more effective than the Follow-Direction Method. With fewer leaders and a large number of evacuees, e.g., a 1:8 ratio, the Follow-Me Method was not effective because the instructions from the leader did not reach every evacuee.

Misumi and Sako [1982] analyzed leader behavior in emergencies using a laboratory simulation with one confederate leader and four naive subjects. Results showed that if the leader first attempted to reduce tensions and then indicated the direction to take, the subjects followed more closely than if the sequence of behaviors was reversed. These authors concluded that panic is reduced by introducing appropriate leadership.

Hodgkinson [1990] noted that panic typically influences behavior in fires. He defined panic as nonsocial, blind, irrational behavior. His research into almost 1,000 fires, however, found that most people acted appropriately; a mere 5% behaved in such a manner as to increase risk. Johnston and Johnson [1988] studied the behavior of workers in the 1977 Beverly Hills Supper Club fire in Kentucky. They supported Hodgkinson's work in the conclusion that panic is not "automatic" in a disastrous fire and that groups can indeed adjust to meet the increased demands of a crisis.

Sime [1983] noted that most models of escape behavior support the panic model of "every man for himself." The panic model says that people will revert to highly emotional, primitive, self-preservation behavior. Researchers generally have concluded that individuals will panic and try to save themselves at the expense of others *only* when a situation is *extremely threatening*. The panic model "assumes that escape will involve a homogeneous population of individuals concerned with self-preservation, competing with each other for limited exits" [Sime 1983]. An alternative model studied by Sime focused on affiliation behavior during escape from a building fire. His affiliative model predicts that "individuals with close psychological ties will attempt to escape in groups of two or more" [Sime 1983]. The affiliative model predicts that in life-threatening escapes individuals will be concerned not only with self-preservation, but will experience a heightened concern for other group members.

It is clear that there are two different schools of thought on group interaction in crisis—*panic*: "every man for himself" versus *affiliation or attachment*: "united we are safer." During a simulation study [French 1944, in Sime 1983], subjects were left in a room and after a short period smoke was leaked into the room. The results showed that organized groups of sport teams responded more quickly to the appearance of the smoke than unorganized groups. The presence of other people, and the type of group threatened, influences responses. Further, it has been suggested that attachment or affiliative behavior has survival value [Bowlby 1973, in Sime 1983]. The function of attachment behavior is in gaining proximity, and consequently, protection from the threat.

Sime studied the 1973 fire that occurred at the Summerland seaside leisure complex in the United Kingdom. Of 3,000 vacationers, 50 died when a fire, started by 3 boys playing with matches, engulfed the solarium area. Five hundred accounts of the event were collected by police. In analyzing the data, Sime targeted four areas: group membership, attachment at cue (cue: signal of the fire), nature of cue (example: ambiguous, unambiguous), and affiliation at exit. The results strongly support the affiliation model. Sime concluded that:

> In an entrapment setting people maintained as far as possible their ties with close relatives during escape. In normal evacuations people are likely to maintain primary group ties. These psychological ties will become even more important rather than disappear in a fire emergency.

Kelley et al. [1965, in Sugiman and Misumi 1988] demonstrated the importance of the emotional aspects of panic. Subjects were placed under a time pressure and could avoid an electric shock by depressing an escape switch which only worked if other members of the group were not pushing theirs. The researchers showed that a sign from one or more subjects indicating they would wait for others to escape increased the number of successful escapes for the group, i.e., cooperation increased the chances for effective escape. Hodgkinson [1990] recognized that the interaction among people is important when there is a choice of exits because people tend to follow the route others are using.

Familiarity behavior in disasters seems to extend beyond affiliation and escape routes. Johnston and Johnson [1988] hypothesized that disaster roles assumed by individuals within an organization are extensions of the ordinary, everyday roles they normally perform. Johnston and Johnston were interested in what organizational roles could be expanded to include disaster-related responsibilities. They concluded that the routine roles of individuals were extended in a crisis and thus the social order was maintained. Canter [1990] echoes this thought: "The social behavior and cognitive processing of individuals stays remarkably close to what can be seen in ordinary, daily behavior." Thus, familiarity with organizational roles affects the ability to survive.

Abe [1976] analyzed the behavior of survivors and victims of a fire in a department store in Japan. He discussed three behavior patterns each, of survivors and victims. The analysis concluded that survival behavior can be more effective with prior knowledge of an area. The research also found that people often return to the familiar and to habit in times of crisis (e.g., they will return to a familiar area). This supports Sime's finding that the tendency of individuals and groups to head towards a familiar route is likely to increase during fires. Abe noted that, in a crisis situation, people lose flexibility. In addition, Abe found that in an unfamiliar place, under dire circumstances, many subjects decided that the only and best thing to do was to follow the person in authority. In this particular department store fire in Japan, this was an unfortunate decision that resulted in the deaths of many subjects.

Although the majority of research has been on individual behavior under stress, with group interaction as a secondary research focus, there is some information on what happens to formal organizations versus small groups under stress. Driskell and Salas [1991] suggest that organizations under stress tend to centralize authority. Decisions move to the upper levels of the hierarchy. A study of small groups under stress, however, found the opposite phenomenon: the group leaders and group members became more receptive to information from others.

The research on the concept of leadership is vast. As Warren Bennis noted, "Of all the hazy and confounding areas in social psychology, leadership theory undoubtedly contends for top nomination. And, ironically, probably more has been written and less known about leadership than any other topic in the behavioral sciences. Always it seems the concept of leadership eludes us or turns up in another form to taunt us again with its slipperiness and complexity [Smyth 1985]."

Holsti [1990] wrote a chapter on crisis management in the book *Psychological Dimensions of War*. Although the focus situations of the text were political crises, not natural disasters or fires, Holsti's observations about leadership in crisis are a propos to further understanding the leadership concept as it applies to escapes from mine fires. The author cites observations of leaders in action that "appear to confirm the conventional wisdom that in crisis decision-making, necessity is indeed the mother of invention." In the mining industry, most underground workers can attest to the necessity of "invention" on a daily basis in their dangerous work environment.

In a study on perceptions of leadership traits, Morris [1991] compared adolescent and adult leaders. He concluded that "integrity and knowledge or skills, are traits of leadership highly valued" and that "effective leaders have positive identities." He characterized them as self-assured, self-actualized, honest, open, and trustworthy. Another valued trait was knowledge or skills. The adults in this study considered consistency and flexibility important components of leadership, a finding that suggests a practical, pragmatic, and realistic approach to problem-solving situations.

In conclusion, the research on leadership during crisis has shown that (1) the importance of studying leader behavior patterns [Hayashi 1988], (2) leaders can have a calming influence and be instrumental in helping others avoid panic [Misumi and Sako 1982], (3) panic is not automatic and indeed individuals have a tendency to follow the prevailing social order [Hodgkinson 1990; Johnston and Johnson 1988], (4) people tend to follow the routes of others and familiar paths [Hodgkinson 1990], (5) attachment/affiliation may have survival value [Sime 1983], (6) cooperation contributes to successful escape [Sugiman and Misumi 1984], (7) people lose flexibility in life-threatening situations [Abe 1976], and (8) information/knowledge can be significant to survival [Abe 1976].

Finally, it is important for the reader to recognize that simulation exercises on human crisis behavior raise ethical issues. Exposing subjects to the threat of electric shock, or an appropriate degree of threat to evoke the panic and fear necessary for accurate data collection is a concern in this type of research. Furthermore, disaster circumstances are unpredictable. Subjects who have faced some type of threat subsequently must be questioned carefully because of the possibility of emotional trauma coloring their responses. In analyzing the data from the mine fires, researchers focused on the behavior and characteristics of leaders from the view of the survivors, official reports, and circumstantial data evaluated after the event.

Profile Characteristics

In the three mine fires studied, there were eight groups of miners that escaped. For each group, a profile of leadership in crisis emerged from the analysis of the eight mine fire escape scenarios. The data suggest several characteristics based on the behavior of the leaders. The leader of each escape may be described as an *aware, knowledgeable* person or as an individual who is alert to his environment, attentive, and discerning. Typically, this person notices details—more so than do other people. The researchers believe that this quality of discernment probably is not limited to the mine environment or to crisis circumstances, but is a typical characteristic of these individuals in all circumstances. Such persons may also excel at incidental learning. Each of the leaders retained information that was instrumental to the escapes. They "remembered" specific details and repeatedly referred to the fact that they "knew" what they were doing through information or deduction.

A second generally shared characteristic of the leaders was the manner in which they took charge. In groups where the regular authority led workers out of the mine, leadership was a natural evolution of group dynamics. It was a continuation of the social order before the fire. A similar dynamic occurred, however, in groups where a definite leader emerged. These emerging leaders did not "muscle in and take charge"; the leadership *developed in a natural way*.

Third, the leaders were *decisive, yet flexible.* They made decisions; yet if circumstances changed they adapted.

Fourth, leaders were *open to input* from others. There is evidence that in most of the escape groups there was a "second lieutenant," an individual who offered worthwhile suggestions, support, and who served as a "sounding board." In instances where there was emergent leadership, the leader usually began in a consulting function to the regular authority.

Fifth, effective leaders seemed to have a *calming* effect on their group. They were aware of others' fears and offered reassurance when it was needed. Miners in each group had *confidence* in the leader's ability to direct them to safety. Finally, there was a *logic* to the leadership. Decisions were appropriate and congruent with available information.

Findings

Each of the group escapes was unique, but some consensus crisis leadership characteristics emerged. Technical descriptions of each of the eight escapes are contained in appendix A. Specific details relative to leadership issues are discussed and supporting evidence for the profile addressed above are organized according to section and mine.

1 Right - Adelaide

This group was a production crew with a new section foreman who was unfamiliar with the affected area of the mine. In fact, the night of the fire was his first night back in the mine after a 5-year absence. In addition, at least three members of the crew were new to the section. While each of the new members had many years of experience in mining, all had been assigned to this crew for only 3 weeks.

The foreman, although the authority figure, did not lead their escape. His behavior was initially appropriate in that he assembled everyone and called the dispatcher with a proposed escape route. He also called back to the dispatcher when the escape route was changed. As the group entered heavy smoke, the foreman simply did not have the knowledge base to make appropriate decisions.

The group was accepting of the foreman's inability to lead in the situation because it was obvious he could not possibly have the appropriate information on his first night back at the mine. The miner operator from the section gave his view: "The boss, I can't blame the boss. This was the first time he was on the section in 5 years." A utilityman from the section expressed a similar sentiment: "It wouldn't have been [the boss's] fault, it was [his] first day in the mine."

It was also clear the crew was protective of this authority figure:

> I'll say he [the boss] did all he could. He did the best he could. He led us, you know, to the fresh air escapeway. He made sure we got through into the return. But as far as being well-versed in the mine, I don't know. There again, I'd really rather not have to make a statement.

On the night of the fire, a former fire boss was working as the continuous miner helper on this section. The position of fire boss had required him to travel throughout the mine, thereby becoming familiar with the mine layout, including the escapeways. As the group's escape progressed, this former fire boss emerged as the leader. Interviews with other members of the group documented this leadership. The former fire boss began his emergence as leader by consulting with the authority figure, the section foreman, making suggestions and advising on alternative actions. The fire boss viewed himself as working *with* the foreman. When directly asked in his interview who led the group out, he responded that although probably the other members of the group would suggest he did, actually he and the foreman led the group out. A bratticeman indicated that the fire boss "was saying what we could do" and the foreman was "like making the decisions." When asked if there was any confusion among the men about leadership, the bratticeman said, "It was pretty much follow [the fire boss] and the boss."

After sizing up the situation, the fire boss suggested that the group might escape by traveling through the bleeder entries to Peterson Shaft on the other side of the mine (see figure 2.1). This suggestion was not accepted by the group, and he chose not to push the idea. Instead, the fire boss explored other possibilities with the group. His behavior at this point indicates decisiveness and flexibility of thinking in crisis. The fire boss said:

> You know, I was thoroughly against going down it. But like I said, I knew, you know, I wasn't going to go by myself down there. If I'd have had to, I would have. If I'd just been by myself, I would have went across. But I knew half them guys would want to walk right into a bleeder. I knew they would...and so I stuck with the guys.

In short, the fire boss tried to get the miners to go deeper into the mine to explore another exit, but because they had only one frame of reference—to "get out"—they could not conceptualize going farther into the mine. The continuous miner operator said "[the fire boss] wanted to go back but nobody said, yeah, let's do that. I think their main concern was, let's get out."

At this point, the group entered the left return airway of the section. Just after getting into the return, the fire boss had trouble with his self-contained self-rescuer (SCSR) and told the group to go on ahead, figuring that they would know where to go from there. A few moments later, several members of the group got lost by following reflective markers they thought led to an escapeway, but in fact marked a bleeder entry examination route which led to another part of the mine. The fire boss had to reassemble the group and told them:

> 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...I told them, ignore the reflectors, because you are going to get lost.

This advice is an example of this leader's awareness of the mine environment.

It was clear by the conclusion of the group's escape that the fire boss was in charge. When one miner did not come out into fresh air with the rest of the group, it was the fire boss who said "we will go back for him" and went back into the smoke with two other miners to look for their missing buddy. "You couldn't see nothing...They [two other miners] said they wanted to go back with me. So we went back." Because of the thick smoke, the fire boss told the two miners with him to hang on to a water pipe as they worked their way back to where they believed their buddy became lost. At strategic locations, the fire boss positioned the other two miners with him so that they would know where to make turns to get back out. Again, he took the responsibility of leader, utilizing his knowledge and giving directions. Everyone in this group successfully evacuated the mine, even though the missing miner followed another route of travel with which he was familiar.

2 Northwest Main - Adelaide

This group, a production crew, was alerted to the fire, gathered together under the foreman's direction, and rode the mantrip until they entered heavy smoke. At this point, the foreman decided to take the crew back to the section and over to the intake escapeway. As they proceeded out the intake escapeway, they encountered smoke again. The foreman then led the crew into the right-side return aircourse, which was also the secondary escapeway. Again the crew encountered smoke. At this time they donned their SCSRs and proceeded out of the mine on foot through the return escapeway. This crew epitomized the value of correct procedures in evacuation and basically escaped without incident. A bolter operator from the section summarized the group's experience:

> We were about as organized as you're going to get. We did real good. We have a mine rescue man that's been on mine rescue for years. He was with us. He's our buggyman and we had the boss and the mine rescue man set it up, the boss in front, he was in the rear. The crew was in the middle. Worked fine, no problem at all.

The authority figure, the section foreman, was the leader and worked with the "second lieutenant," the individual with mine rescue experience. The crew viewed "the boss and the other guy" as the leaders, and the two men saw themselves as working in tandem. When asked who made the decision to put on the SCSRs when they ran into smoke the second lieutenant answered:

> Well, like I say, ...maybe we hit it together, simultaneously, let's say, hey, ...we got to get these people on their oxygen now!

The only problem this group experienced occurred when the miners put on their SCSRs. One miner felt his SCSR was not functioning. The leader dealt with this problem by offering to trade SCSRs. The continuous miner operator described the situation:

> That one guy was nervous. He didn't think his worked right. I remember the boss saying, well, do you want mine then? Because there was nothing much the matter with it. He was just being nervous.

Another man became panicky when his rescuer also appeared not to work. The second lieutenant calmed him, blew into the apparatus to start it, and said, "It's just like kissing you, you old bastard." The leader also made the group slow down so that they did not need as much oxygen and would not overwork the apparatus. A bratticeman described his experience:

> And it seemed like the harder you used, you know, it seemed like you wasn't getting the right amount of air out of them. But then [the boss] said, just slow the pace down.

This knowledge of the operation of the SCSRs and consequent adaptability of behavior is a quality of an *aware* individual.

The leader's behavior also had a calming effect on the crew. This calming was evident in the interviews with the subjects from the group. When asked if the group stopped along the way, several miners commented:

> Yeah, we stopped different times—one guy fell down. I pulled him back up. He fell down. He was a little red and hysterical there a little bit of the

time. And we stopped and the boss talked to him and calmed him down. We stopped periodically, if anybody was having problems. We'd stop and check. Not long, but long enough to talk and see where to go and calm down.

And like I said, the boss, between him and whatcha-call-it, he more or less kept everybody level-headed, you know, like, well, at least not have no panic and everybody take off, you know.

The boss said, "We got to put these (SCSRs) on fellows. This is no drill. Put them on but everybody stay calm, and we'll just take our time and we'll walk out. We'll be all right."

We all stuck together real well. You know, if I got too far or [the miner who] was with me, he'd get out in front of me and if we got too far, the boss or somebody just said, take a break and the one guy was having trouble and he said you know, that he needed to rest some and we just stopped and rested with him.

The leader of the group who was also the authority figure was decisive, logical in his leadership behavior, had a calming influence, and was knowledgeable. All members of this group evacuated the mine without undue difficulty.

3 Left - Adelaide

Most members of the production crew making up this group had been working together for some time. There were three new members on the section the night of the fire, but each was an experienced miner who had worked in other sections of Adelaide Mine. A utilityman who had been with the crew since the section was started noted:

We had some people come and people go, but the majority had been together for at least probably 2½ years.

Despite their history of working as a crew, these miners did not escape as one cohesive group. Instead, they spread out forming a fast subgroup, a slow subgroup, and by the end of their evacuation there were two miners in the middle.

After learning of the fire, the section foreman warned the crew and they gathered at the dinner hole. At this point, most of the miners did not think that they were in danger:

> That did come up, how it (the belt) could catch fire when it wasn't running. You know, but still that hasn't sunk into us that it was burning that hard.

In contrast to other groups where the foreman attempted to calm the miners during the escape, this foreman tried to impress upon the group the seriousness of the situation. According to the utilityman:

> The foreman said, "Hey, look, this is serious shit. You know, we got to get out of here." And then everybody started saying, well, maybe it is burning that hard. But it was still hard to believe it was.

The crew began their escape by traveling outby on the mantrip. When they encountered smoke in the track entry, the miners got off the mantrip, distributed the SCSRs, and planned on going into the intake escapeway. At this point, some miners "took off" and the group began to separate. One miner commented:

> They started passing the self-rescuers out and everybody just started taking one and that's how...we got spread out.

The front group saw themselves as leading the way:

> So we were more or less in the front, leading the way and the foreman was back with some of the other people...We were the ones that were picking the escapeway out.

When the miners hit smoke in the intake escapeway, they moved to the right return aircourse which was the secondary escapeway, but still had to contend with heavy smoke. The crew continued down the return and crossed one overcast. At a second overcast, the group experienced fear beyond that of any other escape group:

> I was the first one there. I had like one guy on either side of me, walked up there to the overcast and I stepped right into it. And it was like a black wall. It was like burning fifty tires and trying to walk through it... And I said we can't go that way. So we walked out and there was some—I know there was doors in those overcasts. I said, the intake's here someplace. All we've got to do is find it. And you'd open up the door and it'd just billow out; and you'd open up another door, and it would billow out. And that's when we had a little team meeting; that's when people really started getting tight. It was like, which way do we go?...And I remember asking the foreman as we opened up the door, it

> looked like it was a black river running by. That's how thick it was. And I said, "Was that the intake?" He said, "Yeah," and—it's not real registered in my head—I remember, "It can't be! It couldn't have burned through already!"

The amount of smoke in the intake and other aircourses led the miners to believe that all exits were blocked by fire. In this case, knowledge about the mine and its ventilation patterns hindered rather than helped those miners with this information. It was later discovered that a door had been left open and the smoke was not following the usual mine ventilation pattern. At the time of their escape, however, the crew had no way of knowing this and logically assumed the fire was blocking all exits.

The group then walked back into the mine, toward the faces, searching for a door into another entry. Near the mouth of the section, the miners in the became lost. The miner operator said:

> We got confused and started going back into the section till we run into the first door and we just made a complete circle and come right back to that main overcast again.

It is important to note that the boss was not in the lead when the group got lost; the group in the front had gone off in the wrong direction.

The crew stopped, realizing that they were lost. The foreman probably figured at that point that the fire was between the crew and any chance of escape. With a door left open, the smoke was entering areas of the mine that "made no sense." In this situation, the foreman's knowledge of the mine confused him because seeing smoke in the return indicated to him that the whole mine was on fire, or at least fire was blocking all of the exits. It appears that this analysis made him too upset to make a clear decision on the direction to travel. The miner operator yelled at the foreman, telling him to calm down so that he could think about their escape:

> Then I myself told the boss—I said, "[Boss], get your composure and get us the hell out of here. We're all scared you know."

The miner operator continued, explaining that at this point the section foreman pulled himself together and demonstrated his knowledge of the section and his awareness of his surroundings, saying:

> "This pile of dirt shouldn't be here." I think he said right or left—I don't remember—but he said, "This pile of dirt shouldn't be here."

This information was all that was needed to point the group in the right direction.

After getting back on track, the front subgroup took off again. The section's utilityman seemed to take charge of this subgroup to some degree. He was the individual who initially asked questions and made suggestions ("Can't we do this, can't we do that?") and potentially could have filled the "second lieutenant's" role, but did not. Instead, this person went with the faster miners and left the foreman and slower people behind.

As mentioned before, the front group saw themselves as leading the way. The slower group, however, did not see it that way. The miner helper said:

> I told them come on, why don't you guys wait for...One of them said, "This is every man for himself." People were scared, do you know what I mean?

One of the bolter operators commented:

> Everyone was together. Then when we got to the return, why someone just took off, you know, never waited on anybody. They panicked and got scared. That's the worst thing in the world to do. Everybody should stick together.

Toward the end of the escape, one of the roof bolter operators was having a great deal of difficulty and the slower group stayed behind with him. The operator's buddy described what happened:

> I was the last one in line and [the bolter operator], I don't know how old he is, he's probably between 55 and 60 years old. I don't know, but I could hear him starting to have trouble breathing in his device (SCSR). And it sounded to me like he was hyper-ventilating himself. He was trying to out-breathe the device. That's what it sounded like to me. I talked to myself, this man is going to go down and when I started to think that he did go down. He fell onto the ground and I spit out my mouthpiece on my unit and I hollered as loud as I could, I need help here. This man's down. Only two people came back. I said there was either 9 or 10 of us going out in a single-file line and I was the last and I hollered as loud as I could and only two people came back. That was the boss and [another miner].

This splitting of the crew resulted in two miners finding themselves in the middle, between the faster and slower groups. Neither heard the bolter operator call for help and did not know a man was down. These miners continued on, as did the faster group, unaware of the problem behind them. All of the miners eventually continued out to fresh air.

The section foreman, the authority in the group, started out in control but eventually lost it and never recovered the authority position with his group. The utilityman characterized the foreman as:

> Excitable...yeah...but he's not to the point of panic or anything like that. He still keeps his composure about it but he's kind of a high-strung guy. That would be more of a term to put on him.

Continuing later in his interview, the utilityman said:

> I do remember the boss was quite excitable and I remember the miner operator telling him, "Now, you're a foreman. Get your shit together. Now where the hell are we at?"

Instead of any one person fulfilling the role of leader, various members of the group displayed some of the characteristics of a leader. The foreman took control of the situation initially and used his knowledge to get the group back on track after they had become lost. The utilityman seemed to assume some leadership of the faster subgroup and directed them to don their SCSRs. When the foreman seemed to be losing his ability to make logical decisions, the miner helper calmed him down. At another point, one of the bolter operators took the lead and went to explore the way over an overcast. A bratticeman on the section that shift, one of the two miners in the middle, assumed the role of assisting the other, who was older and having some difficulty.

The dynamics of the escape for this group were foreshadowed when the SCSRs were distributed and people simply took off. One group member explained the lack of discussion saying:

> Our crew, most of them have a good bit of time in the mine and it was just—as soon as we run into smoke, that was the first thing everybody thought, get into the escapeway.

Throughout the escape, no one person was looked to as the leader. When queried as to who was making the decisions, the miners of this group provided various answers, resulting in no consensus.

4 South - Brownfield

This group consisted of a production crew plus a mine inspector who was in the section the day of the fire. The authority figures in this escape group were the section foreman and the mine inspector. As it happened, these two individuals knew each other and jointly led the escape. The section supplyman commented:

> The boss and the inspector was there, and they were discussing which way to go—which would be the best way to get out. So they decided it would be down the belt. We all went down the belt.

This group, like the 3 Left crew at Adelaide Mine, had a split escape but with dynamics and leadership characteristics dissimilar to those of 3 Left crew. The major problem in the faster group, led by the foreman, was with breathing through the SCSRs because they were moving so fast. The slower group, led by the inspector, had a miner who experienced breathing problems and was continually falling down. Toward the end of the escape, he fell a final time, was left behind by the other miners, and was later rescued.

The foreman felt and assumed responsibility for the men but was strengthened by the support of the inspector. An indication of how well the two men worked together is found in both of their interviews. The inspector, when asked who was in charge, replied:

> I didn't feel like I was in charge, [he] is the section foreman but anything either of us said or did, I've got a lot of respect for [him]. I know [him]. Anything he said I didn't question. Anything that it appeared I said, he didn't question and anything that either of us said wasn't, like I said, there was never once any talk. Even when it came down to who's going to go with the fast men and who's going to go with the slow men, there was never no discussion. It was just one of us said what we'll do, and we did it.

Commenting on his leadership role, the section foreman noted:

> Well, I'm responsible for them. I didn't want them splitting up. I was glad the inspector was there because I felt he's going to watch these people and I'm going to watch the other group...I wanted to stay in the back and know where my people are. That was my first concern. I just didn't like the idea, but didn't want them taking off the way they were. I was afraid, you know. I can't sit on them.

The above explanation documents that the foreman was decisive, yet flexible. During the escape, some of the men began to take off and the foreman was concerned, yet aware enough to know how frightened the men were. The inspector understood the dynamic too, and although against accepted "evacuation policy" of not splitting up a group, considered the decision to allow the faster men to go ahead with the supervisor.

The manner in which the inspector, who functioned as the "second lieutenant" in the group, communicated the fire to one of the crew is evidenced in the following comment from a bratticeman:

> So I started to pick up my tools. He [the inspector] said, "leave the tools behind, don't worry about them, let's get out of here," and with his advice and his quickness and alertness, I became aware that it was serious.

Initially, some of the miners took off immediately ("they ran like deer"), but were stopped by the supervisor who "made them wait till everybody was there so we had everybody before we started." Both leaders responded calmly.

It is interesting to note the behavior of the inspector when the man in the slower group continued to fall:

> I know at one point...I said let's stop and take a minute and the man is sitting there and the mechanic was still with us and I recall looking at my watch, and I thought we had been under oxygen, I believe, it was 20 minutes at this time and I knew we still had a ways to go.

The inspector was continually evaluating the situation and reasoning alternatives, similar to the other group leaders. This same individual made a prophetic observation when the men were first putting on their SCSRs:

> I looked around to make sure they were starting to put theirs on and when I looked over and saw the bigger man—that's about the first time I started getting a little worried because he was shaking somewhat severely, his hands were, you know, very noticeably trembling and I just thought to myself, "Oh, boy." I said, "I think we are going to have trouble because he's having a hard time."

This miner was a large man who weighed in excess of 250 pounds. When he went down the final time, the inspector was in a serious dilemma:

> I don't recall how far, but I know I was struggling with this man and I know he was making me tired and I hadn't had any problem up until

> this point but when I looked down, I realized the bags in my SCSR were flat and I know here again I thought, boy, there was no discussion about it, but the section foreman and those other guys, they're probably way ahead of us by now and here I'm back here with this guy and he having all this trouble and now I'm having trouble breathing and breathing was getting harder and harder. I didn't think to look at my watch, but I didn't know, had I exhausted the machine (SCSR) or was I running the same problems as this man? I was using more, you know, demanding more out of the machine than it was giving. I knew I was working a lot harder now and I started getting concerned about that now too and I guess we continued. I continued with this man. We finally came to a high spot and, like I said, I was still having—I was taking as much outside air in as I was out of the machine...I realized how this man is now because my machine is not giving me air or what, but when we got to the high spot, I knew exactly where we were because from traveling the belt, I knew we were at the intake over where they had cut the overcast for the intake and the man that was having so much trouble, he's down again. He looked at [the mechanic]. I saw him look at [him] and he said, "You guys go. You just leave me here." He said, "I can't go no more." He said, "I'm just going to stay here." I looked at the other guy and I said, "I got to go." I said, "There is no sense in me staying"...I said, "I can't breathe now." I said, "I know where I'm at. I can send somebody back. I'll go out and get somebody."

In desperate circumstances, the inspector continued to follow what seemed to him a logical path. In recounting his story, the inspector noted that although he would like to have thought he was in control, he realized he was not. Each leader had taken an extra SCSR. Although the inspector was running out of oxygen, he forgot he was carrying an extra SCSR ("Maybe I'd taken too much smoke.") This point emphasizes the severity of the situation. The inspector got to fresh air, saw the foreman, and told him of the miner who was down. The foreman said, "He's my boy," and went back in for him. In the meantime, the miner who was down was left alone. The final person who had been trying to assist this miner decided he was:

> Not going to make it, I'm going to try and get out. So I started out and I was only about a hundred foot from [him] when I came through the overcast and I opened the door and I saw No. 7 and I thought, good, this is fresh air, or this is a, you know, the way out...So I thought, "Well, I'm going back in to get [him]."

Actually, this miner was mistaken about his location. However, while he was trying to convince the miner who was down that they could reach safety, the foreman arrived. Together they got the miner going again and out of the smoke. Everyone was then accounted for.

Several leadership questions emerge in relation to this group: Should they have come out together? Should the leaders have insisted on more unity, or had better control over the group to facilitate a cohesive group evacuation? The inspector responded to the inquiry about split groups by stating that there were two individuals who could show leadership and if you have two groups, "don't hinder the one group because of the problems of the other group." Clearly, despite the split escape, there was decisive leadership by both individuals in this group.

5 South - Brownfield

The group, a production crew, was led out of the mine by their section foreman and a roof bolter operator. A shuttle car operator remarked:

> [The foreman] is our boss. He knew—he done right. He got us on the right track and kept us on the right track. Between him and [the bolter operator].

Again, the leadership in this group was basically the authority figure, with the particular assistance of one of the men, a roof bolter operator, but with input of others. This group, after an uneven beginning, ultimately stuck together, even though there were several older miners in the group and one person who had continual difficulties breathing with his SCSR.

After being alerted to the smoke, the crew assembled and began its evacuation. Two miners, both bratticemen, ran ahead of the others in the group. A bolter operator noted that one of the men said at this time:

> "Come on, let's go. We got to get out this way." And he took off. Well, he took off and went down like—and he was leading the pack, okay. When we got down to where the regulator was at and put the self-rescuers on, you know, that's when [the boss] took over. But that's one of the things that I told [him] later on, I says, "You're the boss. One thing you got to do if this ever happens again, you should have a man that's in charge that's going to take his time and walk out of there slow and easy with his SCSR on."

In the course of the escape, the bolter operator assumed the role of advisor to the foreman. One miner explained why the two men took the lead initially:

> See, bratticemen know pretty much what's going on, where everything is at. I'd say the two bratticemen up there pretty much took the lead out—pretty much took us out.

When asked who took the lead in the group, one of the bratticemen said:

> Well, me and my buddy, 'cause we knew everything, every place up there. Some of the bosses don't know their way around, and I've been in that place for eight—near nineteen years.

Both bratticemen felt they had the knowledge to lead, yet they took off, traveling too fast for the group. They were unaware of the needs of other members of the group and the surrounding circumstances. This behavior is not characteristic of effective leaders. In this case, the foreman stayed in the back to assist the slower individuals.

At one point, the foreman left the slower miners to check the mandoors ahead hoping to find clear air. As the foreman opened one door, he saw thick smoke:

> Right then, panic hit, believe me. 'Cause all the teaching and training everything, these are all supposed to be separate splits. Well, the first thing that goes through your mind is everything is burning. In my opinion, there was no sense in even trying to get [out, but] you're still thinking—so I come back.

This leader, although voicing his consideration of giving up when he thought the whole mine was on fire, rapidly moved on to explore alternatives ("you're still thinking").

When the foreman returned to the group, the group members were panicky. He felt everything was out of control at that moment and he knew the group was in trouble. The men had decided that they would wait only 10 minutes for him to return, indicative of the anxiety and the need to "do something".

> I told the guys, I said, you guys want to try to make it over there and before I said much more...the bratticeman said, "We're ahead of the smoke. Let's go." Well, right then—well, everybody seen the smoke here. That's when there was not much control, you know, everybody started just going.

Again the group spread out somewhat, the foreman staying behind with the slowest group members. The section foreman responded when one of the men "took his self-rescuer off and threw it out. [The man] said he couldn't breathe out of it, so I helped him get the little one (filter self-rescuer) off his belt and got it open. He couldn't even open that one, but he got to breathing in it."

The leader of this group made sure everyone was supervised during the escape by taking a position toward the back of the group. He was concerned about the slower men and about someone going down. When the group entered fresh air, everyone was accounted for.

6 West - Brownfield

This group consisted of three individuals, including a maintenance foreman and a mechanic who usually worked together, plus a State mine electrical inspector. The only interviewee from this escape group was the maintenance foreman, who assumed the leadership role. The mine inspector, although an outsider, represented authority and at first exercised that authority. When apprised of the fire, the maintenance foreman initially wanted to ride out on a mantrip, but the inspector said no. When asked about the inspector's reason for this, the maintenance foreman said, "Well, it could cause an explosion he said, for one thing. I mean, we were on the damn thing when he says no."

The maintenance foreman, the authority in this group, went along with the mine inspector until the group hit heavy smoke. He then decided the appropriate escape route and "they never disagreed." When the group encountered the heavy smoke they searched for a mandoor in an overcast but could not find it. The maintenance foreman knew they had to go back and he told this to the other two men:

> I knowed where I was going here in this case, so I mean I knowed exactly where I wanted to get to.

This was an important moment in the leadership dynamics of the group, a natural evolution based on knowledge, logic, and decisiveness. The maintenance foreman continued:

> I mean, the inspector, when I turned around and said, "We got to go back," he says, "No," and I says, "You can do what you want to do, I'm going back." I said, "You can follow me or do what you want." At that point I didn't give a damn who followed me or who didn't. I was getting out of a heavy concentration.

It is interesting to note that the next day the maintenance foreman returned to the area of the mine to find the door; it was there where he "knew" it should be.

The maintenance foreman did not lead thinking only of his own safety. During the entire escape he was attentive to the rest of the group. He said:

> I was in the lead all the while and I mean, I knowed they were in back of me. I mean, if one of them would have dropped back, we would have gone back and got him, or tried to anyway.

This leader had a critical piece of information that none of the other groups had: he knew exactly where the fire was. When the fire boss called to alert them about the fire, the maintenance foreman had asked where the fire was:

> I was the only one out of the guys that knowed where the fire was...and the reason for that is I took and asked [the fire boss] where the fire was.

The maintenance foreman was the only person in all eight groups who knew the exact location of the fire and knew that the group had to travel past the fire to escape. He also knew that the return aircourse was double timbered; there were two rows of posts supporting the roof. He was aware that as long as they walked between the timbers with the beltline on the left, they would pass the fire.

At one point in the escape, this group was passing under an overcast and heard footsteps overhead. It was the crew from 5 South:

> I heard them coming over the overcast, and then I was relieved a little bit because I knowed that boss coming with that crew was real familiar with the mine. I was familiar with it, but not like him.

Knowing that the other crew was going in the same direction increased the maintenance foreman's confidence. The three individuals in this group then continued down the 6 West return aircourse to safety.

7 Butt - Cokedale

This group, under the supervision of a construction foreman, was assigned to relocate a power center on the section. The construction foreman, the authority figure, took charge and led the group out of the mine. Although this group experienced some problems during their escape, the group members never lost confidence in their leader and his ability to manage a successful escape. This individual had set up the ventilation for the section and, according to a motorman on the section the night of the fire, the foreman "knew which way to go...we just followed him 'cause he, he knew the area." A mechanic working in the section said:

> I felt pretty confident though because I knew [the construction foreman] had been up there for a long time walking returns and this and that and he was real familiar with the area.

The construction foreman was aware and knowledgeable as evidenced by the comments of another mechanic on the section:

> We were lucky because we had [the construction foreman] and he just spent a whole, he probably just spent 6 months in that return, posting it and cleaning it up, so we really didn't have any trouble with the return and we basically had enough knowledge of the area.

The leader himself indicated his knowledge of the mine in that everybody:

> Was asking me where we were at, what direction we were headed. And with the information that I had, because the biggest part of this I set up; the ventilation, the overcast and so on, the return escapeway. And I knew first hand, you know what direction we were in, where the mandoors were at.

The group's faith in the foreman continued even when some major problems were encountered early in their evacuation. When notified of the fire, the construction foreman gathered the group together and the crew began their escape in three vehicles: a lead jeep, the foreman's jeep, and a portal bus. When the group encountered smoke in the track entry, they experienced two vehicle wrecks, one of which actually knocked the construction foreman and another miner off their vehicle. In the wreck, the miner lost his hard hat and cap lamp and had to escape without them. This became a problem, since the miner was continually hitting his head against the mine roof on the way out. In addition, this miner pulled the SCSR that he was about to don out of its carrying case. The SCSR could not be reattached to the case, resulting in the device having no carrying straps. To help this miner carry the device, another miner used electrical tape to fasten the SCSR to his buddy's chest. Since SCSRs tend to get very warm with use, the miner also had to contend with this discomfort.

During the escape, the construction foreman remained aware of the condition of others in the group and responded to a miner who was having trouble with his SCSR. When the construction foreman said to put on the SCSRs, a wireman said:

> I was like shakin' like a leaf, couldn't get the damn thing open. And he finally come up to this control and said, "Here, pop this, stick this in your mouth."

It is of interest to note that, whereas in some of the other groups there was a "second lieutenant," in this group the construction foreman was totally in charge:

> I was a foreman in charge of that area, and when I said to these people what we had to do, there was no second-guessing my decision. These people were counting on my knowledge that this was right and there was no second-guessing it. I had no problem with these people as far as my decision...I didn't ask for information or input from anybody else. That was my decision that we were gonna take this course to get out.

The foreman was authoritarian, but did not act as a dictator; he told the group the what and why of his decisions. He remarked:

> I think that once they knew where they were, the direction that they headed, where they were going to come out at and get into a fresh air area, it kinda eased their minds as to knowing. Basically, they knew how long it would take to walk to these different locations and they knew that there would be communications to the surface at these locations. And it pretty much eased their minds.

Leadership of the group was decisive, informed, logical, and confident. All group members safely evacuated the mine.

8 Face Parallels - Cokedale

This group was not normally a working group, and none of the members were involved in coal production. Members of the group typically performed maintenance or support tasks and were doing construction work and moving supplies in the section at the time of the fire. In addition, there happened to be two motormen in the section delivering rails when notified of the fire. Normally, these individuals worked on their own across many areas of the mine.

This group was effectively out of control most of the time during their escape. The foreman, the authority figure, was not in control, and there was considerable notation of blame and emotion evidenced in the interviews of this group. The manner in which the group donned their SCSRs was indicative of the lack of leadership. When asked who decided it was time to put them on, a mechanic responded, "Well, I think everybody decided together but, you know, I already had mine on." Another miner said he kept asking, "Should we put these on?" and the foreman never answered. The regular authority figure, the foreman, proved to be a poor leader. As a mechanic described:

> The guys were more or less talking amongst themselves, and I said, "You know, this is real serious and this boss if we're not careful he's going to get us killed."

A trackman with the group was not familiar with the section and became concerned:

> I can understand how people could be excited and you know, improper decisions could be made. But, you know, it kept snowballing. You know, his improper decisions that he was making, you know. I was getting more and more negative about following this man as we went... I'm not saying that I was the only person that was cognizant that [the boss] didn't know what he was doing. I believe everybody had some, you know, at some level had that feeling. But the fear level was starting to rise.

A mechanic remarked:

> There was a lot of confusion...the [foreman] couldn't figure out how to get into the intake escapeway...a lot of the guys started getting kind of real, losing a lot of confidence in him.

A leader who fit the profile characteristics did emerge: he was knowledgeable and discerning, his leadership evolved, and he was responsive to others in the group. The miner who emerged as leader began in the "second lieutenant" position as an advisor. He "knew" based on an odor that there was something wrong. There was an odor and some smoke and he said to another miner, "Turn that machine off, there is something bad wrong here." This miner was acutely aware and noted numerous details while continually processing information. He could "hear that the power center was on," and that confused him.

A general inside laborer (GIL) at the time of the fire, this miner was a former maintenance foreman and knew that the power center should not be on. He was one of the first to recognize the gravity of the situation while the rest of the group were speculating what was on fire. The GIL knew by the amount of smoke that the fire was not just a trolley wire hanger burning. He recognized that the men were getting upset, and as he explained:

> I am a personal friend of [the foreman] and...the situation, I wanted to talk to [him] but I did not want other people to hear what I wanted to tell him because people were getting upset right off the get-go...I was thinkin' of people I can count on...I guess you would say that it was kind of a feeling of if you were in an airplane and you had to count on someone to hold that parachute for you could you count on that person.

During the group's escape, this miner was continually evaluating the situation. A further example of this was when he discussed his concern that the men were struggling:

> If these guys start droppin', there is no way we, the three of us can pick up three other guys and carry them and get through these old workings, there's no way. So then I'm thinking well the next steps we're gonna have to start barricading ourself, that's all.

The GIL told the interviewer that when the group was in the returns in heavy smoke, he was looking for footprints. He knew that the returns had to be walked periodically by the fire bosses who examine the area for hazards. The GIL said:

> When I see footprints I feel better...Somebody was through here already, there is only one set going out. So chances are that if there was a return set of footprints, I would think somebody had to turn around because it's blocked.

This route, in fact, led the group to safety.

The leader of this group was conscious of the behavior of other members and careful in how he presented his advice to them. When some members of the group left their lunch buckets behind, he was concerned.

> How can I say it? Being a foreman for 8 years, it's hard not to say things sometime...I could see things going on that was wrong, especially the discarding [of the buckets]. So I would say, "I sure wouldn't throw that away." I wouldn't say, "Don't throw that away, you don't know how long we're going to be here or what's going to happen."

The statement above characterized this general inside laborer who had once been a foreman. He presented himself as the foreman's helper during his interview, whereas the other members of the group clearly indicated their foreman was inept and that the GIL led them out. He placed himself in a peer relationship with the group and a peer relationship with the foreman. In his interview, the foreman quoted the GIL often and was resplendent with the sentiment: "I should have." At one point the foreman stated, "I plain freely admit, I screwed up."

Discussion

A comparison of the three mine sites revealed no evidence of differences among the sites that would be relevant to this study. There were no appreciable disparities in communication, emergency systems, firefighting response, safety issues, or subject demographics. Leadership in the eight groups thus will be compared across mines without bias.

Among the persons who led each of the eight groups to safety, five of the group leaders were the regular person in charge (usually the foreman) and three individuals emerged as leaders during the groups' escapes. As described previously, analysis revealed consensus characteristics which, taken together, create a leader profile. The individuals who assumed positions of leadership during the underground mine fires fit a profile that included the following characteristics:

- Aware, knowledgeable
- Decisive, yet flexible
- Open to input from others
- Calming influence; gained followers' confidence
- Logical decision-makers
- Allowed leadership to develop naturally

The reasons that leaders emerged other than the regular authority varied in each of the three groups. In the case of the group from 1 Right at Adelaide, it was the foreman's first night on the job. He maintained his authority in the group but was recognized as incapable of leading because he was not familiar with the mine. For the group from 3 Left at Adelaide, there was a split escape and no clear leader emerged. The third emergent leader, found in the group that escaped from 8 Face Parallels at Cokedale, took over when the hierarchal leader panicked and was ineffective in making decisions.

In examining the instances where there was a lack of leadership from the authority figures, two characteristics emerged. First, a lack of knowledge contributed to an individual's inability to guide his group. Second, leaders "lost personal control" and thus heightened anxiety in their groups. As shown in the group from 1 Right, a lack of knowledge did not necessarily result in a loss of authority. A lack of self-control, however, was more likely to have such an outcome. This seems true even though no evidence of actual panic behavior was found in any of the authority figures or leaders.

Throughout this analysis, support was found for the affiliation model of emergency response, as opposed to the panic model. Although there was evidence of "nonsocial, blind, irrational behavior" as defined by Hodgkinson [1990], the study reported in this chapter found that the majority of subjects behaved appropriately and within the accepted social framework. In fact, the social structure was defended, in several instances beyond reasonable evidence to the contrary, an example of which can be seen with the group from 8 Face Parallels. In this group, the members initially continued to turn to the foreman even after he had shown his indecision and evidenced his inability to lead the escape.

The present study supports previous research in concluding that panic is reduced by introducing appropriate leadership [Misumi and Sako 1982]. Effective leadership also increased the likelihood of efficient evacuation. As found in earlier research [Hodgkinson 1990; Sime 1983; Abe 1976], the miners tended to head for a familiar route and/or follow the route others were using. In all cases, the group's first direction of travel and mode of transportation chosen were those used in routine trips out of the mine. Numerous times throughout the interviews, miners mentioned following the person ahead when the familiar route became impassable. When a knowledgeable person was in the lead and the followers had confidence in that person, the evacuation proceeded more smoothly.

Future Research

Are characteristics identified in the profile presented *required* for an individual to fulfill the role of leader during a crisis situation? What if an individual has some, but not all of the noted characteristics? Some individuals identified during this study evidenced several, but not all, of the profile characteristics. Further analyses are needed to determine the fit of these individuals in the group dynamics and their contributions to the successful escapes. Another realm of crisis behavior only mentioned in this study is the influence of leader/follower familiarity on the ability to lead. Is personal relationship in crisis leadership a component of success or failure? Affiliation theory suggests that familiarity influences behavior. However, analyses were not completed to document relationships between leaders and followers prior to their escapes.

This work supports Hayashi's [1988] emphasis on the study of the anticipated behavior patterns of leaders as complementary to the study of the circumstances of disaster escape. Training for response to mine emergencies, and therefore to other emergency situations as well, should consider the likely human behavior tendencies. Perhaps work crews should be evaluated to ensure that at least one person can and would lead the group in the event of an emergency. These potential leaders may, or may not, be the authority figure who leads during routine production.

This research suggests that the quality of leadership shown during these mine evacuations affected the responses of victims and the efficiency of their escapes. Furthermore, a profile was developed based on the actions and words of the most successful leaders. Perhaps these findings can be generalized to other emergency situations. If so, it may be helpful to share the profile with individuals who could be in positions of authority during a worksite emergency.

The profile could be used as a guide for training in leadership development. Another important finding of this work is the need for explicit communication about all facts known during an emergency. In these fires, increased knowledge of the danger allowed better planning for evacuation and for more decisive actions to be taken. Even in very dangerous situations, knowledge of the problem did not cause miners to panic and act irrationally; instead they continued to think and act based on all the information available. It is therefore suggested that training be given to all miners to promote effective leadership and to reinforce the importance of detailed communication during mine emergencies.

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CHAPTER 10.—FORMAL LEARNING FROM ESCAPE NARRATIVES THROUGH THE CREATION AND USE OF TABLE-TOP SIMULATIONS[1]

This book has employed miners' narratives to illustrate basic concepts about the escape process. One of the most powerful means by which people make sense of their experiences is through the telling and internalization of stories [Bruner 1990]. By couching one's own and others' motives and actions in terms of a coherent narrative, a person is able to learn from mistakes and plan future behaviors that may help ensure survival. A growing body of research suggests that decision-making skills used to deal with emergency situations can be taught and assessed by simulations based on narratives from the real world [Bransford et al. 1986; Brecke 1982; Brener 1984; Connolly et al. 1989; Halff et al. 1986; Jones and Keith 1983; Lacefield and Cole 1986]. Such techniques have been used to address the decision-making of medical personnel, civil and military flight crews, and even people involved in broader life events such as political and military situations [Babbott and Halter 1983; Dugdale et al. 1982; Farrand et al. 1982; Gilbert 1975; McGuire 1985; McGuire et al. 1976; Flathers et al. 1982; Giffin and Rockwell 1984; Jensen 1982; Janis and Mann 1987]. Given the validity of this method of study and the promise it holds for helping people improve the quality of their responses to nonroutine occurrences, it is perhaps surprising that there have been no studies of emergency decision-making among blue-collar workers prior to those conducted by the present authors and their colleagues.

The purpose of this chapter is to describe underground coal miners' decision-making performance on a table-top simulation whose problem structure is derived from interviews with a group of eight miners who escaped from the 5 Left section at Brownfield Mine. The exercise was constructed by a panel of domain experts (mine safety and rescue personnel) with the assistance of an educational psychologist. The simulation includes actual predicaments with wise and unwise decision alternatives that, in the opinion of these domain experts, are characteristic of such escapes. Results reported in this chapter are the scores of a sample of experienced mine workers who completed the simulation. Because the exercise is a series of objective performance tasks coupled with detailed and immediate feedback, this simulation can be used to teach and refresh critical escape skills, as well as to provide data concerning the proficiency of miners at the time of exercise administration.

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[1]A revised version of this chapter has been published as: Cole HP, Vaught C, Wiehagen WJ, Haley JV, Brnich MJ Jr. [1998]. Decision making during a simulated mine fire escape. IEEE Trans on Eng Management *45*(2):153-162.

Complexity of Escaping From a Mine Fire

When a fire occurs, miners must make their escape to the surface by seeking out and traveling accessible routes to a mine portal or shaft. The ventilation system that is designed to bring fresh air to the working faces, carrying away methane and dust in the process, now provides oxygen to a blaze that has a nearly unlimited supply of coal. Fires therefore may produce very high temperatures, dense toxic smoke, and, as they burn through stoppings and other ventilation control devices, unpredictable changes in the direction and velocity of fresh air moving into the mine. If the mine atmosphere is oxygen-deficient or contaminated with carbon monoxide, as is often the case, miners must promptly and correctly don emergency breathing apparatus in order to stay alive.

The process of escaping from a mine fire presents myriad predicaments and requires quick decisions in the face of uncertainty. Information about the location of the fire, conditions in the mine at points along various escape routes, and the whereabouts and condition of other miners are often unknown. The choice of evacuation methods may present dilemmas. For instance, riding out on a mantrip can enable a rapid escape but could ignite a lethal methane explosion if there has been disruption to the ventilation system. Walking out may forestall a methane explosion, but would require increased time and effort, and might result in miners becoming lost. When escaping miners make decisions about these sorts of concerns, many of their subsequent actions are irreversible. Furthermore, the outcomes of these actions cannot be known until they are completed. It is evident, therefore, that miners should be prepared to predict as accurately as possible how future events will be influenced by their choices among alternative actions.

Need for Research and Training in Mine Escape Decisions

In a review of decision-making theory and research, Halpern [1984] made the following points: A decision always involves choosing among two or more competing alternatives. Decisions are made in response to a recognized problem. Yet, unlike traditional academic problem solving, real-world decision-making involves dilemmas in which there is no clear "best" solution to a problem. Inadequate or conflicting information about alternatives always exists. Risks are associated with each choice, and these choices, once made, are often irreversible. The difficulty lies in making judgments about which alternative action is best for maximizing gain and minimizing loss. The decision-maker must attempt to predict how future events will be influenced by his or her choices and does so in an atmosphere of uncertainty.

Halpern also noted two additional characteristics of decision-making as determined from empirical studies. First, even highly trained professionals often make errors in real-world decision-making. Second, when teaching decision-making there is a tendency to use case studies where the outcome of persons' choices are known to those who review the case study, and where the choices of the persons facing the problem are judged sound or unsound in light of the outcome (often by reference to some algorithm). However, this type of instruction may be counterproductive, because during the dilemmas faced in real-world decision-making, the choices among alternatives must be made without knowledge of their effects on outcomes. Good decisions depend on inference and flexible use of heuristics rather than rigid application of algorithms based on a post hoc analysis of events.

The information miners are given in their initial classroom training, required annual refresher training, and mandatory fire drills tends to provide little opportunity for them to engage in problem solving and decision-making [Digman and Grasso 1981; Cole et al. 1988a,b]. That is because traditional classroom instruction tends to produce "inert" knowledge rather than "active" knowledge [Bruner 1990; Cole et al. 1988a,b]. Generally, inert knowledge is presented in the form of simple rules (algorithms) such as the following: "At the first sign of smoke, don your FSR and proceed to the [mine evacuation] assembly point." "Remember the location of the nearest cache of SCSRs (self-contained self-rescuers) and when you get to them, immediately don an apparatus." "Stay together at the designated assembly point until your section foreman orders an evacuation from the mine." "Follow the primary escapeway and stay with the other members of your group." "If the primary escapeway is impassable, exit from the mine by the secondary escapeway." "If escape is not possible, find a good place to barricade, then barricade and wait for rescue."

In actual emergency situations, many factors may prevent the simple application of these rules. For example, although miners are drilled that they should all gather at designated assembly points to begin their evacuation, during actual fires some workers are usually missing and do not arrive at the assembly point. In this event, the gathered miners must decide whether to wait for their missing coworkers, conduct a search, or leave without them. If and when all of the workers are assembled on a working section, they must still decide which routes and methods will be used to leave the mine. Miners are taught that they should stay together when they evacuate, but if a section crew is forced to walk out of the mine, the crew members may have to hurry or risk becoming trapped by the fire. Often, travel is difficult because of low seam height, poor footing, and heavy smoke. Because of individual differences in physical fitness, some miners will always be able to travel faster than others, yet the possibility that individuals may fall behind is rarely addressed in miner training classes, or during fire drills in the mine.

When individual differences do enter the equation, what ought miners do? Should the entire group travel as slow as the slowest crew member and thus risk having their SCSRs run out of oxygen, or risk becoming trapped? Should the group split up, allowing the most able to escape, and perhaps get help for their slower coworkers? A confounding factor is that on many mining sections there are only one or two persons who fully understand the complex escape routes out of the workplace. During an escape, when the smoke becomes thick and the crew is strung out along several hundred feet, what can be done to make sure the persons at the front of the line and those at the rear all make correct turns at key intersections of the giant maze that composes the mine?

The rather cut-and-dried rules that miners are usually taught concerning evacuation and escape procedures do not address these types of questions. Consequently, when workers are involved in actual mine fires, they may be ill-prepared to deal with the ambiguities and complex interactions of real-world variables that turn what might appear to be a straightforward escape task into an ill-defined problem.

Utility of Simulation Exercises for Fire Escape Decision Training

Active knowledge that helps workers become better problem solvers can be facilitated by simulation exercises based on actual mine fires and escapes. These exercises are one way to provide miners with more accurate and realistic conceptualizations of escape procedures. Most workers will never experience an escape from a mine fire. Yet all miners need a good understanding of what such situations are like and how the basic escape rules in which they are drilled must always be moderated by the types of situational factors described in the previous section. Well-designed simulations can provide powerful vicarious learning experiences that may better prepare miners to cope effectively with actual mine emergencies. It is for this reason that the training of mine rescue teams, military personnel, and firefighters routinely make use of both full-scale field simulations and so-called "paper and pencil" (or "table-top") exercises. It is the table-top simulation with which this chapter is concerned.

Table-top simulations are typically based on actual case materials. Unlike case study reviews, however, table-top exercises do not present the outcome of an emergency as a means for evaluating individual decisions made during the course of the event. Rather, the simulation problem unfolds and requires decisions to be made among alternatives with incomplete information similar to the process involved in an actual emergency. Good exercises will simulate the conceptual and emotional decision-making aspects involved in coping with an event.

Table-top simulations have some advantages over full-scale field problems, or even participation in actual emergencies. First, a table-top exercise can foreshorten lengthy problem situations and long sequences of decision-making. An event that might be days in the making can be concluded in 1 to 2 hours with a table-top simulation. Second, errors made during a table-top simulation may be embarrassing but are not dangerous. Similar errors in a full-scale field exercise or during an actual emergency response could be dangerous or even fatal. Third, table-top simulations can provide the learner with a system perspective on the problem situation. During an actual mine fire an individual focuses on his or her situation and role, and may not pay much attention to key relationships and interactions among the other personnel, physical factors, and equipment. A simulation can show such relationships as well as reveal both the predictable and capricious events that are always part of any emergency. This type of overall comprehension of the "problem space" is thought to result in greater insight on the part of the participant. Fourth, table-top simulations provide individuals an opportunity to reflect upon, debate, and gain enhanced wisdom from their decisions. In aviation circles, interactive table-top simulations of the paper and pencil or computer-administered type are used to teach what is often referred to as "air wiseness," with promising results [Flathers et al. 1982; Giffin and Rockwell 1984].

The *Escape From a Mine Fire* (EMF) Exercise

The 5 Left crew at Brownfield Mine encountered extreme difficulty in making its escape. The workers were located nearly 3 miles from the nearest mine portal, and their first warning of the fire came when they observed smoke being carried into their section by the mine ventilation system. The smoke was coming through the intake entry, which was the section's designated primary escapeway. The smoke made this escape route impassable. The return entry, designated as the secondary escapeway, was also filled with smoke. The belt entry, which was not a designated escape route, but which was the only entry not filled with smoke initially, was selected by the miners as the most viable alternative. This entry was constricted by a conveyor belt on one side and a double row of roof support timbers on the other. These obstacles and the 48- to 54-inch seam height left a walkway approximately 3 ft wide, 4 ft high, and a 0.5 miles long (at which juncture the section connected with 6 West Mains, a set of eight entries that eventually led out of the mine over an additional 2.5-mile route).

The workers did not know the location of the fire, were not provided such information by surface personnel, and did not make adequate attempts to obtain this critical knowledge. During their escape, the eight miners worried that they would exhaust the 1-hour supply of oxygen in their SCSRs, because they knew it would take much longer than an hour to stoop-walk the nearly 3 miles to the portal, and as far as they knew, the mine atmosphere could have been contaminated by smoke the entire distance. They therefore chose to "save" their SCSRs by not donning them immediately. Thus, the workers traveled in increasingly heavy smoke until it became impossible to proceed without the breathing apparatus. All eight miners were in dense smoke before they donned their SCSRs and might very well have died from carbon monoxide poisoning if the smoke had been more toxic.

Once they donned their breathing apparatus, and after traveling only a short distance (approximately 200 ft), two miners found that they could not keep up with the group. One was physically unfit and the other old. The older miner could travel, although slowly. The younger, unfit man soon became unable to travel at all without help. The eight miners then made a decision to split up. Four members of the crew who could move rapidly left the section. The older miner followed these four at his own pace. Two fit individuals remained with the disabled worker and attempted to half-carry and half-drag him from the section. After falling down many times and stopping frequently, all three men were exhausted, out of oxygen, and were exposed to smoke. One person then left the other two. The disabled miner and his lone companion remained behind in the smoke, with one man semiconscious and the other hoping they might be rescued, but fearing they would die. The individual who left the section reported being nearly overcome by carbon monoxide, and stated that he was incoherent when he finally encountered fresh air approximately 1,000 ft outby the place where he had left his two coworkers.

Structure and Design of the EMF Exercise

Given the widespread practice of longwall mining, the setting described above is typical of many sections on which miners now work. Additionally, the problems these workers encountered during their escape are characteristic of those recounted by miners who have escaped other fires. Because of these two factors, it was decided to construct a simulation exercise around the experiences of workers on the 5 Left section. The initial simulation was developed by six individuals. One of these was a Federal inspector who happened to be on the 5 Left section that shift. This person escaped with the crew and subsequently helped conduct an official investigation of the fire. Four other developers were domain experts in mine safety or mine rescue who, collectively, represented a wide range of mining conditions and methods. All five experts worked together and in conjunction with an educational psychologist. The mine fire exercise was designed to be both a teaching tool to improve miners' decision-making skills and a research instrument to provide information about the proficiency of workers in planning an escape. The domain experts agreed that data from an administration of this problem applied to a large group of miners could help direct future training as well as the design and deployment of mine monitoring systems.

The structure of the *Escape From a Mine Fire* (EMF) exercise is based on the theory of narrative thinking from Bruner [1990], Bower and Morrow [1990], Sarbin [1986], and others. Bruner notes that there are two ways to understand one's own behavior and the conduct of others. The first way is through narrative thinking. The second is through formal analysis of behavior through logical rules and systems. Persons generally make important personal decisions by reference to compelling stories that they have internalized, *not* by applying formal logical rules. These life-directing narratives have been called "culture tales" and "stories we live by " [Howard 1991]. Since the beginning of human culture, stories and parables have been recognized universally as one of the most effective forms of instruction [Vitz 1990]. On a personal level, lessons learned and insights gained through stories also tend to be highly memorable and easily generalizable to one's own circumstances and plights [Bruner 1990; Sarbin 1986].

The EMF exercise is presented as an interactive story. The content and structure of the story are derived from the actual events that occurred in the mine fire on which the simulation is based. The miners who work the exercise interact with each other and with characters in the story. The exercise is constructed so that each miner assumes the role of a character who must make decisions as the story plot develops. The plot includes obstacles and predicaments that thwart the achievement of the goals (escaping from the fire, staying together, and saving one's buddies). At key points throughout the unfolding story, the miners select from among alternative actions and strategies. The consequences that follow each choice are subsequently presented as part of the interactive story line. Thus, the narrative exercise simulates many of the affective and cognitive dilemmas experienced by miners who are involved in similar decision-making when escaping from actual underground mine fires.

The paper and pencil exercise consists of a linear series of questions at each major decision point. The first 10 questions interspersed in the narrative represent what the domain experts determined to be key decision points encountered by the 5 Left miners during their escape from the fire. The experience of these miners provides the basis for the scenario. The last three questions ask miners to make additional judgments about the merit of particular persons' actions in the face of events that occur in the simulation. Twelve of the questions are followed by three to eight decision alternatives presented in a multiple-choice format. One requires a short written response in which the learner must decide among four alternative actions. The alternatives consist of both correct and incorrect actions (as indicated by expert consensus) at each major decision point (question) in the scenario. The consequences of incorrect answers range from useless to harmful or potentially lethal. These wrong alternatives were compiled from case studies and the interviews of miners who escaped from real fires, and represent judgment errors that workers actually made in such situations (some reasons why they made these errors are echoed by subjects' responses to the simulation questions).

Four of the questions or decision points have only one correct action among the alternatives listed. However, the remaining questions have a combination of two or three correct alternatives along with the incorrect ones. A miner's performance on a given major decision point is not scored dichotomously as a 0 or 1, but is awarded full or partial credit based on the total number of good decision alternatives selected, and the total number of poor decisions avoided (not selected). Finally, each decision point is weighted equally so that when the 13 question scores are added together the exercise total score is scaled from 0 to 100. Thus, the final observed total score for any given miner can be directly interpreted as a percentage of mastery of the exercise skills and content.

The exercise consists of two parts: a problem booklet and a latent-image answer sheet with an attached questionnaire. The problem booklet presents the relevant background information that any miner who was at work in this mine would know, e.g., information about the height of the coal seam, mine ventilation, location and distances of the portals, and the type of mining method and equipment used. The miner working the exercise is directed to play the role of the section foreman, and to make choices among decision alternatives at each question in the exercise. The initial observation is then presented as the arrival of smoke on the section where the crew is working. The booklet includes a section map (see figure 10.1) that shows the number and layout of entries, the location of the smoke, workers' positions, equipment locations, and the direction and distance from this section to the mine's main entries (and to the portal where the miners must exit). Each decision point (question) determined by the domain experts to be a major one is presented in the problem at the rate of one frame (page) at a time. After the miner examines the question and studies the alternatives, he or she then selects the "best" actions by using a special developing pen to mark the appropriately numbered space on the answer sheet.

Each numbered space on the answer sheet corresponds to a numbered decision alternative in that frame of the problem booklet. When the blank space on the answer sheet is rubbed with the developing pen, the invisible ink or "latent-image" answer immediately becomes visible. The message contains two types of information: first, it tells if the decision was correct or incorrect (as determined by the panel of domain experts); second, it provides additional information related to the decision. For example, in question D (the sixth frame and fourth major decision point in the exercise), miners are asked which actions they should take as they prepare to leave the section on foot in the belt entry. One of the eight decision alternatives for this question is:

> *Before you leave, send one miner to the pager (section telephone) to ask for information about the location of the fire, and to report (to the surface) that you are walking out.*

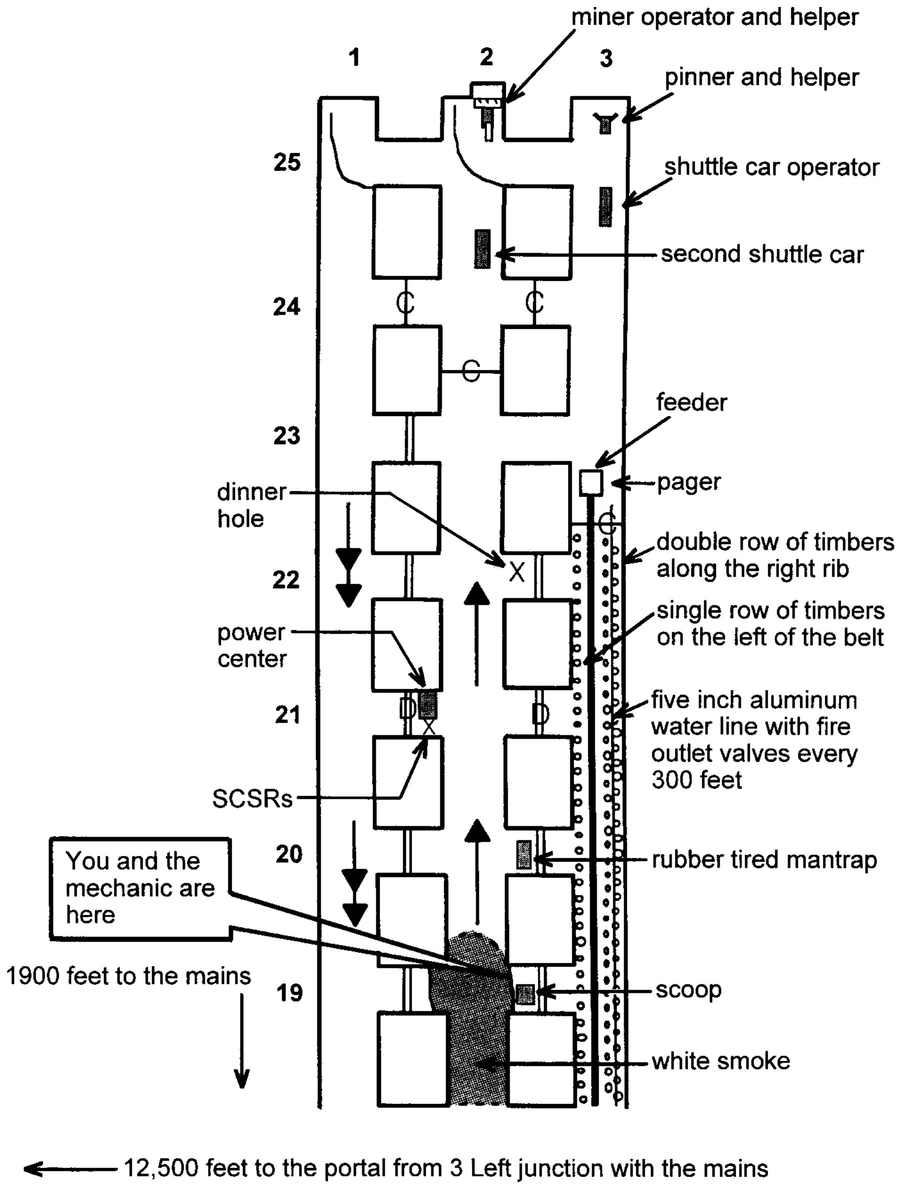

Figure 10.1.—Section map of imaginary mine in problem booklet.

When the miner rubs the corresponding blank space between the brackets on the answer sheet, the following message is instantly developed:

> *[Correct! But the miner returns and says the pager is no longer working.]*

Each frame in the problem booklet presents the scenario over a sequence of time and contingencies. The miner working the exercise knows only what has happened to the point at which the problem has been worked. The correctness and consequences of the decision alternatives selected for each question are also known only as these choices are made. In this manner the trainee must work through the problem as it unfolds, without knowing the outcome or the effects of his or her decisions until after they have been made.

Figures 10.2 and 10.3 depict two frames in the problem booklet. Figure 10.2 shows question B with six decision alternatives; figure 10.3 shows the latent-image answers that correspond to the decision alternatives. The entire exercise is constructed to teach and assess the choice of alternative actions at major decision points like those encountered by the miners who experienced the fire.

The major decision points include (1) deciding what to do when the smoke is first noticed, (2) ordering priorities in terms of alerting other miners versus first donning emergency breathing apparatus, (3) seeking more information about the fire, (4) choosing an escape route and method, (5) deciding what equipment to take along during the evacuation, (6) modifying the escape plan when heavy smoke reduces visibility to less than 2 ft and when two miners in the crew are unable to keep up, and (7) deciding how best to rescue a worker who had to be abandoned in a smoke-filled area of the mine. The options chosen by those working the exercise are discussed in a section to follow.

Interactive Latent-Image Format

The paper problem booklet and latent-image answer sheet system were chosen because they were inexpensive to develop and are easy to administer in any setting with a minimum of equipment. Only a problem booklet, a specially printed latent-image answer sheet, and a developing pen are needed. This combination of high technology instructional design with respect to exercise structure, combined with the low-technology latent-image delivery mode, provides a very effective interactive simulation—a basic format which has, in fact, been used for many years in medical education [Bollet 1984; Kacmarek et al. 1985].

Field Evaluation of the Exercise

After its construction, the EMF exercise underwent two rounds of field testing. A preliminary round involved authentication of the exercise by a group of 10 nationally recognized mine fire and mine rescue authorities using well-established mine rescue criteria. The criticisms, corrections, and comments of these persons were used to revise the exercise before its formal field test. This second round of field testing was conducted at four sites with six groups of experienced miners from several States.

Question B

While still in No. 19 crosscut, you and the mechanic put on your FSRs and then begin to move toward the face to warn the others and to call outside. As you approach the power center, you see the SCSRs. What should you do now? (Select as MANY as you think are correct.)

7. Stop at the power center and you and the mechanic each don an SCSR.

8. Tell the mechanic to grab a couple of SCSRs, and you grab a couple and continue on to warn the others and to call outside.

9. Wait at the power center until the other miners assemble.

10. Stop and check the condition of each SCSR, and then lay them out to make it easier for the other miners to get the units on.

11. Deenergize the power center.

12. Wearing your FSRs, go directly to the face area to warn the others and to call outside.

Figure 10.2.—Question B with six decision alternatives in problem booklet.

Question B (Select as MANY as you think are correct.)

7. [Your FSR is sufficient for now. You need to warn the others and call] [outside.]

8. [When you leave, other miners may come to the power center and] [find SCSRs missing. They may think you have left the section.]

9. [You need to make sure all the other miners are warned and go to the] [assembly point by the power center.]

10. [Warning others to assemble is more important.]

11. [Correct! This is a proper procedure and is an additional warning for the] [crew that something is wrong.]

12. [Correct! Smoke is light. You are protected from CO. You need to warn] [others on the section and outside, and you need more information.]

Figure 10.3.—Latent-image answers that correspond to the decision alternatives shown in figure 7.

A total of 134 underground coal miners, including two females, were involved in formal field testing of the exercise. The mean age of these workers was 41.1 years, with a standard deviation of 8.83. These miners averaged 15.9 years of experience in underground coal mining, with a standard deviation of 7.16. The persons in the sample represented three major job categories found in the underground mining industry. These include (1) miners/laborers who are hourly employees and who are engaged in the various jobs directly related to extracting and transporting the coal out of the mine; (2) maintenance/technical staff who are electricians, mechanics, health and safety inspectors, engineers, surveyors, and other personnel who do not directly mine coal but who work underground in and around the sections; and (3) supervisors/managers who are salaried employees and who include the first-line supervisor (section foreman) all the way up to the mine superintendent. Figure 10.4 presents the proportions of these persons in the sample.

In the mining industry the job categories depicted in figure 10.4 are associated with increasing levels of skill and knowledge. Mine foremen and other supervisors must pass examinations and be certified in such areas as mine maps, ventilation, health and safety, first aid, escape, and rescue procedures. Similarly, mine maintenance and technical workers must be certified in their specialties. In addition, their work often requires them to travel widely throughout the mine, usually in pairs. Because they have to be responsible for themselves as they work and travel about, maintenance/technical workers need to be more aware of the mine layout, escape routes, and escape procedures than do the typical miners/laborers.

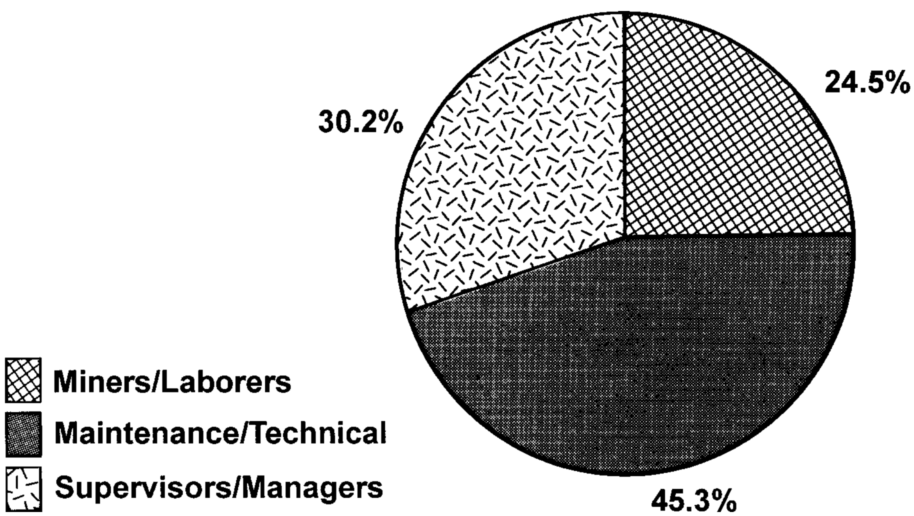

Figure 10.4.—EMF exercise: percentage of sample by job category (n = 134).

This sample is somewhat older than and has greater experience than a more typical sample of miners. In addition, miners/laborers are underrepresented in the sample, while mine maintenance/technical personnel and supervisors are over-represented. An earlier national sample of 3,658 underground coal miners from 12 States found a mean age of 37.2 years with a standard deviation of 9.0, and a mean of 11.9 years of mining experience with a standard deviation of 7.2 [Cole et al. 1988a,b]. Miners/laborers comprised about 50% of that much larger sample; maintenance/technical personnel and supervisors comprised about 25% each.

Two important generalizations can be made about the field test sample. First, this group of miners had more experience and better training in either fighting or escaping from mine fires than would a representative grouping of miners. Second, most of the working miners, technical personnel, and supervisors included here were attending regional health and safety meetings for persons in the mining industry. These facts suggest that the exercise performance scores of this sample ought to be higher than the scores of miners from a completely random selection.

Results

The results of the field test are presented in three parts. The first part presents miners' evaluation of the authenticity and utility of the simulation. The second part analyzes psychometric properties of the exercise, including assessments of its validity and reliability. The third part describes the performance of miners in choosing among the 63 alternatives contained in the 13 questions or major decision points.

Miner Evaluation of the Exercise

Each person who worked the simulation was asked to complete a standard 10-item Likert scale rating form. The first three items on the form were designed to elicit the miner's evaluation of the authenticity of the problem and its worth as a training device. The remainder of the items addressed the functionality of the exercise structure and design. Ratings of all miners on each of these 10 items are presented in table 10.1. Even though this sample consisted of highly experienced workers, all persons reported that the exercise was authentic and would help them remember important details. Additionally, nearly 94% reported that they learned something new from working the exercise.

Validity

Four estimates of exercise validity were obtained. First, the 10 experts who reviewed the simulation during its authentication stage and in its final form judged the content validity to be high. This is not surprising, since the problem was based on the behavior and decision choices of miners who had escaped from actual mine fires. Second, the 134 miners in the field test sample judged the face validity of the exercise to be high, as can be seen from their ratings in the first three items in table 10.1. Third, the 63 decision alternatives discriminated positively with respect to the exercise total score. When decision alternatives are valid, the number of wrong alternatives selected should correlate negatively for persons with high total scores, but correlate positively for persons with low total scores. Likewise, the number of correct alternatives selected should correlate positively for persons with high total scores, but negatively for persons with low total scores. When multiple-choice test questions (or exercise alternatives) behave in this manner, they are said to discriminate positively among levels of ability within the sample. Table 10.2 presents the proportion of exercise alternatives that positively and significantly discriminated with respect to high exercise total score.

Table 10.1.—Miners' rating of exercise validity, relevance, quality, and utility (frequency %, n ' 134)

Content	4 (definitely yes)	3	2	1 (definitely no)	Mean	Standard deviation
Exercise is realistic/authentic	88.5	11.5	0.0	0.0	3.9	0.32
Helped me remember important things	62.3	37.7	0.0	0.0	3.6	0.49
Learned something new . . .	52.7	41.1	3.1	3.1	3.4	0.71
Exercise is too long	3.1	7.0	29.5	60.5	1.5	0.76
Liked working the exercise .	60.6	31.5	6.3	1.6	3.5	0.69
Instructor's directions are clear	64.9	29.1	1.5	0.0	3.7	0.51
Written exercise directions are clear	62.2	35.4	1.6	0.8	3.6	0.57
Graphics are easy to understand	65.1	33.3	0.8	0.8	3.6	0.55
Scoring is easy to understand	43.1	44.8	6.0	6.0	3.3	0.82
Exercise is easy to read . . .	66.4	33.6	0.0	0.0	3.7	0.47

Table 10.2.—Proportion of answers discriminating positively, negatively, and not at all with the exercise total score (p<.05)

Positive	51/60 (85.0%)
Negative	2/60 (3.3%)
No relationship	7/60 (11.7%)

The final estimate of exercise validity was determined by conducting an ANOVA of exercise total scores by job category. As explained earlier in the section that described the sample, knowledge of mine rescue and escape skills may be expected to increase across job categories from miners/laborers through maintenance/technical workers to supervisors/managers. The analysis was run on 106 persons for whom there was a complete vector of exercise question and total scores, and for whom there was also a definitive job category assignment. Table 10.3 presents means and standard deviations of the exercise total score for these three groups, and table 10.4 presents the ANOVA results by job categories. Figure 10.5 plots observed total score means and standard deviations for the three job categories. Job category was found to account for approximately 29% of the observed variance in exercise total scores.

Table 10.3.—Means and standard deviations for exercise total score by job category

Job	n	Mean, %	Standard deviation
Miners/laborers	26	71.1	11.03
Maintenance/technical staff	48	79.9	7.47
Supervisors/managers	32	85.5	7.38

Table 10.4.—ANOVA results for exercise total score by job category

Source	Degrees of freedom	Sum of squares	Mean square	F ratio	p<
Between groups	2	3,051.92	1,525.96	21.31	0.00
Within groups	103	7,302.54	71.59	—	—

Eta squared ' 0.293.

Reliability

The Cronbach alpha generalizability coefficient was calculated for the exercise as an estimate of its internal consistency. The observed reliability of 0.74 might be expected to increase if a more heterogeneous sample of miners were used to achieve a more symmetrical performance distribution on item and total scores.

Question and Total Score Performance

Individual performance on each of the exercise questions was scored by awarding full or partial credit based on the total number of good decision alternatives selected and the total number of poor decision alternatives avoided. A mean percentage and standard deviation for each question score was then calculated. An ANOVA was carried out for each question score to determine which of the 13 items significantly discriminated among the three job categories.

The ANOVA was based on the 106 persons who could be clearly identified as belonging to one of the three categories. Figure 10.6 presents the pooled means and standard deviations for each of the 13 questions for the entire sample of 134 miners who completed the exercise. The total exercise score (TS) and its standard deviation are represented in the last column of the histogram. The scoring metric is the percentage of correct responses, so that all question scores and the exercise total score can be compared to one another in terms of difficulty. The eight questions that significantly discriminated among job categories are marked with an asterisk.

Inspection of figure 10.6 reveals an important finding. Questions H and K were the most difficult decision points in the exercise, as evidenced by the fact that there was no significant difference among the scores on these items across workers in the three job categories. Additionally, the mean score for question H was 53.2%, with a standard deviation of 25.8. The mean for question K was 62.3%, with a standard deviation of 39.9. These means are well below the desirable proficiency level and the variance is very large. Questions H and K are difficult because they have in common a dilemma, described below, that is encountered in actual escapes from mine fires (and that participants reported as a rationale for their chosen options) but that is rarely discussed in training classes because these classes tend to focus on escape algorithms and rules.

Figure 10.5.—EMF exercise: means and standard deviations by job category.

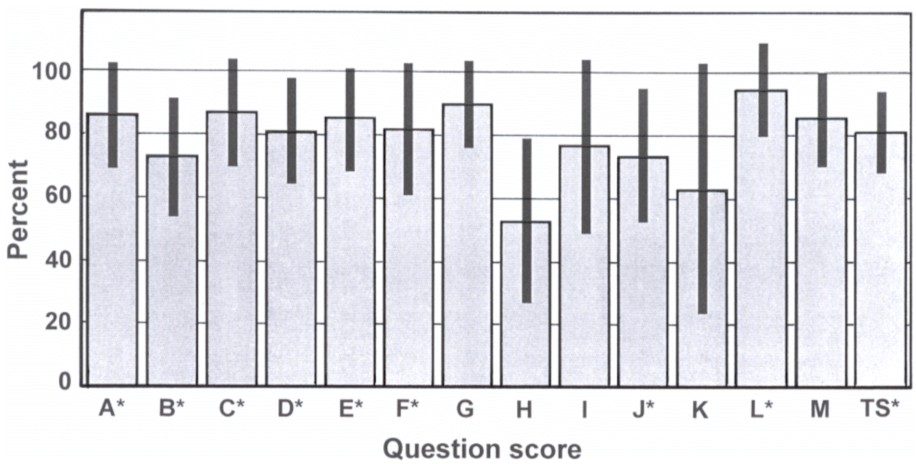

Figure 10.6.—Question score means and standard deviations. (An asterisk (*) indicates a question that significantly discriminates among job categories (p#.05). TS = total exercise score.)

In question H, the scenario has developed to a point at which the miners are in heavy smoke wearing their SCSRs and having difficulty moving in the narrow, low walkway along the belt entry. The unfit miner is unable to maintain a pace needed to escape from the section before conditions become fatal. The three decision alternatives include (1) trying to force the straggler to keep up and having all of the other miners slow down, (2) letting the group split up and leaving the straggler on his own, and (3) having members of the crew take turns carrying the unfit miner. The weight of the straggler (260 pounds), his poor physical condition, the narrow and low walkway, and restrictions on heavy work imposed by wearing an SCSR, make the first and third options difficult and dangerous. The correct (but troubling) decision is to let the group split up so that those miners who can travel rapidly have a chance to escape. Discussions following the exercise suggest that this experienced group of miners understood the dangers of the two incorrect alternatives and the logic of the correct decision. Many persons in all three job categories, however, selected wrong alternatives to this question.

Question K addresses an issue that arises when miners are missing in mine fires and other workers wish to find and rescue them as soon as possible. Prior to this point in the problem scenario, two of the escaping miners had tried to help the straggler but were unable to do so. Finally, he was abandoned, semiconscious but still alive. All of the other miners had reached relative safety in fresh air about 1,000 ft farther along the escape route. The question concerns two miners who wish to don new SCSRs and reenter the smoke filled area to search for and bring out the missing worker. The predicament arises from the need (as perceived by the survivors in our interviews) for prompt rescue of the missing miner if he is to live, and weighed against the dangers of using SCSRs to attempt the rescue. The person working the exercise is asked to weigh the merits of the two miners' rescue plan, and decide if rescue attempts should wait until the fire is under control, fresh air is restored to the area being searched, and/or a mine rescue team with proper breathing apparatus and related equipment arrives. Based on many accident investigations and interviews, such decision alternatives are known to be problematic for miners. Likewise, these decision alternatives proved difficult (as indicated by low scores and failure to discriminate) for the persons who worked the simulation exercise. This outcome was observed even though the sample was a highly knowledgeable and select group who clearly understood the risks.

The issue centers around the design of SCSRs—they are designed for self-rescue and escape. They do not provide an adequate supply of oxygen for rescue work and are not mechanically and ergonomically suitable for such activity. Yet, if a missing miner is not rapidly retrieved from the smoky area of a mine, he or she may die from CO intoxication and smoke inhalation. The issue of mounting rescue efforts with the aid of SCSRs is hotly debated by workers involved in both the field tests of this simulation and other similar exercises. While all persons recognize the good intentions of miners who want to use SCSRs to rescue missing individuals, they disagree on the merit of such attempts. Experienced mine rescue personnel and other experts often argue that it is very difficult to travel and work in smoke while wearing SCSRs, and that the risks are too great to justify any attempt to rescue a trapped miner while using the apparatus. Potential problems associated with such attempts, according to these individuals, include (1) would-be rescuers becoming lost or disoriented, (2) workers having great difficulty finding, lifting, and moving a disabled miner, and (3) potential rescuers displacing their SCSR mouthpiece or nose clips, and/or running out of oxygen during the rescue attempt. Some or all of these difficulties are very likely during the rescue attempt. Singularly or in combination, these problems could easily result in serious injury or death for the would-be rescuers.

Such an outcome would further complicate a rescue of the original missing miner(s), and endanger additional lives because (1) more miners would be missing and need to be rescued, (2) fewer persons would be immediately available at the scene to conduct the support work necessary for a successful rescue, (3) those individuals who subsequently must attempt a rescue of the additional victims would be endangered even when they were properly equipped with mine rescue apparatus, and (4) rescue of the original victim(s) might be delayed, thus increasing the probability of their death.

Mastery Levels

Each question score is weighted equally so that when the 13 subscores are averaged the exercise total score is scaled from 0% to 100% (figure 10.7). Each question score in figure 10.7 is also presented on a 0% to 100% scale. Thus, the final observed total score and the question scores for any given miner or group of miners can be directly interpreted as the percentage of mastery of exercise skills and content.

Self-rescue skills like those presented in this simulation should be learned to high levels of mastery in order to minimize errors that can be very costly in terms of death, injury, economics, and public image. As a general rule, proficiency levels for these types of critical skills are set at a minimum of 90% correct performance by at least 90% of the trained population [Cole et al. 1984]. Figure 10.7 plots the percentage of individuals in the sample who scored in one of seven mastery level intervals. As shown, only 13.6% of the miners scored at or above the 90% mastery level as assessed by total score performance. Nearly 50% of the sample performed below 80% mastery. A completely random sample of miners might be expected to perform at lower levels of mastery than did this group of highly experienced and well-trained workers. If the exercise is valid and reliable, this suggests that miners need additional training in the decision-making that is involved when escapes from mine fires must be planned and executed. Simulations like the *Escape From a Mine Fire* exercise may be one cost-effective way to provide realistic practice in these critical nonroutine skills.

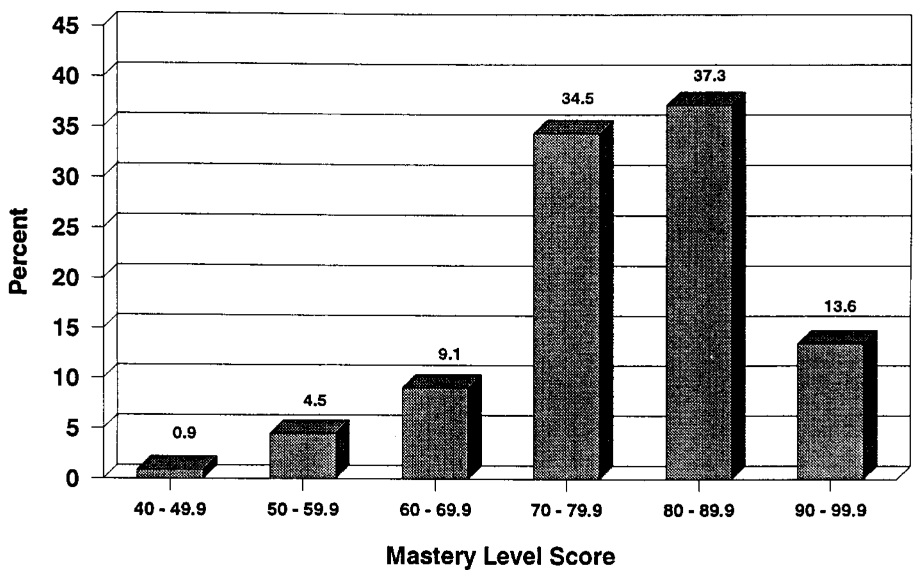

Figure 10.7.—Percent of miners attaining various mastery levels on the EMF exercise.

Conclusion

The mean performance scores of groups in all three job categories fell well below the 90% level of mastery for the self-rescue and escape skills presented in the EMF simulation. However, the exercise total score discriminated significantly among job categories (F = 21.314, p#0.0001), with supervisors obtaining the highest mean score (85.8%), maintenance/technical workers an intermediate mean score (79.9%), and miners/laborers the lowest mean score (71.1%). The exercise total score also discriminated significantly (F=17.352, p#0.0001) between those persons with mine rescue training (mean = 81.6%) and those without such training (mean = 73.0%). For the dilemmas presented in questions H and K, though, there are no significant differences in the mean performance scores by job category or by mine rescue training level. This finding suggests that the issues associated with having to abandon a helpless miner, or engaging in unsafe rescue attempts of missing workers by using SCSRs, are clearly problematic decisions for all miners regardless of training level. Workers in all three job categories appeared to understand the potentially lethal consequences of unsafe rescue attempts, but frequently chose unwisely in the simulation. It should be noted that this also happens in real life, where a significant proportion of deaths in confined spaces are would-be rescuers of victims who are usually already dead [Manwaring and Conroy 1990].

We have observed that when miners and accident investigators alike discuss actual escape or rescue attempts, the merits of workers' decisions are nearly always judged post hoc in relation to the outcome of their actions. If the decision choices were successful, the miners are seen as brave and wise. If the decisions were unsuccessful, and especially if more persons were injured or died, the workers' actions may be seen as well intentioned but foolish (and perhaps illegal). Nevertheless, this approach to reviewing the merit of actual decisions in terms of prior knowledge of the outcomes may be counterproductive, because it develops a mindset that cannot be effective in the decision-making required during an actual mine emergency. When these types of decisions are made in real life, the participants cannot know the outcome of their actions prior to the action. Knowledge of the outcome cannot be the basis for the decision [Fischoff 1975]. Rather, such decisions must be based on the incomplete information that is available at the moment, estimates of the feasibility of alternative actions and their likelihood of success, and a weighing of the relative risks associated with each alternative.

The simulation discussed in this chapter was designed to provide a vicarious experience that would enable miners to confront the life and death choices involved in escaping from a mine fire. Undoubtedly the vicarious experience of completing such an exercise is not sufficient to prepare a miner for such a real-world experience. However, it is almost certainly better to have studied and debated the decisions encountered in such a simulation than to encounter them for the first time in a field situation. The EMF exercise is not just a "story." Rather, it is a composite of a type of emergency that too often claims workers' lives. To the extent that such simulations accurately reflect the dilemmas and decisions encountered in actual fires (and the present one is taken directly from a real incident), they provide better training for these nonroutine events than the more traditional method of teaching facts and escape algorithms. Likewise, they are more effective than a post hoc analysis of case studies where the merits of decisions are judged by knowing their outcomes a priori.

The EMF exercise is a dual teaching and testing device that presents a series of decision tasks embedded in a text or narrative. These types of educational materials have a long research tradition. Skinner [1965], Rothkopf [1966] and many others independently developed instructional programs consisting of a series of test items embedded in text. These programs were used to teach and test knowledge and skills of military personnel and many other groups. More recently, simulation problems with embedded test items have been used to teach and test proficiency among a wide range of technical personnel including health professionals, veterinarians, military and civil aviators, and other groups [Cole 1994]. The EMF exercise teaches miners through immediate feedback about the consequences and correctness of each decision they make. The immediate feedback reinforces correct knowledge and judgments and remediates incorrect decisions. At the same time, the objective nature of the exercise decision alternatives allows a performance score to be recorded and calculated for each individual. As demonstrated earlier, these performance data can be treated as test scores. To the extent that the exercise is valid and reliable, performance scores aggregated across groups of persons provide useful information about the degree to which miners have mastered particular skills and concepts and where more training is needed.

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AFTERWORD.—THEORETICAL AND PRACTICAL IMPLICATIONS[1]

A major reason for the previously mentioned scarcity of systematic knowledge about social and behavioral aspects of fire is that most efforts to minimize human and economic loss have focused on engineering solutions. Canter [1980] argued that there is already enough evidence to support the argument that, as far as "hardware" solutions are concerned, "such provisions are frequently insufficient and in many cases inappropriate...human aspects of the causes and developments of fire must be understood if its disastrous effects are to be minimized." According to Canter, what is known empirically about human response to fire follows certain general themes that may be used as a base for understanding the phenomenon theoretically (and which, incidentally, also provide some insights applicable to mining).

First, the literature asserts that the place of human action in the cause of fires must be considered, even when arson is exempted. It is likely that many fires start as the result of human error. For instance, according to a preliminary report released by the Mine Safety and Health Administration [1987], the Wilberg disaster originated with an electric air compressor whose overtemperature safety shutdown switch had been bypassed. At Adelaide, while the cause of the fire is in doubt, a contributing factor is not. A stopping near the head drive had been knocked out because float dust was collecting behind it. This allowed 60,000 cfm of air to go across the belt. According to the account of the mine examiner who discovered the blaze, things got out of hand quickly. At Brownfield, a trolley motor was left energized and on first point. In addition, a door in the supply chute was left open. Thus, not only did combustion take place, the smoke was quickly carried into the mine's primary escapeways.

A second theme in the literature deals with the fact that much information-gathering must take place before an individual comes to understand the nature of the problem, his or her role, and the appropriate rules that should be followed [Canter et al. 1980]. Given that a fire, at least in its early stages, is an uncertain event, it can be seen that a lot of time may be lost in defining the situation. On the night of the Adelaide fire, the dispatcher, who stated that the mine had "been getting tons of those false alarms," engaged in a series of conversations with the dumper underground. Following that, he (1) received a phone call from the face boss on the section contacted by the dumper wanting to know what was going on, (2) got through to another section and told the person who answered that there was a fire on the belt and to "get your guys out of there," (3) contacted the remaining section and "told the man on the phone to get the guys together," and

[1]An earlier version of this discussion is contained in: Vaught C, Wiehagen WJ [1991]. Escape from a mine fire: emergent perspective and workgroup behavior. J Appl Behav Sci *27*(4):452-474.

(4) received a call 5 minutes later from the last section contacted wanting to know what was going on. Only one worker (the maintenance foreman) at Brownfield took time to learn where the fire at his mine was located.

The third theme involves people's reactions once the situation has been defined. Sime [1980], among others, has offered evidence that the concept of "panic" does not apply to human behavior in fires. In fact, the reverse is more nearly true; people continue to carry out their normal roles long after the time for action has arrived. The severity of conditions at Adelaide was not communicated to the miners in such a way that they felt obliged to depart from normal routine—individuals who were operating equipment recounted how they went through regular shutdown procedures, tramming back from the face, going to the load center to kill the power, retrieving lunch buckets and coats, and walking to the mantrip. This same tendency to normalize their situation was reported by workers at the other two sites.

A fourth theme involves what happens once the decision is made to take action. Best [1977], in his account of the Beverly Hills Supper Club fire, illustrated the fact that even when people have entered an escape mode, their behavior tends to take place within the organizational parameters that existed prior to the emergency. For instance, waitresses at the restaurant showed their patrons out of the building. One professional firefighter, who happened to be dining at the club, allowed the waitress assigned to his table to lead the group to safety, and then reentered the building to help fight the blaze. At Adelaide, leadership emerged more or less gradually out of an initial state of disorganization. There was no previous determined gathering point in case of a fire like this one, which occurred outby the section. Although an escapeway map was posted on each section, no one thought to take it—despite the fact that there were miners on all three sections who had not had an opportunity to walk the escapeways and hence did not know the way out. At all three sites, the workers delayed donning their self-contained self-rescuers an average 10-15 minutes after encountering smoke—the reason most often given for this delay was "I knew these things [SCSRs] only last for an hour, and I didn't know how long it would take me to get out." Yet, no one thought to protect himself or herself in the meantime by using the filter self-rescuer every miner carries on his or her belt. Individuals took their mouthpieces out to talk or to get a deeper breath at points where the smoke was less concentrated, despite the fact that there was no way to determine how much CO might be in the atmosphere. Miners were disoriented by the smoke, and on at least one section, misinterpreted cues and became momentarily lost.

The final theme concerns the behavior of people once they have reached an area of relative safety. Bryan [1977], in a cross-cultural comparison of two large data sets, noted that fully a third of the individuals who made it to safety subsequently reentered the fire site to look for others, to check on the progress of the fire, to "do something" while waiting for firefighters, or to get personal property. At Adelaide, three individuals went back to search for a miner they believed to have "frozen up," but who had actually left the group and had come out another way. These three miners placed themselves in great jeopardy. At Brownfield, a mechanic put his own safety at risk in order to stay with a co-worker who had given up and believed himself unable to travel farther. Finally, a face boss jeopardized himself in a successful attempt to locate these two men.

In essence, there seems to be enough substantive agreement at this point to suggest that it is possible to arrive at a scientific understanding of people's activities in fire. The present analysis of worker behavior in mine fires supports existing research regarding human responses to structural fires. At the same time, however, it adds some complementary insights into individual and group behavior in a type of social subsystem different from those usually studied. In these mine fires, strong continuities between organized and collective behavior, hypothesized to exist in all emergencies, induced the workers to help each other negotiate thousands of yards of smoke-filled entryways to safety, and led them to define any actions that seemed to violate the sacred code of "buddyhood" as somehow needing explanation.

Given that escape, for many of these workers, seems to have been a very problematic *group* effort, this book can be used to increase an awareness of some difficulties that may be encountered during any escape from a mine. Readers should gain an appreciation for the following factors: (1) Initial warnings are often unclear, sometimes due to the way technology behaves, and sometimes due to faulty or incomplete communication. This can lead to different interpretations of the problem. (2) People frequently fail to gather the right kinds of information which prevents them from making appropriate responses to the situation. (3) Once any decision is made, individuals respond well to a leader. If leadership is lacking, however, people tend to become confused. (4) Apparatus used in mine emergencies, such as page phones and self-rescuers, may not work as expected, or may fail. (5) Individuals become disoriented very quickly in smoke. Additionally, smoke rises, obscuring markers and landmarks in enclosed spaces.

Given these five factors, the following recommendations are offered to mine safety specialists. It is expected they can be related back to procedures in place at their operations:

Trainers should periodically review with workers the escape and evacuation procedures at their mine(s). Include a description of (1) how warning messages will be communicated, who will make the call, or how the warning will be conveyed; (2) what the content of the message will be; (3) what information to seek when communicating with someone outby the fire area (location, distance to fresh air, suggested escapeways, etc.); (4) mine rescue team support; (5) the marking system for primary and secondary escapeways; (6) the storage plan for SCSRs; (7) what equipment, supplies, and materials to take from the section; and (8) the assembly points for workers on each section.

Research on fires in complex structures such as high-rise buildings (some of which was cited earlier) shows that there is an overdependence on the telephone as an emergency warning device. Such was the case at the mines discussed in this book—miners at the operation did not routinely answer section telephones. There are undoubtedly certain aspects of the warning and communications system at any mining operation that are taken for granted and, on reflection, could be a problem. These attributes should be spelled out and, insofar as possible, made foolproof. For instance, a separate device such as a flashing strobe could be mounted on or near the telephone to alert workers that the incoming call is not routine. These features should then be spelled out during training.

There seems to be too much dependence on engineering hardware solutions without a concomitant understanding of how miners will use those systems. For instance, state-of-the-art mine monitoring equipment may be installed without providing adequate training to the dispatcher or communications person. In many cases, a definition of what constitutes adequate training can only be accomplished by testing the system; thus, there is a need for emergency simulations and structured fire drills, activities that are not widely practiced in the industry.

Once a decision is made to take action during a fire, people respond well to leadership. If this leadership is lacking for some reason, they tend to become confused. On Adelaide's 2 Northwest section the foreman took the lead and a section utilityman, who was trained in mine rescue, brought up the rear. Everyone stayed together and had relatively little trouble during their evacuation of the mine. Safety managers should compare this scenario with those situations on some of the other sections at all three sites and develop a strategy allowing for the most competent person (whether a supervisor or a rank-and-file miner with specialized experience) to assume leadership early in an event.

As an emergency progresses, people who are less well-prepared tend to experience sensory overload. This causes them to focus on small parts of the problem rather than trying to comprehend the entire situation. This point is illustrated by the miners' tendency to "save" their SCSRs until the smoke got heavy, but not protect themselves from CO in the meantime by using their filter self-rescuers. Miners should be assisted in developing a protocol for how they will employ their emergency breathing apparatus—one that goes beyond the trainer's rote "put on your SCSR at the first indication of fire or smoke," which may be good advice but obviously is not heeded in actual situations.

Research on fires in buildings has shown that people frequently reenter a fire site after reaching safety, often to search for someone they believe is still inside the structure. This observation is borne out here as well. One of the miners went back with two buddies to look for an individual who left the group. Trainers should impress upon their workers some of the consequences of leaving the group, either to help a buddy, or to escape on their own. If groups are to split up, it should be according to a previously determined plan of action.

Finally, it is recognized that people become disoriented very quickly in smoke. Unless one knows the escape route very well, such disorientation could be fatal in a mine fire. It is suggested that safety managers review their site plan for conducting fire drills. This review might be an opportunity to elicit renewed commitment to a company's emergency preparedness program and procedures for ensuring that miners walk their escapeways periodically. Measures could then be enacted, if needed, to ensure these plans and procedures are implemented in the manner intended by law.

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APPENDIX A.—DESCRIPTION OF APPROXIMATE ESCAPE ROUTES TAKEN BY THE GROUPS

Adelaide Mine

1 Right

This group boarded the rail-mounted mantrip and started to come out of the mine. They traveled nearly 0.7 miles before encountering smoke. At this point the crew stopped the mantrip, got out, and began walking off in various directions. The foreman and another miner got the crew back together. After reassembling, the crew decided to go to the intake escapeway and walk the rest of the way out of the mine. After getting into the intake escapeway, the crew traveled about 500 ft on foot before encountering smoke in this escapeway. The crew then moved into the left-side return entry where they confronted smoke again. After putting on their rescue breathing apparatus, group 1 continued for about 0.3 miles before turning right. After turning right, this crew continued to move through the smoke-filled return entry for another 0.8 miles before finally getting past the location of the fire and reaching clear air.

2 Northwest

This group boarded the rail mounted mantrip and started to come out of the mine. The crew traveled about 0.1 miles in the mantrip before encountering smoke. At this point, the crew stopped the mantrip, got out, and decided to move to the intake escapeway and continue to egress the mine on foot. The crew traveled about 0.1 miles on foot in the intake escapeway before encountering smoke. Upon being confronted with smoke, the crew moved to the right return entry to continue their escape. After traveling several hundred feet more in the return entry, this group encountered smoke again. At this point, the group put on their rescue breathing apparatus and continued their escape, traveling about 0.4 miles in the return before turning right. After turning right, the group traveled another 0.2 miles in the smoke-filled return entry. At this point, the group became disoriented in the smoke and began to go the wrong way by walking back toward the working section. The group traveled about 200 ft in the wrong direction before a miner in the group realized that they were going back into the mine. At this point, the group turned around, and continued to egress the mine, traveling an additional 0.4 miles before passing the location of the fire and reaching clear air.

3 Left

This group boarded the rail-mounted mantrip and started to come out of the mine. The crew traveled about 0.1 miles in the mantrip before encountering smoke. At this point, the crew stopped the mantrip and decided to go back to the section. The crew rode the mantrip back to the section, got off the mantrip, proceed to the intake escapeway, and began walking out. This group walked about 500 ft before encountering smoke in the intake escapeway. The crew then moved into the right-side return entry and continued to proceed out of the mine. After moving into the return entry, this group walked several hundred feet more before running into smoke in the return. At this point, the miners put on their rescue breathing apparatus and then continued on foot about 1 mile through smoke before passing the location of the fire and reaching clear air.

Brownfield Mine

4 South

The foreman and mechanic with this group noticed smoke coming up the intake escapeway. This crew assembled at the section power center. This group elected not to follow the intake escapeway since it was already filled with smoke. Similarly, the miners chose to avoid the alternate escapeway in the return aircourse since they knew that it would be filled with smoke. The crew decided to escape via the mine entry in which the conveyor haulage belt was located, since they believed that this entry should have clear air. This group walked the belt entry for about 600 ft when they encountered smoke. Group 4 traveled for about 0.4 miles in heavy smoke to the point where the conveyor belt entry intersected with the main supply haulage track. Here, the group turned right and moved into the haulage entry and followed the main haulage entry for about 0.1 miles until they were past the fire location and in clear air.

5 South

This group assembled at the rescue breathing apparatus storage station in the No. 1 intake entry. The group traveled on foot several hundred feet and, after being confronted with heavy smoke, moved into the belt conveyor entry where the smoke was lighter. This group traveled about 400 ft on foot in the belt entry until they hit heavy smoke again. At this point, the group moved into the alternate escapeway entry and proceeded to travel the section and main return aircourse through smoke for about 0.25 miles before passing the fire location and reaching clear air.

6 West

These miners assembled at the beginning of the intake escapeway on the working section. After putting on their rescue breathing apparatus, this group traveled on foot for about 700 ft in the intake escapeway before being confronted with heavy smoke. At this point, the group moved to the alternate escapeway where the smoke was lighter. After moving to the alternate escapeway, the group continued to travel on foot for about 0.25 miles before passing the location of the fire and reaching clear air.

Cokedale Mine

7 Butt

Because the primary escapeway was filled with smoke, this group decided to follow the alternate escapeway out of the section. These miners got into the alternate escapeway in the left return aircourse of the section and traveled this escapeway on foot for about 0.3 miles. The crew then made a right turn and followed the escapeway for another 0.25 miles. At this point, the group turned left and continued on foot for about 1 mile before reaching fresh air.

8 Face Parallels

These miners gathered at the beginning of the primary escapeway and proceeded to travel this escapeway on foot about 0.3 miles before being confronted with heavy smoke. Upon hitting heavy smoke, the crew turned around and followed the primary escapeway back to the section. After returning to the section, the group then got in the section's left return aircourse. The group followed the left return aircourse for about 0.2 miles before realizing that they were not in a designated escapeway. The group turned around and followed this aircourse back to the section. At this point, the group crossed the section and made their way into the right return airway (the designated alternate escapeway) and followed it for 0.1 miles before turning left. After turning left, the group continued on foot through the alternate escapeway for about 0.2 miles before turning right. After turning right, the group continued on foot for another 0.3 miles before turning left into the main alternate escapeway. After turning into the main alternate escapeway, the crew continued for about 1 mile before reaching clear air.

APPENDIX B.—MINE FIRE INTERVIEW GUIDE

1. 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 that there might be a problem in getting out of the mine?
   - Did you communicate with anyone? With whom?

2. What did you do after making sure that there was a problem?

   - Walk with anyone? Where?
   - Did you go anywhere to get anything after you left your equipment?
   - Did you pick up anything on the section?
   - Did you talk with anyone? About what?

3. Was there a point where the crew assembled?

   - Where was the assembly point?
   - Was this a designated point? Were you trained to go to it?
   - What was the conversation about when you met up with the whole crew?
   - Does anything about the conversation stand out?
   - How would you describe the feeling within the crew?
   - Did you or anyone have any concerns about getting out?
   - Was there any sign of smoke at this point?

4. When did you first encounter smoke?

   - What was the crew's reaction?
   - Did someone take charge?
   - What was being said at this time?
   - Was there any confusion or indecision?
   - What were your thoughts at this point?

5. How was the plan of action to escape decided on?

   - Did the crew meet to decide the course of action?
   - Did anyone distribute assignments?

- Was there general agreement about what to do? Who disagreed? How was that handled?
- What was the feeling within the crew?
- Would the crew have walked out the intake without donning their SCSRs if it were smoke-free?
- How did you begin to go out?
- How much time passed between starting out and donning the SCSR?
- How would you describe that period of time?
- Did you at any time feel that this was a life-threatening situation?

6. What was it like when you first began to don your SCSR?

   - Who made the decision to don?
   - What were the conditions? Could you see?
   - Did anyone take a CO reading?
   - Did you check the apparatus?
   - Did you get more than one?

7. What part did you SCSR training play when you began donning the apparatus?

   - Which of the devices have you been trained on?
   - What position were you in?
   - Can you show us the steps you used to get the SCSR on?
   - Did you have any problems? Did you see anyone else having problems?
   - Did anyone help you? Did you help anyone?
   - Did you have confidence that the SCSR would work correctly?
   - Did anyone experience any problems once the device was on? What were they?
   - How long did it take everyone to get ready to move out?

8. How did you go about actually escaping from the mine?

   - Who made the decision?
   - Did you escape alone or in a group?
   - How was the escape route chosen and followed?
   - Were markers visible?
   - Were there communications along the way? What was it like?
   - Were there problem, especially with the SCSR?
   - Were you aware of any risks in taking out your mouthpiece?

- Did anyone advise you not to remove the mouthpiece?
- How many times did you or the crew stop to rest or talk?
- Did you get rid of anything along the way?

9. At what points were there strategic decisions in making your escape?

   - What were the conditions?
   - How was decision made? Who made it?
   - Was there any disagreement or confusion?
   - Did you feel other crews were in trouble?
   - Where did you think the fire was?

10. Thinking back, what would have made your escape less complicated?

    - Would you have done anything differently?
    - Would you have taken anything else with you?
    - Probe about walking the escapeways.
    - Probe about SCSR donning.

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