Decision Making During a Simulated Mine Fire Escape

Henry P. Cole, Charles Vaught, William J. Wiehagen, John V. Haley, and Michael J. Brnich, Jr.

Abstract—**Forty-eight workers who had escaped large underground coal-mine fires were interviewed using an open-ended protocol. This information, and the actual experiences of one eight-person mine-section crew who escaped from a fire, were used to construct an 18-frame (page) table-top simulation exercise, which was then field tested with 134 miners. The exercise is a research tool that measures miners' proficiency in the information-gathering and decision-making skills related to escaping from a mine fire. It also helps miners to learn and practice these cognitive skills.**

The exercise was found to be valid and reliable. All miners reported that the exercise was authentic and would help them to remember important information. The exercise total score, and all but two item scores, significantly discriminated among miners with different levels of training. The two items that did not discriminate dealt with whether or not to abandon a helpless fellow miner. When the exercise total score data were pooled, only 13.6% of the miners achieved a desirable score of 90% mastery or greater. The simulation is important because it teaches and assesses critical judgment and decision-making skills that are rarely addressed in miner training.

Index Terms— **Coal mining, critical skills, decision making, emergency escape and evacuation, escape from fire, judgment training, mining, safety training, simulation training, underground mine fires.**

I. Introduction

A GROWING body of research from a number of fields suggests that decision-making skills needed to cope with emergency situations can be taught and assessed by well-designed simulation exercises based upon real-world cases [3]–[5], [11], [19], [25], [27]. This technique has been used to teach and study the decision making of medical personnel [1], [13], [14], [18], [20], [26], [29], [30], civil and military flight crews [16], [17], [24], and people involved in business, military, and political crises [23]. The validity of this method of study, and the promise that it holds for helping people to improve the quality of their responses to emergency situations, is well documented. It is surprising that there have been so few simulation studies of emergency decision making among miners prior to the work of the authors and their colleagues [7], [8], [10], [33].

The purpose of this paper is to describe the decision-making performance of underground coal miners on a table-top simulation exercise. The exercise content and structure are derived from interviews with individuals who escaped serious mine fires. Performance scores are reported for 134 coal miners who completed the simulation. Because the exercise is a series of objective performance tasks coupled with detailed and immediate feedback at each decision point, it can be used to teach and refresh critical decision-making skills as well as to obtain information about the proficiency of miners at the time of exercise administration.

The simulation was constructed by a multidisciplinary team. Content domain expertise was provided by specialists in mine fires, mine ventilation, mine rescue, and mine safety and a federal mine inspector, who himself had escaped from a fire. A sociologist and educational psychologist, both with extensive experience in mine safety research, provided expertise in decision making and simulation design. The simulation presents vicariously the predicaments encountered by a mine-section crew who had great difficulty in escaping from a fire. Workers completing the exercise select from among a series of problematic decision alternatives actually confronted by the miners in the case example.

The exercise content and structure were initially validated by two other means. First, interviews were conducted with an additional 40 workers who also had escaped major mine fires. Second, many Mine Safety and Health Administration investigations of mine fires were studied, including the mine fire in Wilberg, UT, that resulted in 29 fatalities [22]. Thus, the predicaments and decision alternatives presented by the simulation are characteristic of those involved in actual mine fires.

II. Complexity of Escaping from a Mine Fire

Underground coal mines are developed as huge arrays of parallel tunnels called "entries" crossed at right angles and regular intervals by other tunnels called "cross cuts." Both the entries and the cross cuts are approximately 18-ft wide. Their intersections leave undisturbed blocks of coal 80 × 100 ft called "pillars" that help support the mine roof. This pattern of entries, cross cuts, and pillars often extends for several square miles throughout a tabular coal seam located a few hundred feet below the surface. Many different sections of the mine

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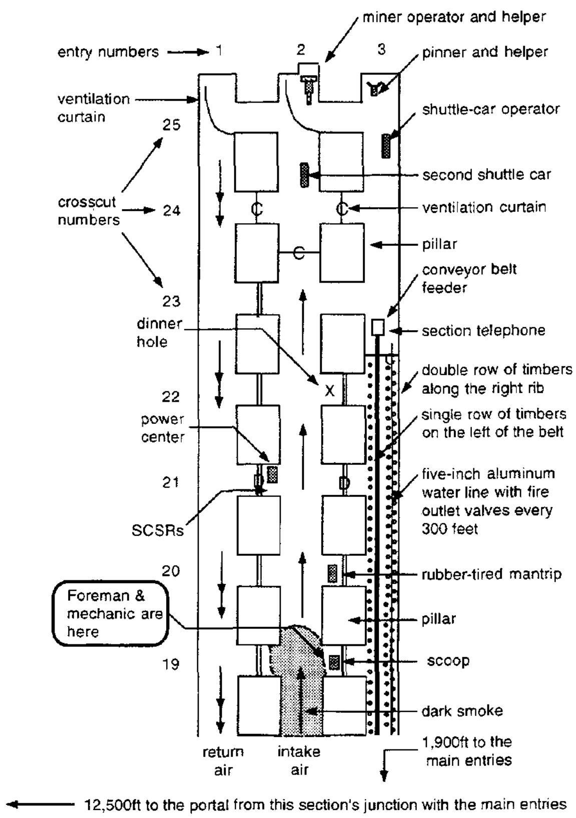


Fig. 1. Mine section map.

connect with each other in complex ways and with only a few openings to the surface, which comprise the entry and exit points for workers and equipment [34].

Fig. 1 depicts a small portion of a typical mine section with a set of three entries (numbered 1, 2, and 3 at the top of the map) that have advanced for 25 cross cuts. (Cross cuts 19–25 are shown on the left side of the map.) At the bottom of the map, the three entries (tunnels) run outward for 1900 ft, where they connect to another set of eight entries that run an additional 12 500 ft to the surface. The entries shown in Fig. 1 are being advanced approximately one mile in order to install a long-wall mining machine. As it retreats, the long-wall machine will cut all the coal from a 1200-ft-wide and 1-mi-long block of coal.

Escape during a fire can be further complicated by the ventilation system that circulates fresh air throughout the mine through an arrangement of large above-ground fans and underground partitions that are constructed in the cross cuts that separate entries. The fresh air is drawn into the mine through a few "intake air" entries (the number 2 entry in Fig. 1) and carried to where coal is being mined as the entries advance. As the intake air is directed by ventilation "curtains" (plastic tarps) across the "face" (the area where the coal is cut), it sweeps up coal dust and methane liberated by the mining activity. This contaminated air is then exhausted from the mine through a set of "return air" entries (the number 1 entry in Fig. 1) [21]. The mine section intake-air and return-air entries connect with other main entries (tunnels) that run thousands of feet to the surface.

During fires, the mine ventilation system can provide a continuous flow of oxygen, and the coal a nearly unlimited supply of fuel. Fires produce very high temperatures, dense toxic smoke, and unpredictable changes in the direction of fresh air moving through the few intake air entries that are the primary escapeway for miners [21]. When a mine fire occurs in this underground maze, miners must escape to the surface by seeking out and traveling accessible routes to one of only a few mine portals (entry and exit points). To escape a mine atmosphere that is oxygen deficient, smoke filled, and contaminated with carbon monoxide, miners must promptly and correctly don emergency breathing apparatus and then find their way out of the mine.

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 can present dilemmas. For example, riding out on a powered personnel carrier called a "mantrip" can enable a rapid escape but sometimes may ignite a lethal methane explosion. Walking out may prevent a methane explosion but requires much time and effort and can result in workers' becoming lost. When escaping miners make these types of decisions, many of their actions are irreversible. Furthermore, the outcomes of the decisions cannot be known until the miners' actions are completed. Therefore, miners should be prepared to predict as accurately as possible how future events will be influenced by their choices among alternative actions.

III. Decision Making and Miner Training

In a review of decision-making theory and research, Halpern [20] makes the following points. A decision always involves choosing among two or more competing alternatives in response to a problem. Unlike traditional academic problem solving, real-world decision making involves dilemmas in which there is usually no clear-cut "best" solution to a problem. There is always inadequate or conflicting information about alternatives. Risks are associated with each choice, and the choices, once made, are often irreversible. The difficulty lies in making judgments about which alternative action is best in terms of maximizing gain and minimizing loss. In an atmosphere of uncertainty, the decision maker must attempt to predict how future events will be influenced by his choices among alternative actions.

Halpern [20] notes 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 the individuals' choices are known *a priori* to those who review the case study. The instructor and trainees tend to judge the merits of decisions made by the individuals involved in the case depending upon the outcomes of those decisions. 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. As Fischoff [15] noted long ago, *hindsight does not equal foresight*. Good decisions depend upon inference and flexible use of heuristics rather than rigid application of algorithms based on post-hoc analysis of events.

Mandatory training for coal miners includes an initial 48 hours of training, an annual eight hours of refresher training, and monthly fire drills. As usually conducted, the training provides little opportunity for miners to engage in problem solving and decision making related to escapes from mines. Generally, escape training is presented in the form of simple rules (algorithms) such as the following.

- "At the first sign of smoke, don your filter self-rescuer (a gas mask) and proceed to the mine evacuation assembly point."
- "Go to the nearest cache of self-contained self-rescuers (SCSR's) (one-hour oxygen-generating breathing devices) and immediately don the apparatus."
- "Gather at the designated assembly point until your section foreman orders an evacuation from the mine."
- "Follow the primary escapeway from the mine and stay with the other members of your group."
- "If the primary escapeway is impassable, exit from the mine by the secondary escapeway."

This rule-bound instruction provides little opportunity for miners to practice problem solving and decision making [8], [12].

In actual escape situations, many factors prevent the simple application of these rules. For example, during actual fires, almost always some miners are missing and do not arrive at the assembly point. A predicament arises when the assembled miners must decide whether to wait for their missing coworkers, conduct a search, or leave without them. If and when all the miners from a working section are assembled, they must decide among routes and methods by which to leave the mine. If a section crew is forced to walk out of the mine, they may have to hurry or risk becoming trapped by the fire. Travel often is difficult because of low seam height, poor footing, and poor visibility from heavy smoke. Miners are taught that they should stay together during the escape. Another dilemma arises because of individual differences in physical fitness. Always, some miners are able to travel much faster than others. What should the group do? Should the entire group travel as slow as the slowest member of the crew and risk death from exhausting their SCSR's oxygen supply or by having their escape route blocked by fire? Should the group split up, allowing the most able to escape, and perhaps to get help to assist their slower coworkers? Another confounding factor is that on many mine sections, there are only one or two persons who fully understand the complex routes out of the mine. During an escape, when the smoke becomes thick and the mine crew becomes 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 and find their way out of the giant maze that comprises the mine? The cut-and-dried rules that miners are taught about evacuation and escape procedures do not address these types of questions. Consequently, when miners are involved in actual fires, they may be ill prepared to deal with the ambiguities and complex interactions that often turn what might at first appear to be a simple escape task into a complex and ill-defined problem.

IV. Utility of Simulations for Decision-Making Training

Simulation exercises based upon actual mine fires and escapes 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 be moderated by the types of situational factors described in the previous section. Well-designed simulations may better prepare miners to cope with actual mine emergencies. It is for this reason that the training of mine-rescue teams, military personnel, and fire fighters routinely use both full-scale field simulations and paper-and-pencil or "table-top" simulations [19], [27].

Table-top simulations are typically based on actual case materials. Unlike case-study reviews, table-top simulations do *not* first present the outcomes of an emergency event as the means by which to evaluate the merit of individual decisions made during the course of the event. Rather, as the simulation problem unfolds, it requires that decisions among alternatives be made with incomplete information and much uncertainty. Well-designed exercises simulate both the conceptual and emotional aspects of decision-making required for coping with an actual emergency event.

Table-top simulations have some advantages over full-scale field simulations or even participation in actual emergencies. First, a table-top simulation can usually be carried out in less time and with less expense than a full-scale field 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 event, could be fatal. Third, table-top simulations can be constructed to foreshorten long periods of time. A real emergency situation that might develop and be resolved over a period of several hours or a few days can be simulated and discussed within an hour. Fourth, table-top simulations can provide the individual with an overall perspective of the key relationships and interactions among the human players, physical events, and equipment and reveal both the predictable and the capricious events that are always part of any emergency situation. This type of overall comprehension of the "problem space" is thought to result in greater wisdom on the part of the participant. 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" [16], [17].

V. Design of the Simulation Exercise

The "Escape from a Mine Fire" (EMF) simulation exercise was developed and field tested over a period of three years. This section describes the exercise content and structure.

A. Exercise Origin

In the summer of 1988, a major mine fire forced the evacuation of three section crews from a large underground coal mine in the eastern United States [31]. All workers survived, but one section crew encountered extreme difficulty in making their escape. Interviews with these individuals, and study of official investigation reports, produced the scenario for the EMF exercise. This simulation recreates many of the predicaments and decision-making alternatives faced by these eight miners.

B. Exercise Scenario

In the simulation, the crew is working in a 52-in coal seam located nearly three miles from the nearest portal. The problem begins when smoke appears in the section's one intake-air entry (see Fig. 1). Not all the miners are immediately aware of the smoke, while others gather at the designated assembly point. The foreman attempts to gather all the miners at the assembly point and to learn the fire's location (which remains unknown because the mine-section telephone is dead). The smoke becomes thicker.

The miners' escape alternatives include driving the mantrip directly into the blinding oncoming smoke (and perhaps the fire) in the number 2 entry to make a rapid escape or stoop walking in the so-far-uncontaminated air of the number 3 belt entry (see Fig. 1). The belt entry is crowded by a conveyor belt on one side and a double row of roof support timbers on the other, leaving a walkway only 52 in high and 3 ft wide. In the simulation (as in the real event), after long delays, the miners eventually gather at the assembly point and then start moving out the still smoke-free conveyor belt entry. They do *not* first don their SCSR breathing apparatus. Frequently, in both real life and the simulation, miners chose to carry and "save" their SCSR's rather than to don them, because they know the one-hour oxygen supply will not last the two or three hours needed to escape.

Soon, dense, blinding, choking smoke appears in the belt entry. The miners are forced to stop and don their SCSR's. With their SCSR's on, they attempt to stay together and follow the conveyor belt out of the mine. After traveling only 200 ft, one miner must stop and rest every few steps. Four of the other miners are able to move out rapidly, and one older miner can move at a slower but steady pace. The miners must decide whether to split up, leaving the slower miners behind, or to stay together and travel very slowly. In the simulation (as in real life), the miners split up. Five miners leave the section and arrive at fresh air about 1200 feet away but still well within the mine. Two healthy miners stay with and attempt to assist the disabled miner. They drag him only a few hundred feet before they both run out of oxygen. All three collapse in the dense smoke. One of the three miners manages to get up and make his escape but is incoherent from carbon monoxide intoxication when he reaches his coworkers and fresh air.

The five coherent miners who escaped must next decide how to help their two missing coworkers. The choices include 1) making changes to the ventilation to direct fresh air to the trapped miners, 2) calling and waiting for proper mine-rescue equipment, or 3) donning fresh SCSR's and going back to search for and rescue the two missing miners.

C. Exercise Design and Structure

The simulation consists of two parts, the 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., details about the coal-seam height, mine ventilation, location of and distances to the portals, mining method and equipment used, etc.). The miner working the exercise is directed to play the role of the section foreman and to make choices among decision alternatives at each of a series of 13 questions throughout the exercise.

A mine section map is provided that shows the location of the smoke, miners, and equipment, the number and arrangement of entries on the section, and the distance and direction from this mine section to the main entries that lead to the portal (see Fig. 1). Each major decision point (question) in the problem is presented one frame (page) at a time. The miner examines the question and studies the alternatives, each of which is numbered. Using a special developing pen, the miner then selects the "best" alternative actions by marking numbered spaces on the "latent-image" answer sheet that correspond to the alternative choices in the problem booklet. When the blank space on the answer sheet is rubbed with the developing pen, an invisible ink or "latent-image" answer immediately becomes visible.

The latent-image message contains two types of information. First, it tells if the decision was correct or incorrect, and 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 what actions they should take as they prepare to leave the section on foot in the conveyor belt entry. One of the eight decision alternatives for this question is:

> Before you leave, send one worker to the section telephone to call the surface to ask for the location of the fire, and to report that your crew is walking out the belt entry.

When the miner rubs the pen in the corresponding blank space between the brackets on the answer sheet, the following message is instantly developed.

> Correct! But the worker returns and says the section phone is no longer working.

The pages of the problem booklet present the scenario as a chronology of events like those experienced by the miners in the reference case as they made their escape. The miners completing the exercise know only what has happened to the point at which their simulated escape has progressed. The correctness and consequences of the alternatives selected at each decision point become known only as these choices are made. In this manner, the miners being trained work through the unfolding predicaments without knowing the effects of their decisions until after they have been made.

Wise, useless, harmful, and potentially lethal actions are provided as alternatives at each major decision point throughout the simulation. The problematic as well as the wise alternatives are taken from the actions of miners in the reference case and from interviews with other miners who also escaped from mine fires.

D. Exercise Scoring

Individual exercise questions (or decision points) list from one to four correct actions among the alternatives. From two to five incorrect alternatives are also listed at each decision point. An individual's performance on a given question (major decision point) is awarded full or partial credit based on the total number of good decision alternatives selected and the total number of poor decision alternatives avoided (not selected). Each decision point is weighted equally so that when the 13 question scores are added together, the exercise total score is scaled from zero to 100. Thus, the total score for any individual can be directly interpreted as percent mastery of the exercise content and skills.

In addition to the total score, item scores can be calculated for each person. This is because the exercise is constructed to assess the individual's choice of alternatives at specific decision points throughout the simulation. Among others, these decision points include:

1) deciding what to do when the smoke is first noticed;
2) prioritizing escape activities;
3) seeking more information about the fire;
4) choosing an escape route and method;
5) deciding what equipment to take along during the escape;
6) modifying the escape plan when heavy smoke reduces visibility to less than two feet;
7) deciding what to do when two miners in the crew are unable to keep up;
8) deciding how to rescue two missing miners who had to be abandoned in the smoke-filled area of the mine.

E. Utility of the Interactive Latent-Image Format

The table-top problem booklet and latent-image answer-sheet format was chosen because it is inexpensive to duplicate and administer in any setting with a minimum of equipment. Only the problem booklets, specially printed latent-image answer sheets, and developing pens are needed. This combination of a high-technology instructional design with respect to exercise structure and content, combined with the low-technology latent-image delivery system, has proved to be an effective interactive simulation exercise format. The format has been used for many years in medical education. The authors of this paper and their colleagues have developed more than 70 other simulation exercises with different content but similar formats. More than a quarter-million copies of these types of simulation problem booklets and latent-image answer sheets have been distributed throughout the United States by the National Mine Health and Safety Academy [32].

VI. Evaluation Methodology

The EMF exercise underwent two rounds of field testing. A preliminary round involved authentication of the exercise by a group of ten nationally recognized mine-fire and mine-rescue authorities. The criticisms, corrections, and comments of these persons were used to revise the exercise before the formal field test. The second round of field testing was conducted at four sites with six groups of experienced miners from several states.

A. Sample Characteristics

A total of 134 miners (including two women) were involved in the formal field testing of the exercise. The mean age of these workers was 41.1 years, with a standard deviation of 8.83. The miners averaged 15.9 years experience in underground coal mining, with a standard deviation of 7.16. This sample is somewhat older and more experienced than a more representative sample from an different study of 3658 underground coal miners from 12 states. In this earlier study, the miners' mean age was 37.2 years, with a standard deviation of 9.00. That group had a mean of 11.9 years mining experience, with a standard deviation of 7.20. The proportion of females in the present study and in the earlier sample are approximately the same [8].

The persons sampled for this study represented three major job categories found in the underground mining industry. These include:

1) miner-laborers (M-L's), hourly employees who are engaged in the various jobs directly related to extracting and transporting the coal out of the mine;
2) maintenance-technical staff (M-T's) such as surveyors, electricians, mechanics, inspectors, engineers, and other technical personnel who do not directly mine coal but who work underground in and around the mine sections;
3) supervisors-managers (S-M's), salaried employees who include the first-line supervisor (section foreman) all the way up to the mine superintendent.

In the mining industry, these job categories are associated with increasing levels of knowledge and skill. Mine foremen and supervisors must pass examinations and be certified in multiple areas, including mine maps, ventilation, health and safety, escape and rescue procedures, etc. Similarly, mine maintenance and technical workers must be certified in their specialties. In addition, their work causes them to travel widely throughout the mine. Because they have to be responsible for themselves as they work and travel about, maintenance and technical workers tend to be more aware of the mine layout, escape routes, and escape procedures than the typical miner-laborer.

In the present study, miner-laborers are underrepresented (24.5%), while mine maintenance-technical personnel (45.3%) and supervisors (30.2%) are overrepresented. In the earlier

TABLE I
MINERS' RATING OF EXERCISE VALIDITY AND QUALITY (FREQUENCY %) (n = 134)

content	Likert rating scale definitely yes			definitely not	mean	s.d.
	4	3	2	1		
exercise is realistic and 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 were 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

study, with the much larger and more representative sample, miner-laborers comprised 50% of the total sample, with maintenance-technical personnel and supervisors comprising 25% each.

Most of the miner-laborers, technical personnel, and supervisory personnel included in the present study were attending regional safety meetings for persons in the mining industry. This fact, as well as these individuals' greater mean age and experience and the higher proportion of technical and supervisory personnel in the sample, suggests that the group is more expert in the exercise content than a more typical sample of miners. Therefore, their mean performance scores also may be higher than the scores of a more random sample.

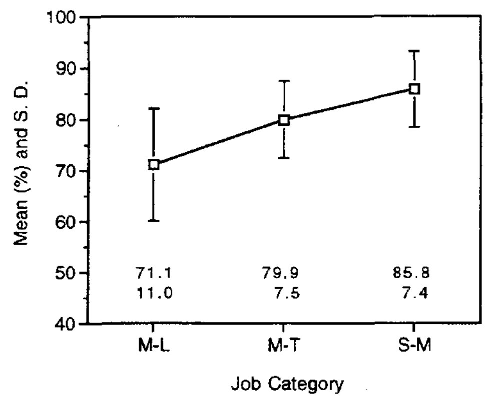


Fig. 2. Total score means and standard deviations by job category.

B. Exercise Validity

Four estimates of the exercise validity were obtained. First, the ten experts who reviewed the exercise in the authentication stage and in its final form judged the content validity to be high. This is not surprising, since the exercise is based on the experiences of miners who had escaped from actual mine fires.

Second, the miners in the field-test sample judged the face validity of the exercise to be high, as can be seen from their ratings on the first three items in Table I.

Third, 85% of the exercise's 63 decision alternatives discriminated positively ($p < .05$) 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 exercise 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 decision alternatives) behave in this manner, they are said to positively discriminate among levels of ability within the sample.

Fourth, the ability of the exercise to significantly discriminate among levels of expertise was determined by an analysis of variance (ANOVA) of exercise total scores by job category. As explained earlier, knowledge of mine rescue and escape procedures can be expected to increase across job categories from miner-laborers through maintenance-technical workers to supervisors-managers. The ANOVA was run on the 106 persons for whom there was a complete vector of exercise question and total scores and for whom a definitive job category assignment was listed. Fig. 2 plots the means and standard deviations of the exercise total score for these three groups by job categories. Table II presents the ANOVA results. Job category accounted for approximately 29% of the observed variance in exercise total scores.

C. Exercise Reliability

Using the item and total score performance data for the 134 miners, the Cronbach alpha generalizability coefficient was calculated for the exercise as an estimate of its reliability. The

TABLE II
ANOVA RESULTS FOR EXERCISE TOTAL SCORE BY JOB CATEGORY (n = 106)

source	sum of squares	d. f.	mean square	F	p≤
between groups	3051.92	2	1525.96	21.31	0.00001
within groups	7302.54	103	71.59		

eta squared = 0.293

observed value of .74 is a respectable reliability coefficient. The reliability of the exercise could be expected to increase if a more heterogeneous sample of miners were used. This present sample consisted of miners who were highly trained and more experienced than is typical.

VII. RESULTS

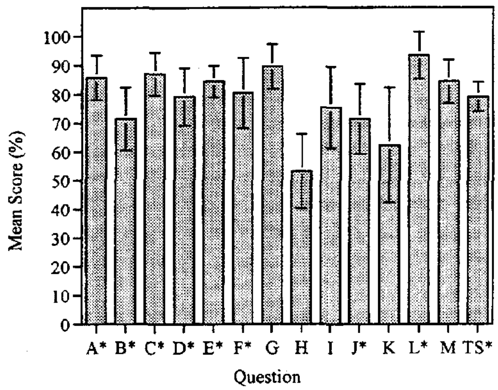
The results of the EMF field test are presented in three parts. The first part presents the miners' evaluation of the authenticity and utility of the exercise. The second part describes the miners' performance in choosing among the 63 alternatives for the 13 major decision points. The third part describes the mastery level of the miners.

A. Miner Evaluation of the Exercise

Each person who worked the simulation completed a ten-item Likert-scale rating form. The first three items on the form are designed to elicit the miners' evaluation of the authenticity of the exercise and its worth as a training device. The remainder of the items dealt with the functionality of the exercise structure and design. Miners' ratings on each of the ten items are presented in Table I. Even though this sample consisted of highly experienced workers, all persons reported that the exercise was authentic and would help them to remember important things, and nearly 94% reported that they learned something new.

B. Question and Total Score Performance

An individual's 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 score and a standard deviation for each question score were calculated. An ANOVA was carried out for each question score to determine which of the 13 items significantly discriminated among the 106 persons who clearly fit within one of the three job categories. Fig. 3 presents graphically 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 percent correct so that all question scores and the exercise total score can be compared to one another in terms of difficulty. The eight question scores that significantly discriminated among job categories are marked with an asterisk.



*Questions that discriminate among job categories (p < .05)
(Question scores = A - M, TS = exercise total score)

Fig. 3. Question and total score means and standard deviations.

An inspection of Fig. 3 reveals an important finding. Questions H and K are the most difficult decision points in the exercise, and there is no significant difference among the scores on these items across workers in the three job categories. Additionally, the mean score for Question H is 53.2%, with a standard deviation of 25.8. The mean for Question K is 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 have in common a dilemma that is encountered in actual escapes from mine fires but is rarely discussed in miner training classes, where the focus tends to be on escape algorithms and rules.

In Question H, the scenario has developed to the point where all the miners are in heavy smoke, wearing their SCSR's, and having difficulty moving in the narrow, low walkway along the belt entry. An unfit miner is unable to maintain the pace needed to escape from the section before conditions become fatal. The four decision alternatives include 1) forcing the straggler to keep up, 2) having all the other miners slow down, 3) having members of the crew take turns carrying or dragging the unfit miner, and 4) letting the group split up leaving the straggler on his own. The weight of the straggler (260 pounds), his poor physical condition, the narrow and low walkway, and the restrictions on heavy work imposed by wearing an SCSR make the first and third options difficult and dangerous. The correct (and troubling) decision is to let the group split up so that those miners who can travel rapidly have a chance to escape. Discussions with miners following the exercise suggests that they understand the dangers of the two incorrect alternatives and the logic of the correct decision. However, many persons in all three job categories selected wrong alternatives to this question.

Question K addresses a predicament that arises when workers are missing in mine fires and other miners wish to find and rescue them as soon as possible. The question concerns two miners who wish to don fresh SCSR's and reenter the smoke-filled area of the mine to search for and bring out a missing miner. The person working the simulation exercise must weigh the merits of the two miners' rescue plan against decisions that the rescue attempt should wait until 1) the fire is under control, 2) fresh air is restored to the area being searched, and/or 3) a properly equipped mine-rescue team arrives. Based upon many accident investigations and interviews, these decision alternatives are known to be problematic for miners. As indicated by their low scores on these items (see Fig. 3), these decision alternatives also proved difficult for the 134 miners who worked the simulation exercise, even though this is a highly knowledgeable and select group who clearly understand the risks.

As perceived by the survivors in our interviews, this predicament arises from the need for the prompt rescue of the missing miner if he is to live and the dangers of using SCSR's to attempt the rescue. SCSR's are designed *only* 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 rescue activity. Yet, if the missing miner is not rapidly retrieved from the smoky area of the mine, he may die from carbon monoxide intoxication and smoke inhalation

This issue of mounting rescue efforts with SCSR's was hotly debated by the miners involved in the field tests of this exercise. While all persons recognize the good intentions of miners who want to use SCSR's to rescue missing individuals, they disagree on the merit of such attempts. Experienced mine-rescue personnel argue that it is so difficult to travel and work in smoke while wearing an SCSR that the risks are too great to justify any attempt to use the device to rescue a trapped miner. Potential problems with such attempts include the would-be rescuers' 1) becoming disoriented and lost, (2) having great difficulty finding, lifting, and moving the missing miner, (3) displacing their SCSR mouthpiece or nose clips in a toxic atmosphere, and (4) running out of oxygen. These difficulties are very likely during the rescue attempt and singularly or in combination can easily result in serious injury or death. Furthermore, the loss of the would-be rescuers makes the original situation much worse because:

1) more miners are missing and must be rescued;
2) fewer persons are immediately available at the scene to conduct the support work necessary to a rescue;
3) those persons who subsequently must attempt rescue of the additional victims are also endangered, even when they are properly equipped with mine-rescue apparatus;
4) the rescue of the original victim(s) will be delayed increasing the probability of his (their) death.

1) Mastery Levels: Each question score in Fig. 3 is scaled on a 0–100% 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 percent mastery of exercise skills and content.

Self-rescue skills like those presented in this simulation exercise should be learned to high levels of mastery in order to minimize errors that can be very costly in terms of injury, death, economics, and public image. As a general rule, proficiency levels for these types of critical skills are set at a minimum of at least 90% correct performance by at least 90% of the trained population [9], [27]. Fig. 4 plots the percentage of persons in the sample who scored within each of seven mastery-level score intervals. Only 13.6% of the 134 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 random sample of miners might be expected to perform at lower levels than did this group of highly experienced and well-trained workers.

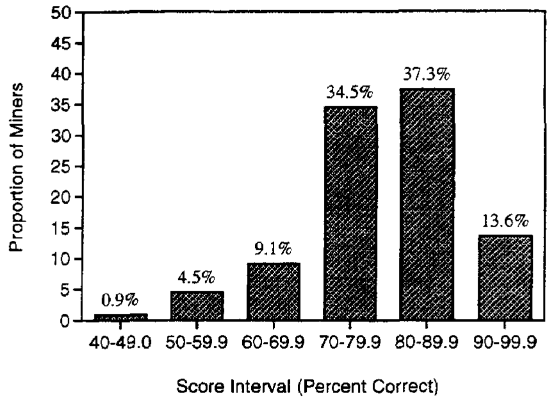


Fig. 4. Proportion of miners attaining various mastery levels.

VIII. Conclusion

The mean performance scores of all three job-category groups fell well below the desirable level of mastery for the critical self-rescue and escape skills presented in the EMF simulation exercise (see Fig. 2). The exercise total score, however, 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 miner-labors the lowest mean score (71.1%). The exercise total score also significantly discriminated ($F = 17.352$, $p < 0.0001$) 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 were no significant differences in the mean performance scores by job category (see Fig. 3) or by mine-rescue training level. This finding suggests that the issues associated with having to abandon a helpless miner, and engaging in unsafe attempts to rescue missing workers, are clearly problematic decisions for all miners regardless of their training level. Miners in all three job categories appear to understand the potentially lethal consequences of unsafe rescue attempts but frequently choose unwisely in the simulation exercise. It should be noted that this also happens frequently in real life, where 39% of deaths in confined spaces are to would-be rescuers of earlier victims who are often already dead [28].

We have observed that when miners and accident investigators alike discuss actual escape and 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 are injured or die, the miners' actions tend to be seen as well intentioned but foolish, and sometimes illegal. This approach to reviewing the merit of escape decisions with prior knowledge of outcomes may be counterproductive. It may develop a mindset that cannot be effective in the decision making that occurs in an atmosphere of uncertainty during an actual mine emergency. During real and ongoing crises, workers' decisions and actions must precede knowledge of the consequences of those actions. Such decisions must be based on 1) the incomplete information that is available at the moment, 2) estimates of the feasibility of alternative actions and their likelihood of success, and 3) the weighing of the relative risks associated with each alternative.

This EMF simulation provides a vicarious opportunity for miners to confront the life-and-death choices involved in escaping from a mine fire. Undoubtedly, the vicarious experience from such a simulation is not sufficient to prepare a miner for a real-world mine fire. It is almost certainly better, however, to have studied, worked, and debated the choices and decisions encountered in the simulation exercise than to encounter them for the first time during an actual mine fire. The EMF simulation exercise is not just an interactive "story." Rather, it is a composite of a type of emergency situation that too often claims miners' lives [22]. To the extent that such simulations accurately reflect the dilemmas and decisions encountered in actual fires, they provide better training for these nonroutine events than does only the more traditional teaching of facts, escape algorithms, and post-hoc analysis of case studies.

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