CHAPTER 9

Psychological and Behavioral Aspects of Occupational Safety and Health in the US Coal Mining Industry

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Overview

In the US mining industry, psychological aspects of safety and health are defined very broadly as psychosocial issues. Psychology is embraced literally as the study of human behavior, and the focus is on studying human behavior as it relates to injuries and fatalities with the goal of mitigating further instances.

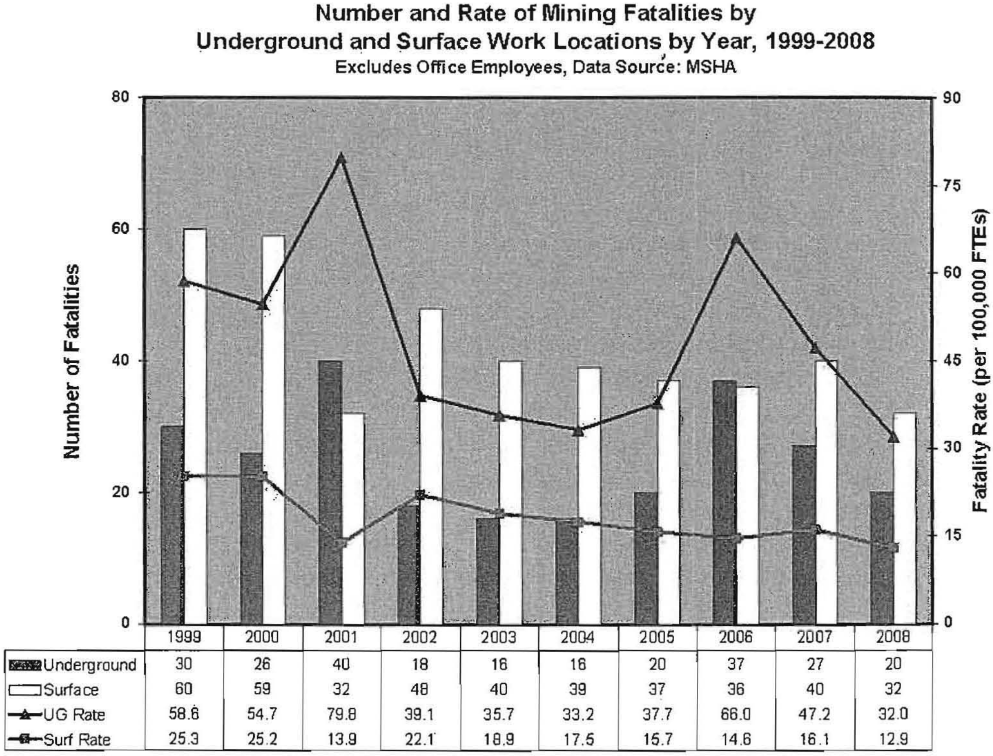
This chapter explores the psychological and behavioral dimensions of occupational safety and health (also referred to as OSH) for workers mining coal underground. Mining has a history of disasters that have formed the framework for an array of OSH interventions. Within the mining industry, the severity of the hazardous environment has necessitated a focus on controlling, managing, and changing the physical environment or "engineering out" the hazard. More recently, a growing body of research indicates that specific job/task and organizational-level factors may have a powerful influence on safe work practices and accident deterrence—thus reducing injuries and deaths of coal miners (DeJoy, Gershon and Schaffer, 2004). Although it must be noted that many psychosocial aspects of OSH in mining are relevant to all major mining sectors (that is, coal, metal, non-metal, stone, and sand and gravel) as well as many other hazardous industries (commercial fishing, transportation, agriculture) the human behavior issues addressed here have tended to arise from underground coal mining.

The chapter is organized to first present the reader with an introduction to the underground coal mining environment, followed by lessons learned from mining disasters. The authors present a model to reduce worker exposure. The research in key psychosocial areas is discussed including judgment decision making and leadership in escape, training, and the introduction of refuge chambers into underground mines. Research on the aging mining population, shift work, hazard recognition, job stress, and resiliency is discussed. The authors conclude with a summary and thoughts for the future.

Introduction—Mining Environment

Mining is one of the oldest occupations known to mankind, perhaps second only to agriculture (Hartman and Mutmansky, 2002). Removal of minerals from the earth has often resulted in heavy human losses. Each year, around the world, thousands of miners die as a result of mining accidents.

In 2008, there were 925 underground and 13,982 surface mining operations reporting employment to the US Department of Labor, Mine Safety and Health Administration (MSHA). Most of the underground mines are for coal extraction (n = 665, 72 %), while the majority of surface mines produce sand and gravel (n = 7,132, 51%). The fatality rate and lost time injury rate at underground mining operations has been consistently higher than the rates for surface mines (Figures 9.1 and 9.2).


Number and Rate of Mining Fatalities by Underground and Surface Work Locations by Year, 1999-2008

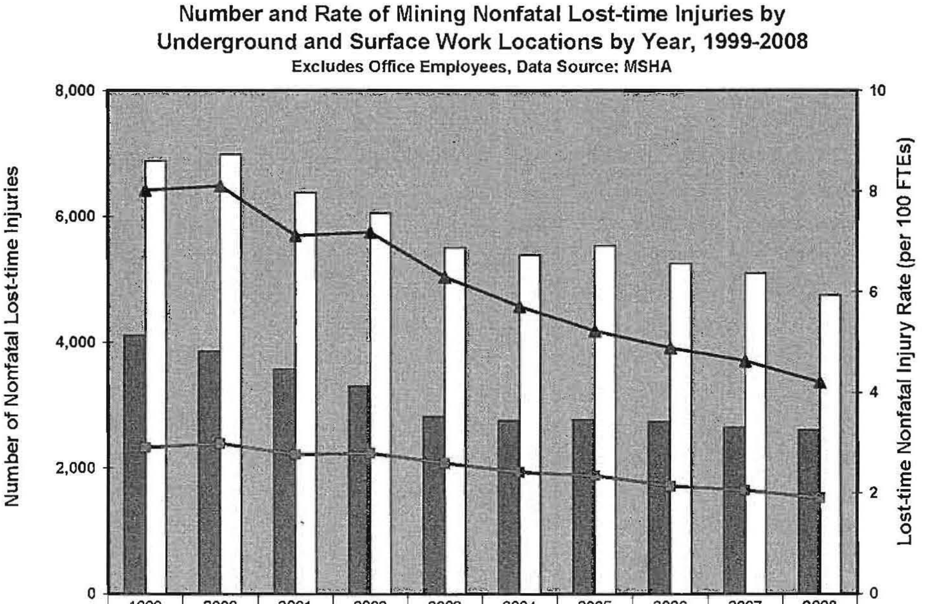
Excludes Office Employees, Data Source: MSHA

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
▨ Underground	30	26	40	18	16	16	20	37	27	20
☐ Surface	60	59	32	48	40	39	37	36	40	32
▲ UG Rate	58.6	54.7	79.8	39.1	35.7	33.2	37.7	66.0	47.2	32.0
■ Surf Rate	25.3	25.2	13.9	22.1	18.9	17.5	15.7	14.6	16.1	12.9

Figure 9.1 Mining occupational fatality rate by work location (1999–2008)

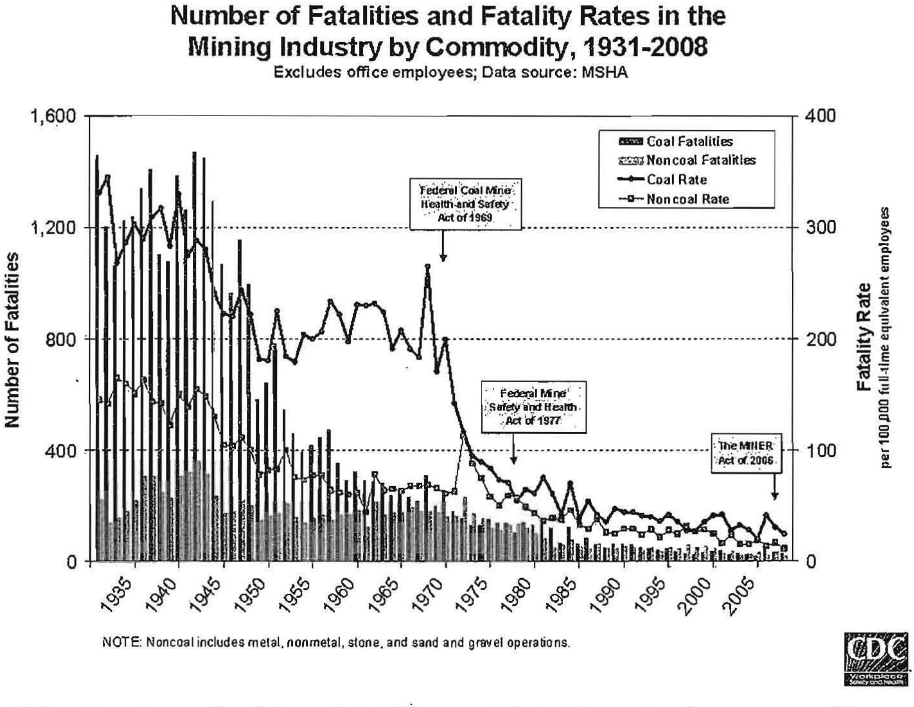
In addition, coal has the highest number of fatalities of all commodities mined, as illustrated in Figure 9.3.

Many regions of the US are underlain by horizontal coal beds (seams) that cover an enormous area. Sometimes a seam of coal will underlay a significant portion of an entire state.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
▨ Underground	4,103	3,854	3,570	3,306	2,818	2,753	2,772	2,739,	2,645	2,600
☐ Surface	6,881	6,985	6,379	6,052	5,504	5,386	5,538	5,249	5,097	4,748
▲ UG Rate	8.0	8.1	7.1	7.2	6.3	5.7	5.2	4.9	4.6	4.2
▨ Surf Rate	2.9	3.0	2.8	2.8	2.6	2.4	2.4	2.1	2.0	1.9

Figure 9.2 **Mining non-fatal lost time injuries by work location (1999–2008)**



NOTE: Noncoal includes metal, nonmetal, stone, and sand and gravel operations.

Figure 9.3 **Number of mining fatalities and fatality rates by commodity (1931–2008)**

These seams may be anywhere from 28 inches to 12 feet or more in thickness. There are two primary underground mining methods used to extract the coal seams—room and pillar, and longwall. With the room and pillar method, the coal seam is "developed" by driving sets of three to eight parallel tunnels, 16 to 20 feet wide, called "entries." These entries, whose centers are 60 to 100 feet apart, may be several thousand feet long. They are connected at right angles by "crosscuts," also 16 to 20 feet wide, at intervals of 60 to 100 feet. The purpose of the crosscuts is to maintain ventilation, and to allow the movement of mobile mining machinery between the entries. Coal is produced as a result of excavating these entries and crosscuts, which constitute a "section" and the points at which coal is actually being extracted are called "working faces." The faces are mined in a cycle. First, a remote-controlled "continuous" mining machine, equipped with a large steel revolving ripping head, takes coal from a face. The mining machine dumps the coal onto "shuttle cars," which haul it to a dumping point ("tailpiece") where it is fed onto conveyor belts and transported out of the mine. After the mining machine reaches a predetermined point at one face, it backs out and goes into the next entry and begins on that face. A "roof bolting" machine is driven into the vacated place and its operators insert steel bolts, some six feet long, vertically into the "roof," or overhead strata. These bolts are installed to prevent the roof from caving in. The pillars of coal created by this system of entries and crosscuts are left to provide additional support.

In a longwall operation the longwall is developed by driving two parallel three-entry sections, approximately 2,000 feet apart, into the coal seam for as much as three miles. The sections, called "longwall setup sections," then turn toward each other and connect. This creates a horizontal block of coal that is then extracted using a "shearer." A shearer is a machine that travels back and forth across the longwall face shearing coal from along its entire width and dumping it directly onto a conveyor belt to be taken outside (see Figure 9.4) As the coal is mined, the longwall retreats toward the point at which the setup began, with the roof caving in behind it as it goes. This process may take months. Once the block of coal is mined, the equipment is moved to another setup and the process begins again.

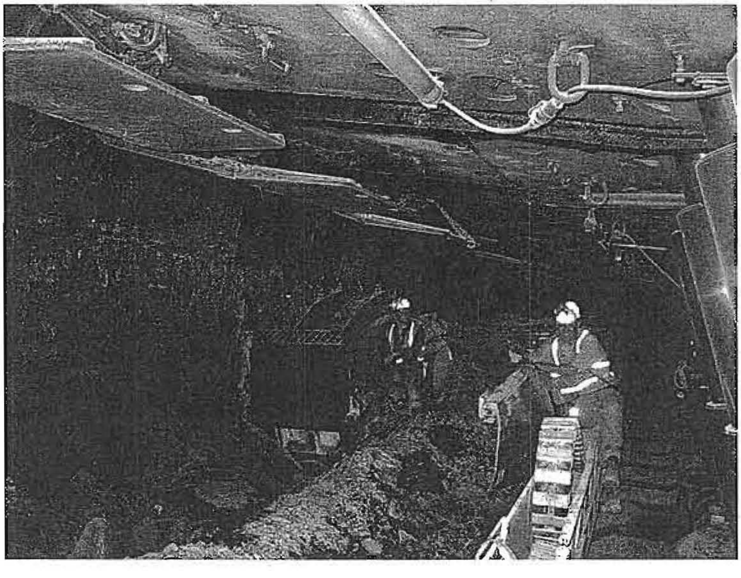


Figure 9.4 Miner at longwall face

All working faces, including the longwall face, are ventilated with fresh air from the outside. The air is brought into the mine by large fans that pull it down "intake" air shafts. In order to get the air to each face, it is directed through certain designated entries by constructing "stoppings" (concrete block walls) in each crosscut. At the faces, the air is routed by hanging plastic "brattice" curtains. It sweeps across, removing explosive dust and deadly gases and taking them down "return" entries where the exhaust fans pull them outside.

Even under normal conditions, as is widely recognized, an underground coal mine is filled with potential hazards and discomforts. There are limited opportunities for egress in the event of an emergency, workplaces at the face may be confined and noisy, and the only available lighting comes from miners' battery powered cap lamps or powered machines. There are also the usual frustrations of equipment malfunction, mud, water, dust, electrical hazards, and minor injuries such as slips, trips, and falls. Additionally, working in low-height coal is quite challenging to miners' backs and knees, given the need to "duck walk" or crawl in the confined space available.

Workers at the face are not the only ones affected by hazards and emergencies. Dispersed throughout the miles of entryways are a host of support personnel, performing such tasks as laying or repairing track, building stoppings, timbering (installing wooden props in areas needing extra support), cleaning under haulage belts, inspecting hoses, belts and cables, cleaning up roof falls (collapses), pumping water out of low-lying areas, and hauling supplies. Many of these workers work alone or in small crews, sometimes without direct supervision. In most mines today mining activities take place during three shifts, seven days a week.

The potential for injury and emergencies is ever-present. For instance, miners must be aware of oxygen deficiency in locations that may not be adequately ventilated. And, the coal mining process releases dangerous gases, including highly explosive methane gas, that are trapped within the coal seam and their release is part of the mining process. Miners may have to deal with carbon monoxide should there be a fire or explosion underground. In such an event, to give miners a better chance to escape, some of the intake air entries are isolated from others. They may be miles long, but are designed to provide clear air to escaping miners as they make their way out of the mine in the aftermath of a fire or explosion. Sometimes the primary escapeways become compromised in an incident and workers may try to escape through "secondary" escapeways.

As per federal regulation, miners are required to carry oxygen-generating devices for use during an emergency like a fire or an explosion as the mine air becomes unsafe to breathe. These devices are always carried on their belts when inside the mine, and are called "self-contained self-rescuers" (SCSRs) (Figure 9.5). The SCSR is designed to provide one hour of oxygen to the user and comes with goggles (to protect the eyes) and a mouthpiece and nose clip (to isolate the lungs). The units' average weight is 3 to 4 lbs.

A substantial number of miners may face the need to escape from a mine emergency, usually a mine fire, at some point in their career. The basic protocol for escaping from an underground coal mine in an emergency has changed little in the past century. Miners are taught to make every attempt to escape if there is an emergency, following the designated escapeways to safety. If escape is impossible, miners previously were trained to seek temporary safety by erecting a barricade and awaiting rescue. A barricade is erected with available materials such as cement blocks or brattice curtain—used for mine ventilation—

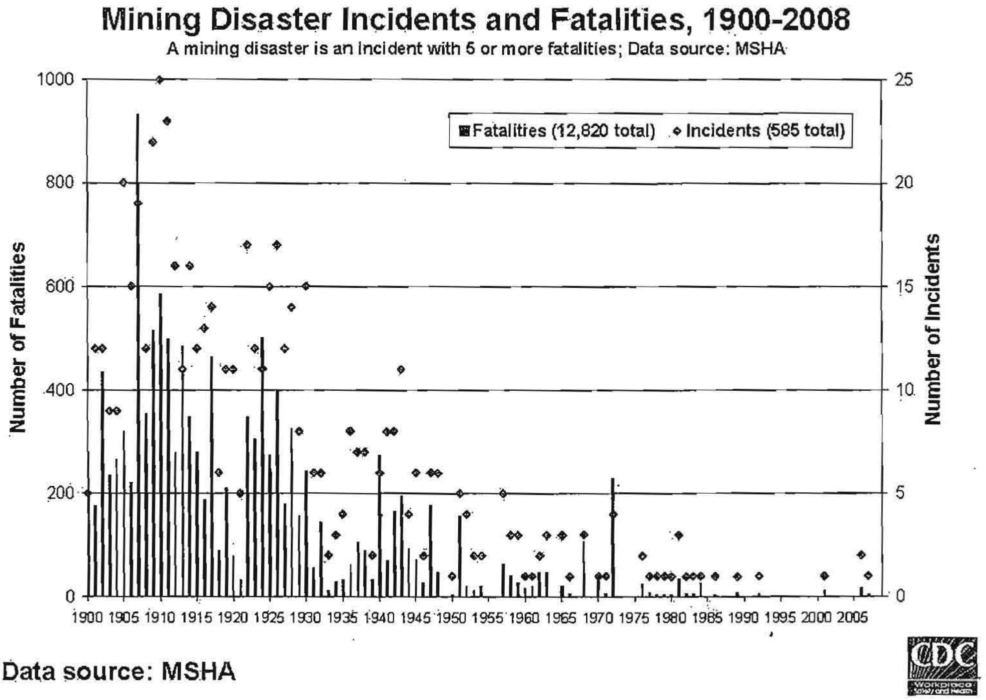
Figure 9.5 Miner donning self-contained self rescuer

with the goal of isolating the miners from toxic air. Since the Sago Mine Disaster in 2006, if escape is impossible, miners are trained to seek shelter in a refuge alternative.

Lessons Learned Through Mining Disasters

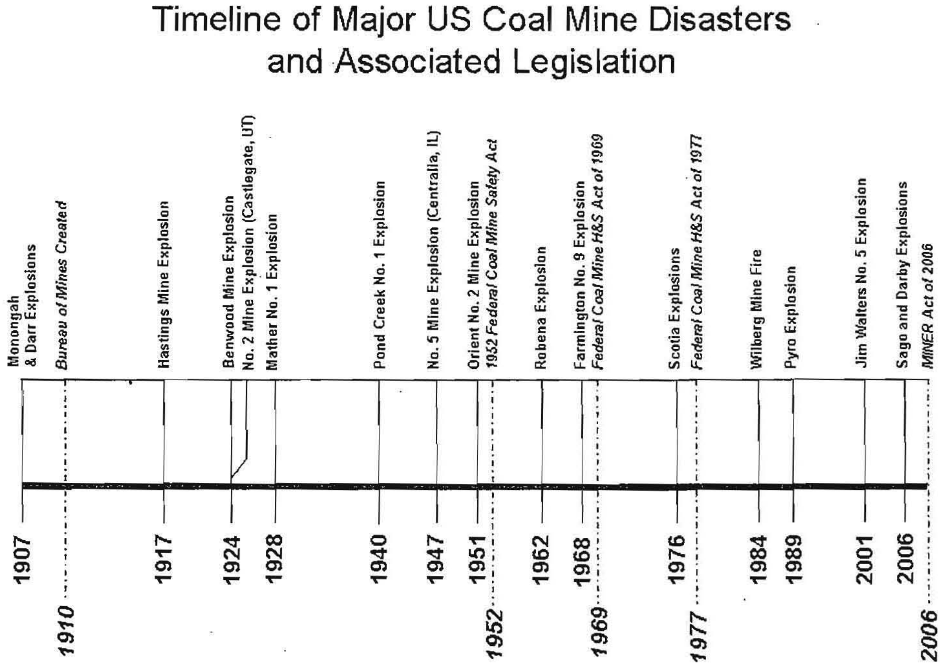
Figure 9.6 illustrates mining disaster incidents and fatalities 1900–2008 and Figure 9.7 provides a timeline of major mine disasters and the resulting legislation that they spurred. Each major piece of legislation had an impact on the fatality rates and the direction of research in the industry. Each of the various Congressional acts dealt with more than just responses to disaster. The 1977 Act, for instance, required that miners receive annual refresher training, which is composed of ten courses. Only one of the courses deals directly with escape and emergency evacuation. The rest include such topics as mandatory health and safety standards, first aid, accident prevention, and health.

Within a five-month period in 2006, three separate mining incidents occurred in the US and resulted in the deaths of 19 miners. All three incidents received nationwide attention, particularly the Sago, West Virginia Mine disaster, which occurred on January 2 and resulted in the deaths of 12 miners. The other two incidents, which occurred at the Alma No.1 Mine, also in West Virginia on January 19 and the Kentucky Darby No.1 Mine on May 20, resulted in the deaths of two miners and five miners, respectively. The occurrence of three fatal incidents in five months was a departure from recent trends in underground coal mining safety (refer to Figure 9.6). Before 2006, the frequency of mining disasters had decreased from a high of 20 in 1909 to an average of one every four years during the time period 1985–2005 (Kowalski-Trakofler et al., 2009; McKinney et al. 2002).



Data source: MSHA

Figure 9.6 Number of fatalities and rates (five-year aggregates) in the mining industry (1911–2008)



Fgure 9.7 Timeline of mining disasters and resultant legislation

Prior to the Sago incident, mines were only required to provide miners with a single self-contained breathing apparatus (SCSR), which provided one hour of safe air to the user. The sole survivor of the affected Sago mining crew reported that some of his fellow miners thought their SCSR was not working properly. The availability of extra SCSRs might have made a difference in the crew's decision to barricade instead of continuing their escape. These events led to renewed attention to mine safety, health, and training by organized labor, mine operators, lawmakers, and the general public (US). The public outcry resulted in the enactment of the Mine Improvement and New Emergency Response Act (MINER Act, 2006). The MINER Act requires mine operators to develop and maintain better plans for emergency preparedness and response. The legislation requires mine operators to provide caches of SCSRs along escapeways. The protective equipment must be spaced no more than 30 minutes travel time apart along the entire length of each escapeway, thus providing a minimum of two hours of safe air.

The inability of trapped miners to communicate with rescuers during the Sago Mine disaster led to other features in the MINER Act. Mine operators are now required to install wireless two-way communication and mine worker tracking systems between underground and surface workers. Congress subsequently passed an emergency supplemental appropriation to accelerate implementation of (1) emergency oxygen supplies; (2) refuge chambers; and (3) communication and tracking systems.

Occupational Safety and Health Intervention Model to Reduce Worker Exposures

In a hazardous and physically demanding work environment such as underground coal mining, a simple three-tiered model enables researchers and OSH practitioners to systematically design and evaluate interventions to protect workers. These interventions are termed "controls" as they are used to reduce or prevent, albeit control, worker exposure to the health and safety hazards in the work (mine) environment. The first tier of the OSH intervention model is engineering controls, which attempt to remove dangers to workers by optimal process and/or equipment design (technology). Examples of successful engineering solutions include advances in mine roof support technology (prevents roof collapse), noise abatement through equipment design (preserves hearing and enables better signaling), reduction of coal dust dispersion by dust control methods (reduces lung disease and improves visibility), and personal protective equipment technology (such as the SCSR, which generates safe breathing air for the user). Administrative controls represent another line of defense by ensuring appropriate rest and work cycles through shift schedules, safety training, and pre-shift mine safety evaluations. The final OSH intervention model tier is behavioral controls, which focus on whether safe work practices are effectively utilized—including training (knowledge and skills) and proper use of personal protective equipment (for example, SCSRs). This speaks to judgment, decision making and actual work performance (Figure 9.8).

Engineering Controls or interventions are physical manipulations of the sources of the hazard or the manner of exposure to the hazard. Examples include controlling noise, chemical exposure, and heat; erecting barriers; positioning switches for safer use; and redesigning electrical tools and equipment.

Administrative Controls are initiatives by management to modify a work process or exposure (organizational issues). Examples include developing a standard operating procedure and adjusting work practices such as job rotation or better shift schedules. Training is sometimes considered an administrative intervention.

Behavioral Controls focus on influencing workers' and employers' attitudes, knowledge, beliefs, or behaviors concerning work hazards or issues of worker health. Examples include training workers to wear personal protective equipment, using behavior modification techniques such as feedback to promote safer behavior, and encouraging worker health. Training may also be considered a behavioral intervention.

Figure 9.8 Occupational safety and health intervention model to reduce worker exposures

Key Mining Occupational Safety and Health Research Extends Beyond Engineering Controls

Engineering the danger out of the mining environment, the job task, tool, or machinery has represented the vast majority of the safety and health interventions in the US mining industry to date. The importance of training gained recognition in the latter third of the twentieth century, but focused mainly on training workers on the use of technology, tools, machinery, and later, job tasks. Almost 20 years ago, Canter, in discussing issues of escape from structural fire, argued that there is already enough evidence to support the contention that as far as "hardware" solutions are concerned, "such provisions are frequently insufficient and in many cases inappropriate...*human aspects* of the causes and development of fire must be understood if its disastrous effects are to be minimized" (Canter, 1990, p. xii, xiii, 2). Training remains a key component of health and safety in the mining industry, but, while still dealing with "hardware" issues, now pays attention to the human element as well.

Before the 1990s, mining research on behavioral aspects of OSH was conducted mainly through government contracts and reporting mechanisms. Peters (1989) reviewed the earlier research that was focused on organizational and behavioral factors associated with mine safety. Using the context of our OSH interventions model, Peters' review included administrative/organizational issues and individual behavior. The administrative review covered themes such as training, planning, commitment to safety, production pressure, incentive programs, and supervisor-employee relations (DeMichiei et al. in Peters, 1989). Individual behavioral themes gleaned from the review included worker autonomy, absenteeism, role ambiguity, role overload, and role conflict (Goodman et al. in Peters, 1989). These early efforts identified a number of important psychosocial issues in mining, eventually leading to a more structured internal research program by the US Government.

In 1984, the United States Bureau of Mines (now The Office of Mine Safety and Health Research (OMSHR) and the National Institute for Occupational Safety and Health (NIOSH) initiated a program of research to develop performance-based teaching and evaluation methods for assessing critical non-routine health and safety skills (that is, those needed in emergency situations like fires and explosions). This research moved beyond engineering controls and furthered administrative and behavioral control interventions for safety and health in mining through training. Previously, most training had focused on providing miners with routine technical information and experience with machines, tools, job tasks, and personal protective equipment (PPE). Fires and explosions are a major hazard in underground coal mines, yet, from the perspective of most miners, fires and explosions are considered infrequent events. At the time, little was known about the behavior of mine personnel in non-routine circumstances.

A substantial amount of research suggests that worker behavior is a very important contributor to many types of mining accidents. For example, Sanders and Shaw (1988) assessed the extent to which various types of factors contributed to 338 accidents in US underground coal mines. Expert raters assessed the degree to which each of ten types of potential causal factors played a role in each accident. Researchers concluded that "perceptual-cognitive-motor" error of the injured employee was involved to some degree in 93 percent of the cases and when involved, averaged about 33 (of 100) points of causality. The factor was considered a primary causal factor in almost 50 percent of cases and a secondary causal factor in another 24 percent. Management was the second most important causal factor. It was considered a primary factor in 22 percent of the cases and a secondary factor in another 12 percent. A similar study was commissioned by the Queensland Department of Mines and Energy in 2009. Utilizing a Human Factors Analysis and Classification System, researchers reviewed 500 accidents and incidents, and found that human error resulting in unsafe acts was a major contributor, 94 percent of the time.

Mine OSH researchers have begun incorporating principles of adult learning into training and evaluating the efficacy of training using models from the social sciences. Psychological and behavioral OSH research areas in the mining industry now include traumatic incident stress, the effects of the aging mining population on the industry, issues of perception in hazard recognition, the effects of fatigue in shift work, psychological issues related to the introduction of refuge chambers in underground coal mines, potential mental health issues related to the environment, safety culture, the effect of the dynamics of small rural communities in disaster response, and the overall question of how to make the mining workforce more resilient. A few of these areas will be presented in more detail below.

ENHANCING JUDGMENT AND DECISION-MAKING SKILLS

Electrical injuries in mining are not unusual in underground mines. The largest single category of electrical injury is the non-contact electric arc flash. An arc flash is the sudden release of electrical energy through the air when a high-voltage gap exists and there is a breakdown between conductors. An arc flash gives off thermal radiation (heat) and bright, intense light that can cause burns. Temperatures have been recorded as high as 35,000 °F. High-voltage arcs can also produce considerable pressure waves by rapidly heating the air and creating a blast. This pressure burst can hit a worker with great force and send molten metal droplets from melted copper and aluminum electrical components great distances at extremely high velocities. The National Institute for Occupational Safety and Health (NIOSH) examined behavioral control factors using personal interviews with victims and witnesses and an evaluation of the safety climate (Kowalski-Trakofler and Barrett, 2007). A surprise finding in this study was that qualified workers with ten to 16 years of professional experience were making inappropriate behavioral choices that led to the circumstances in which they were injured. Therefore, study recommendations included programs for the seasoned miner that added training in judgment and decision-making skills, while continuing to focus on technical skills and knowledge.

NIOSH evaluated three major mine fires that had forced the evacuation of miners who were working beyond the area of the fire and had to escape through smoke-filled passages in a very hostile environment. Forty-eight of the escaped miners were interviewed about their escape experiences, which provided NIOSH with a rich data base which readily supported a focus beyond engineering and administrative controls to the study of human behavior in escape from mine fires (Vaught et al., 2000). Researchers analyzed the data from the mine fire interviews in a variety of ways over the following decade, including examining individual and group behavior. They discovered that the miners underwent a complex decision-making process as they escaped the smoke-filled mines. Researchers constructed a model of the judgment and decision-making process along with analysis of fire warnings and the uncertainty of information in an emergency environment. The interactive judgment and decision-making model reflects the underlying demand on decision makers in most life and death situations (Figure 9.9).

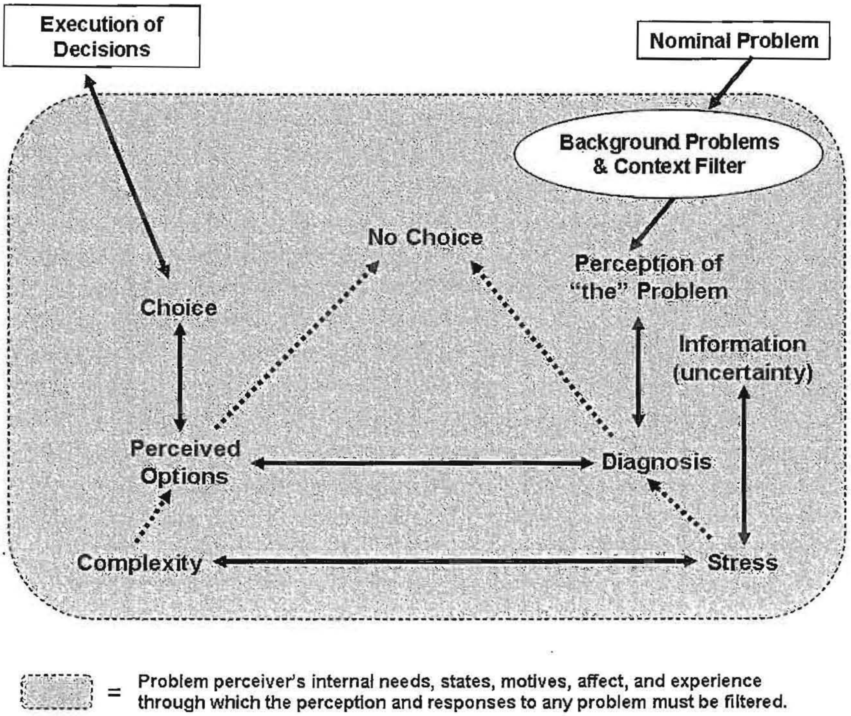


Figure 9.9 Model of judgment and decision making
Source: Vaught et al., 2000.

As miners escape, they go through a multi-step process of judgment and decision making. This process is ongoing and continues from when they first perceive there is a problem until they reach safety. Initially, miners are presented with the nominal problem. In the case of the 48 miners interviewed, this was a mine fire. As miners begin to perceive the problem, background problems and contextual issues factor in. Background problems include information such as knowledge of the fire location or the smell of smoke. Contextual issues include miners initially framing the problem as a routine event, such as smelling smoke from bonds being welded at rail joints, instead of as a non-routine event that could be signaling an emergency situation.

Once the miners perceived the problem, they entered a diagnosis (or analysis) phase. Stress from a variety of sources, including information uncertainty, affected their ability to effectively analyze the situation. After analyzing the situation, miners assessed options available for responding to the circumstances. Then, they selected an option and executed their decision. In some instances, miners made choices and executed decisions only to find that they made the wrong choice. They then re-evaluated the situation, perhaps through further diagnosis, and made new decisions about courses of action. This judgment and decision-making process continued throughout the entire escape.

An emergency makes it necessary to deal with an enormous amount of information in a rather short timeframe, and the information may be faulty. Researchers identified several important points about judgment and decision making in this environment. First, miners often initially placed the warning signs of the problem, such as the smell of smoke, within the context of normal activities, rather than as an emergency situation. This delayed accurate identification of the problem. Second, the diagnosis made by escapees was affected by the nature of the warning message they received, that is, for some the warning came in the form of a phone call while for others the warning was delivered face to face. Those contacted by phone spent time trying to verify the message, whereas those warned face to face tended to act more quickly. Third, miners' perceived options and choices were impacted most by their overall knowledge of the mine and the quality of information available. The researchers determined that "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 viable options. A warning system should be designed to provide the most information possible to comply with these two needs" (Vaught, 2000 p. 114).

EVOLVING LEADERSHIP IN MINE DISASTERS

Information on escapee leadership supports an affiliative model of emergency response, where people help each other rather than a more chaotic depiction of "every-man-for-himself." Although it is common to think that people panic in an emergency, a significant body of social science research has shown that panic is not a valid construct to explain group behavior during crisis situations (Clark, 2002; Quarantelli, 1989). The roles of individuals in a crisis, though not routine, tend to be similar to their normal roles, thus maintaining the social order (Johnson and Johnston, 1988). "The social behavior and cognitive processing of individuals stays remarkably close to what can be seen in ordinary, daily behavior" (Canter, 1990 p. 3). For example, the "Miracle on the Hudson" demonstrated the orderly egress of passengers and maintenance of authority by the flight crew after an emergency aircraft landing in the Hudson River in New York City in 2009 (Prochnau and Parker, 2009). This does not mean individuals are not afraid, and some may exhibit erratic behavior, but the overall tendency in such a situation is to maintain normal behavior and, some research has shown, to help one another (Sime, 1983).

The miner escape interview database allowed researchers to examine group escape and leadership in escape. The majority of miners behaved appropriately and within the accepted social framework and stayed together in escape. An additional analysis of these data was aggregated by escape group and coded for (1) evidence of leadership behavior; (2) evidence showing a lack of leadership; and (3) characteristics of the person leading the group out of the mine safely (Kowalski et al., 1994). The researchers found that some escape groups experienced an apparenont breakdown of leadership during their escape, while new leaders emerged in others. Consensus characteristics showed that successful leaders were aware and knowledgeable; decisive, yet flexible; open to input from others; and a calming influence. They were able to gain the follower's confidence. The leaders were logical decision makers and their leadership role evolved naturally, rather than by an individual seizing power. Effective leadership increased the likelihood of successful evacuation (Kowalski et al., 1994).

In the US mining industry, command leadership in a mine emergency is what may be described as a modified *unified command.* According to the US National Incident Management System (NIMS), unified command allows agencies with different legal, geographic, and functional authorities and responsibilities to work together effectively without affecting individual agency authority, responsibility or accountability (National Incident Management System, 2008). For mining, the unified command is termed a Mine Incident Management Command and may have up to four entities participating; and includes the company representative (mine owner), who is legally responsible for the incident, the state mine authority representative, a federal mine authority representative, and a worker representative (miner union) if the mine has one. MSHA is the agency responsible for determining the cause of the incident and determining fines and penalties. There is not a formal protocol that has been practiced consistently for the interaction of these four groups, as evidenced by the command experiences in the mine disasters of the past decade. The following vignette illustrates the hazards of leadership:

> *A small village in Lassing, Austria—population 2000—became famous after a tragic mining accident in July, 1998. At a depth of 60 meters underground, water and mud broke into a shaft of the mines in Lassing. What is left in memory from this incident ten years later is the huge hole in the earth that swallowed up several houses, the mine workers who survived for ten days, who could not be reached and remain buried in the mine, the rescue leader declaring the death of all mine workers prior to the rescue of the one survivor and the chaos that prevailed for one week. Lassing became a synonym for crisis mismanagement. Initial leadership was lacking and the most crucial after-the-fact finding was that most mistakes were caused by selfish fights over which group would be in the lead agency ... [T]he lack of a clear leadership structure in a crisis can be catastrophic.*
>
> (Hersche and Wenker, 2008).

Leadership is a key factor in mine escape and rescue activities, and lack of leadership can be debilitating for missing miners' families, other miners, and the community. In the Sago disaster in West Virginia in 2006, misinformation and poor communication controls led to the release of information stating that all miners were alive followed over an hour later by the report of 12 deaths; this type of communication error can be devastating.

Both command leadership and escapee leadership are important for successful resolution to mine emergencies.

TRAINING TO FACILITATE APPROPRIATE ACTION UNDER DURESS: SETTING EXPECTATIONS

The 2006 incidents at the Sago, Alma, and Darby mines raised a number of issues about mine emergency preparedness and response, particularly as they relate to:

1. miners' donning of and expectations when wearing an SCSR and the need to switch to additional units for escape (refer to Figure 9.5);
2. miners' judgment and decision-making processes under the stress and uncertainty of a mine escape;
3. emergency communications, including equipment, and the transmission of appropriate important information;
4. the layout and marking of emergency escapeways in mines (recently addressed by regulation) and miners' familiarity with escape procedures;
5. way finding and navigation in smoke;
6. the psychosocial aspects of mine emergency escape and response; and
7. evaluation of mine emergency training programs (Gates et al., 2007; Light et al., 2007; Murray et al., 2007).

Many of these issues are not new and have been identified in previous research on self-rescue and escape, including human response issues such as individual and group behavior, judgment and decision-making skills, warnings and communication, way finding (the ability of an individual to move from one point to another through physical space relying on a cognitive map of spatial representations), and leadership in escape (Vaught et al., 1996; 2000). Previous research has also looked at judgment and decision making under stress (Kowalski-Trakofler and Barrett, 2003). It is only within the context of the 2006 mine incidents that these concerns have once again been brought to the surface (Brnich and Kowalski-Trakofler, 2010).

After the Sago disaster, analysis focused on the root cause of the explosion (Gates et al., 2007) without trying to understand the decisions miners made to barricade and to take off and/or share some of the SCSRs. The sole survivor reported that four of the units did not work, yet NIOSH tests indicated the SCSRs had not been used to capacity. This supports the hypothesis that the miners *may* have removed their SCSRs because they thought that the units were faulty.

NIOSH researchers completed one study after Sago to determine what effects or symptoms miners could expect to encounter while donning or wearing a properly-functioning SCSR unit (Kowalski-Trakofler, Vaught and Brnich, 2008). Researchers determined nine key areas representing issues that might influence a miner to remove his/her breathing apparatus. The nine areas included opening and starting problems, coughing when first starting to breathe, taste when breathing, breathing resistance, air being warm and dry, nose clips slipping and uncomfortable, goggles fogging up and the bag not inflating completely. NIOSH provided MSHA recommendations and information focused on cognitive, behavioral, psychological, and physical responses to trauma, which were integrated into training developed for exchanging SCSRs underground.

Additionally, NIOSH developed a new program called "expectations training" that has been implemented by MSHA. Expectations training is "training that provides the trainees with sufficient physical, cognitive, psychological, and behavioral information (beyond the necessary technical information and hands-on experience) to allow them to understand any potential symptoms they might experience while performing a task or action" (Kowalski-Trakofler, Vaught and Brnich, 2008). Thus, miners would be more prepared to deal with the symptoms that can arise from the emergency situation and their life-saving equipment.

USE OF REFUGE CHAMBERS IN MINE ESCAPE AND RESCUE

A substantial number of miners may face the need to escape from a mine emergency, usually a mine fire, at some point in their career. A 1996 study focusing on miners' preparedness to respond to a fire was conducted at seven US underground coal mines. The study revealed that 38 percent of the 180 miners interviewed had evacuated from a mine because of a fire. In addition, 21 percent said they had donned a breathing device because of a fire (Vaught et al., 1996).

The basic protocol for escaping from an underground coal mine in an emergency has changed little in the past century. Miners are taught to make every attempt to escape if there is an emergency, following the designated escapeways to safety. If escape is impossible, miners are now trained to seek temporary safety by going to a refuge alternative. The introduction of refuge chambers provides miners with another option if escape is impossible, but also raises new psychological considerations.

The 2006 MINER Act mandated research be conducted by NIOSH on refuge alternatives. Using this data, MSHA published its proposed rule in 2008 stating mines must install refuge chambers capable of sustaining miners for up to 96 hours in US underground coal mines by 2009 (US Deptartment of Labor, 2008). The final rule on refuge chambers specified that there be annual expectations training on refuge alternatives (CFR 75.1504 (c) (3)), and training on their use should be given quarterly and integrated with mandatory evacuation drills. NIOSH has developed refuge chamber expectations training for miners on the physical and psychological issues they may face (Margolis, Kowalski-Trakofler and Kingsley-Westerman, 2009).

The psychological considerations involved for underground mine workers who choose to remain in refuge chambers include a variety of issues. What are the psychological effects of potentially staying 96 hours in a chamber and what about the group dynamics in a confined space over time in a stressful situation? What supplies are important for maintaining physical and mental health while in the chamber? Under what conditions might miners leave the refuge, given the internal and external situation? Application of research from studies on confined spaces in the military and other industries could benefit the mining industry.

Miners are trained to escape the mine in an emergency. If miners elect to stay in a refuge chamber, they must believe that it is the last alternative and need to have confidence someone will rescue them. Present mine rescue practice in the US has not been changed to accommodate large numbers of trapped miners. In 2002, a drill and escape capsule was used successfully at the Quecreek Mine in Pennsylvania, where nine miners were trapped by an inundation of water after machinery broke through into a sealed-off adjacent mine. Since many US underground coal mines are in hilly or mountainous terrain, and may have less favorable access for this type of rescue than Quecreek, mine rescue teams must be prepared to enter the mine to rescue miners waiting in refuge chambers.

Previously, the US Bureau of Mines contracted for a review of the literature and development of guidelines for designing, constructing, stocking, and maintaining rescue chambers in underground mines (McCoy et al., 1983). Examples of reports reviewed 24 years ago included fallout shelter studies, underwater habitability studies, NASA manned spaceflight human factors research, mine disaster field studies, and laboratory studies on sensory deprivation, confinement, and social isolation.

Predictable psychological reactions to such confinement included anxiety, withdrawal, apathy, aggression, hostility, depression, and irrational and impulsive behavior. Research on the effect of deprivation and isolation on task performance was found to be inconsistent. However, visual illusions and hallucinations were reported in mine disaster field studies where trapped miners were subjected to prolonged periods of darkness (one to two weeks) and uncontrolled hazards (roof falls). Researchers noted a shift in the behavioral dynamics of trapped miners in the two case studies reviewed—with task-oriented behavior emerging in adaptive attempts to escape; followed by more emotion-based behavior as efforts needed to be redirected toward group survival and enhancing social stability. Miners were deemed likely to be confused and disoriented upon entry into the chamber, and consequently very anxious, mainly due to the effect of the disaster. Emergent leadership required different skill sets depending on the behavioral dynamics and duration of the confinement. Managing boredom, restlessness, and fluctuating despair/hope appear to loom larger as confinement persists. Specific stressors noted to cause significant stress included a lack of outside communication, prolonged darkness (sensory deprivation), the presence of severely injured/dying miners (powerlessness to help; guilt; identifying with the suffering), and miners that died (stench, fear of gas poisoning).

Hot, humid, closed, and cramped refuge chamber environments are likely to be uncomfortable and tax coping strategies. Individuals with well-controlled chronic mental illness (for example, depression, generalized anxiety disorder, post traumatic stress disorder (PTSD) or certain chronic physical disorders that can be triggered by stress (for example, asthma, peptic ulcer disease, irritable bowel syndrome, hypertension, coronary artery disease, diabetes) may experience exacerbations in their underlying symptoms if stress overwhelms psychological and social coping strategies.

IMPACT OF THE AGING POPULATION

The approaching departure of "baby boomers" from the workforce is expected to have a profound impact on the US economy and that of other nations around the world. Changes in the workforce will have a greater impact on mining than in many other industries because of past hiring patterns and improved technology. The coal mining boom of the late 1970s led to the employment of many new miners, most of whom were in their twenties. As coal mining became more capital-intensive in the 1980s and 1990s, downsizing and layoffs occurred, and there was a concomitant decline in the hiring of new miners. (Kowalski-Trakofler et al., 2004). According to the US Bureau of Labor Statistics, in 2002 the median age of the coal mine workforce was 45.2 years, while the median age of all workers in the US was 40.1 years (Mallet and Schwerha, 2006). That same year, 57 percent of the coal mining workforce was over 44 years of age. If workers are entering and leaving the industry in a consistent way, comparing ten-year work groups should show similar percentages of workers in each group. Instead, the 45–54 age group is 44 percent of the total, with the 35–44 age group at 23.8 percent and the 25–34 age group at 14.3 percent (Mallett and Schwerha, 2006). Older workers have increased experience and knowledge, which may help them work "smarter." The mining industry today not only faces issues related to an aging population in a physically intense workplace, but the training of new miners to replace the experienced and knowledgeable miners who are ready to retire. The National Mining Association (NMA) estimates a total of 50,000 new employees will be needed in coal mining over the next ten years to meet increasing demand and to replace retiring workers (NMA, 2009). Capturing the institutional knowledge of the older generation of miners to benefit the younger miners is a challenge, along with conducting training for mixed-generation classes.

Coal mine accident statistics from 1978 to 1980, after the last large influx of new miners, suggest that being young and inexperienced leads to higher injury rates among workers. This relationship is consistent across the 15 companies that provided data on the age of their work force, as well as for each of the years 1978, 1979, and 1980: Miners between the ages of 18 and 24 have an injury rate nearly twice that of miners aged 25 to 34, who have a rate about 25 percent higher than miners aged 35 to 44, who in turn have a rate over 40 percent higher than miners who are at least 45 years of age. Hence, a young miner (18–24) is about twice as likely to be injured than is a miner aged 25–44, and about three times more likely to be injured than is a miner 45 years of age or older (National Academy of Science, 1982).

Recently, Mallett and Schwerha (2006) reported that the median age for injured underground coal miners was 43-years-old, based on injury data from MSHA. Data also suggest that these older workers, while injured less often, as the above discussion indicates, sustain more serious injuries with more lost time from the job (Fotta and Bockosh, 2000; Margolis, 2011). In addition, the effects of certain injuries, such as musculoskeletal injuries (MSIs), may be more extreme for older workers. The data show not only that MSIs are a type of injury that tends to happen more frequently to workers over age 30, but that the number of days lost per injury also increases. Over the 11 year period from 1992–2002, over half of all workdays lost were due to musculoskeletal-related injuries. On average, about 40 percent of all injuries that occurred during this period were musculoskeletal in nature (Porter et al., 2008). From an injury prevention perspective, the three-tiered intervention model is useful. Engineering solutions, such as reducing the weight of materials, should be followed by administrative and behavioral interventions. Attention to work organization, informing miners of appropriate PPE, and knowledge of protective behaviors such as correct lifting practices are very useful in reducing the injury rate.

Age-related changes result in diminished physical, sensory, and cognitive capabilities, all of which can affect a miner's safety in the workplace. Mines are challenging environments, and low illumination, noise levels, and difficult terrain are all sources of concern for the aging mining population. Many people, as they age, experience diminished visual acuity and have difficulty seeing in low-lit areas. It is important for miners to wear appropriate safety glasses and be aware of reduced vision in their workplace, using cap lamps to the best advantage. Engineering controls to reduce noise levels of machinery in mines, administrative controls in providing hearing loss information, appropriate PPE, training, and individual behavior can make a significant impact on hearing loss, which is a major health issue in mining. As aging affects balance, slips, trips, and falls become more of an issue, particularly with the uneven nature of mine floors.

SHIFTWORK

Shiftwork, generally defined as working outside normal daylight hours, is a fact of life in the mining industry. Mine workers may work a day, late afternoon, or night shift; they may also work a longer shift (10–12 hours) or overtime. Many mines have rotating shifts, and some may have so many days "on" and then days off. Shiftwork schedules are demanding and likely to produce stress and fatigue (Rosa and Colligan, 1997). Overall research on shiftwork has shown rates of fatigue and number of work accidents are higher in shift workers (Halvani, Zare and Hobobati, 2009).

Although there is limited shiftwork data on the underground coal mining population in particular, a growing body of evidence suggests that long working hours adversely affect both the physical health and mental health of workers. Bise and Breysse (1999) examined the effect of extended shifts on injuries experienced at underground longwall coal mines in the US. They reported finding a trend between the non-fatal days lost incidence rate and shift length. Specifically, for every hour of shift length above eight hours, the non-fatal days lost incidence rate was 1.185 implying that an 18.5 percent increase in the number of non-fatal days lost incidents is predicted when a shift is extended one hour in the range from eight to nine, or nine to ten hours.

Other studies have associated overtime and extended work schedules with an increased risk of hypertension, cardiovascular disease, fatigue, stress, depressions, musculoskeletal disorders, chronic infections, diabetes, general health complaints, and all-cause mortality (Dembe et al., 2005; Caruso et al., 2004). There are relatively few studies comparing long work hours and risk for occupational injuries and illnesses. Some studies have shown evidence of a relationship between long working hours and an increased risk of occupational injury among specific occupations and industries, including mining (Duchon and Smith, 1994). Fatigue has also been shown to result in job dissatisfaction among iron ore miners (Halvani, Zare and Mirmohammadi, 2009).

Shiftwork often results in workers performing their duties out of sync with their circadian rhythms. Circadian rhythms are a major body rhythm, with regular ups and downs in a 24-hour day. People perform best when alertness and internal body activity is high and worst when alertness and activity are low. Alertness affects safety behavior and is a concern for shift workers especially in volatile and constantly changing hazardous environments. There are personal differences in circadian rhythms, but for most people, the high activity portion of their circadian rhythm occurs in late afternoon or early evening. The body's ability to produce energy from food (metabolism) is highest in the afternoon to evening. The least activity usually is in the middle of the night when most people are asleep.

Long working hours, rotating shifts, working out of sync with natural circadian rhythms, and the long commutes often required to reach remote mines can all contribute to limited and/or interrupted sleep. In turn, this leads to fatigue, and fatigue can affect safe performance.

There have been few major studies to date on the effects of shiftwork in the US coal mining industry, although data from shift workers in other types of mining (Duchon and Smith, 1994), and in the medical community, indicate definite safety and health concerns. The effects of shiftwork on occupational health and safety in the US mining industry are an issue worth inquiry.

HAZARD RECOGNITION[1]

In mining, as in most other production-related industries, the safety of the worker is dependent on many interrelated factors, one of which is the workers' ability to recognize hazards in the workplace. The ability to recognize hazards in mining is critical because the work environment is dark, confined, inherently unsafe, and constantly changing during the mining process. The mining process creates exposure to dust, noise, and powerful machinery. Workers must be alert and continuously cognizant of their surroundings. The information necessary to recognize conditions that are precursors of danger is often available in the form of visual cues, which may be difficult to perceive in the low-light environment of an underground mine. MSHA and US Department of Labor descriptive accidents report data have shown that "failure to perceive" a hazard consistently appears as a contributing factor to both fatal and non-fatal injuries.

There had been limited research on training for the recognition of mine hazards and none based on principles of perception until the mid-1990s when researchers applied the military concept of degraded images to training for underground mine workers (Perdue et al 1995; Barrett and Kowalski,1995). At the time, studies suggested that perceptual judgments are susceptible to training and the most extensive base of information came from military studies on target detection (Farnsworth, Malone and Sexton, 1952; Jones, Freitag and Collyer, 1974; Leibowitz, 1967). Laboratory research also suggested that visual degradation of a stimulus hinders its correct identification by slowing both the initial stimulus encoding process and the search for that stimulus in memory. It takes longer to "clean-up" the mental representation and thus, training that cultivates degraded mental representations and creates content for memory identification can shorten the time necessary to identify, and consequently react to hazards. The military research on target detection had found that if the eventual target stimuli are to be searched for and identified under degraded conditions, observers should be trained to recognize them using training stimulus that are similarly degraded (Cockrell, 1979). NIOSH researchers tested the theory that in training miners to recognize hazards and hazardous situations in their highly variable and often visually degraded environment, it would be desirable to give them experience with equally variable representations of these hazards in the training presentations. Previous to this, miners were shown focused, highlighted hazards and told to avoid them. Unfortunately, in an actual mining environment, these hazards are in low light, hazy, and oftentimes competing with other hazards.

NIOSH researchers designed two training programs, one with highlighted hazard visuals and one with degraded visuals. Three separate studies were conducted with underground mines in Pennsylvania, West Virginia, Alabama, and Illinois. Results showed that after the degraded imaging training over a one-year period, incident rates dropped significantly in Alabama (30 percent) and Illinois (27 percent). In each case, however, there was another factor introduced by the company at approximately the same time—management for safety in Alabama, and a flex and stretch program in Illinois. This made it impossible to determine how much of a drop in incident rates was due to training itself. However, in interviews with the trainers, their observations credited the degraded hazard recognition program with a major part in the decrease in injury rates (Kowalski-Trakofler

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[1] Some text excerpted from Kowalski-Trakofler and Barrett (2003).

and Barrett, 2003). This program has applications for many different hazardous work environments and has been used in the construction and agriculture sectors.

EXPANDED SAFE JOB PERFORMANCE MODEL

NIOSH researchers developed a theoretical Safe Job Performance Model, which expands the basic three-tiered simple model shown in Figure 9.8, in order to define and integrate the various aspects of performing a job safely. This expanded model, shown in Figure 9.10, may be utilized in analyzing specific safety and health problems in mining, in the development of interventions and in the planning and evaluation of training (Kowalski-Trakofler and Barrett, 2003). The core of the model is the safety climate or the work environment of the company or organization. Six components serve as a foundation to support both the organization and the individual to ensure safe job performance. They combine the original three tiers—engineering controls, administrative controls, and behavior controls—with three new components: technical skills, knowledge, and judgment and decision-making ability (Figure 9.10). Technical skills refer to the hands-on skills and abilities needed to get the job done and complete a task successfully. Technical skills explain "how" a worker does the job. Knowledge refers to the basic information needed in order to understand the process of the task. Knowledge is an important underpinning of safe job performance. Workers need to understand the task within the context of the overall job, in addition to having the skills to perform the task. Judgment and decision making refers to the worker's ability to make sound and safe decisions.

NIOSH researchers found that most safety interventions in the mining industry today include technical skills and knowledge, as well as some administrative controls.

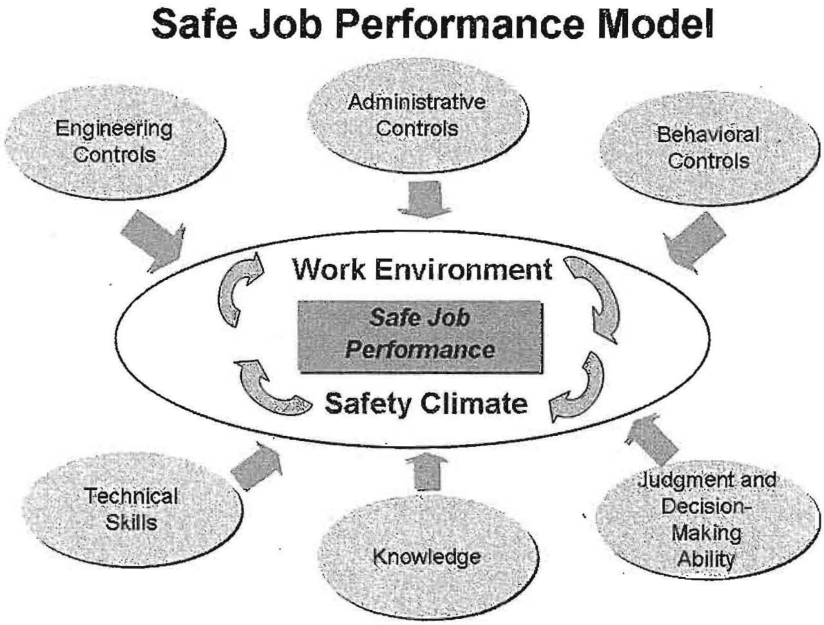

Figure 9.10 Safe Job Performance Model

Source: Kowalski-Trakofler and Barrett (2007).

The addition of further administrative and behavioral controls, plus improved judgment and decision-making ability, can enhance the effectiveness of worker safety programs. This model has application as an evaluation tool for specific safety and health interventions and training programs, as well as overall organizational safety programs.

PERCEIVED JOB STRESS AND HEALTH IMPACT

Five of the ten leading causes of disability worldwide are mental health problems (WHO/ ILO, 2000). Even so, the importance of psychological well-being and mental health in the workplace is generally underestimated and seldom included in studies of occupational health. Unfortunately, there are limited psychological studies on the mental health of the US mining population, although issues affecting every workplace population working in a hazardous work environment are most likely relevant.

Althouse and Hurrell (1977) examined how much job stress and psychological strain underground coal miners experience, and how levels of job stress and strain reported by miners who work in mines with high-accident rates compares with the stress and strain reported by miners who work at mines with low-accident rates. Overall, there was surprisingly little difference between the high and low accident mines in terms of reported levels of job stress and psychological strain. The researchers also point out that these findings do not necessarily mean that miners do not experience considerable psychological strain in *both* high-and low-accident mines. The researchers compared the reported stress and strain of coal miners with other nationally sampled blue-collar workers, and found that miners fared better than average on most measures of job stress, and, in fact, were low in subjective job stress experiences. With respect to strain, however, miners were much more irritated than other blue-collar employees. They also experienced greater than average anxiety, depression, and had more physical complaints. However, on average, they expressed higher job satisfaction, lower workload dissatisfaction, and less boredom than other blue-collar workers. Althouse and Hurrell conclude that miners were higher in their affective psychological strain, but lower than the average blue-collar worker on behavioral strain indicators.

DISASTER RESILIENCY OF MINE WORKERS

Based on the extensive studies after the Oklahoma bombing in 1995 and the terrorist events of September 11, 2001 in New York and Washington, DC, the likely outcomes of events such as mining disasters include traumatic incident stress disorders, including acute stress disorder, post-traumatic stress syndrome, and suicides (NIOSH, 2002). At present, only anecdotal evidence supports this idea in mining. Researchers at NIOSH are focused on raising awareness of the issue and developing information for emergency responders (NIOSH, 2002).

Suicides and depression can be the result of inadequate psychological support during and after an emergency response. It has been suggested that the most vulnerable time emotionally is from six months to one year after the event. There is increased anger, self-destructive behavior, and even suicide. "The despair, the helplessness gets so intense ... it bursts out" (Lagnado 2002). There were suicides in the aftermath of both the Quecreek and Sago events. Two miners who were at the site of the Sago Mine disaster committed suicide within about six months of the event. Neither man was blamed in the tragedy, nor was it clear why they committed suicide; however, family members claimed that these men were continually bothered by the event. Another suicide victim was the man who successfully pinpointed the location to drill to affect the rescue at Quecreek, but it is not clear how his involvement in the Quecreek emergency may have played a role in his suicide. These cases support the need for specially-trained counselors in disaster mental health. Their services would be beneficial before, during, and after a mine disaster. Currently, interventions after-the-fact and educational programs on the expected human response in crisis may be limited. Individuals who need help are generally referred to the local county mental health office. Unfortunately, local, rural mental health facilities rarely have personnel with specific training in disaster mental health. In some communities, the Red Cross is available to provide qualified emergency mental health support at the time of the crisis, but is not present for follow-up.

Rescue workers, co-workers, and family members are also subject to the psychological after-effects of a traumatic incident. From a psychological perspective, many times the trauma is just beginning when individuals reach safety. Research in this area has shown that interventions may mitigate serious emotional, behavioral, physical, and cognitive consequences to personnel (Everly, Perrin and Everly, 2008). The MINER Act mandates attention to family support. Some mining states are looking into ways to address the needs of mine families, recognizing the needs of family and community during a mine disaster, and the need to base interventions on empirical data. For example, Pennsylvania's Mine Families First legislation mandates that the families of miners involved in an emergency be provided with information, access to counseling and other social services, and other considerations in the event of an emergency.

Humans are efficient survival machines, individually and in groups. Survival is accomplished, not by brute strength or avoidance, but by the ability to cope with a potentially hostile environment by recognizing and solving problems. Today's terminology sometimes refers to this construct as *resilience*—the ability of an individual or organization to both withstand significant adversity and to "bounce back" after a trauma. Resilience has been described as a dynamic process of healthy adaptation in adversity. Resilience is multidimensional and involves personal, organizational, and environmental factors including hardiness, flexibility, optimism, and availability of social resources, sense of connectedness and support, and overall intelligence (Reissman et al., 2010; Reissman, Kowalski-Trakofler and Katz, in press). Resilience is emerging as an umbrella concept for positive behavioral emergency response, with identifiable factors that are applicable to improved escape and rescue strategies. Developing resilient mine workers is a reasonable goal for the industry.

Conclusions

Coal mining disasters have decreased substantially in frequency and number of fatalities in the past 100 years. Engineering hazards out of the environment has been the primary method of reducing these incidents. Engineering improvements that have impacted the health and safety of the mineworker include developing newer, safer mining methods; creating better, safer tools and machinery; understanding and controlling mine gases; more sophisticated roof control and ventilation plans; and overall better ways to remove coal safely from the earth. The health and safety focus today remains in the engineering arena. Yet, since 1988, increasing amounts of research have been completed in the area of human behavior in mining. During the past 20 years, there has been a steady increase in research on miner behavior in mine escape, hazard recognition, communications, expectations training, and, most recently, attention to the human interface with mandated refuge chambers. Training has been developed from this research based on the empirical data. Program evaluation is a key issue. During the past 40 years, knowledge of the causes of work-related disease and disability has grown dramatically; however, ways to evaluate occupational health and safety interventions remain limited. In addition, the industry is continuing to adapt management principles and models identified through social science research. Further benefits are likely to accrue by applying social sciences research and knowledge learned within other hazardous industries.

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