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Behavioral and Organizational Dimensions of Underground Mine Fires

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UNIT OF MEASURE ABBREVIATIONS

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

ACRONYMS AND OTHER ABBREVIATIONS

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

BEHAVIORAL AND ORGANIZATIONAL DIMENSIONS OF UNDERGROUND MINE FIRES

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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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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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