# USING COAL MINERS' EXPERIENCE TO IDENTIFY EFFECTIVE OPERATING CUES

Kim M. Cornelius
Lisa J. Steiner
Fred C. Turin

NIOSH, Pittsburgh Research Laboratory
Pittsburgh, Pennsylvania

Like many experienced workers, remote control continuous miner operators perform their everyday jobs making choices and decisions that they may not consciously think about. While performing tasks, they are continuously processing feedback and cues which guide them for the next move. Initial training teaches the operators the tasks necessary to operate the equipment and perform the job. However, with experience they are better able to deal with hazardous conditions and non routine situations. To better understand what potential cues and feedback help to guide the operators, a questionnaire was developed to learn what factors affect decisions. Operator responses address issues related to specific tasks, equipment operation, visibility, lighting, and communication issues. The information collected is useful to understand what cues experienced operators use to make task performance decisions. Results will be used to develop interventions and training for safe and effective operator performance.

## INTRODUCTION

Continuous mining is a method used for extracting coal in an underground mine. It has evolved from the worker riding on the machine to using a remote control unit and standing away from the machine. When miners operated from onboard the machine, they developed experience in knowing what feedback and cues were necessary to complete their tasks effectively. The industry switched over to remote control mining with minimal changes made to the machine. Some advantages were gained by removing the operator from the machine, yet there were disadvantages. While riding onboard the machine, visibility was limited by the confines of the compartment and the canopy overhead. However, this compartment protected them from roof and rib falls. By using the remote control unit, the operator can move to a position to see what is necessary to operate. Yet, this exposes operators to risk factors such as moving equipment and falling pieces of rock and coal.

The most dangerous area in underground coal mines is the working face where coal is extracted. Some of the conditions which make this a hazardous location are roof falls, large moving machinery, decreased visibility due to low lighting and high dust levels, and noise of the machines making communication between crew members difficult. In addition to cutting the coal, operators must focus attention on where they are positioned, the location of other crew members, and the proximity of the machine to the crew. Unsafe areas exist into which the remote control continuous miner operators must not move. Some areas are clearly defined such as beyond the supported top, which is defined by the last row of bolts supporting the roof. But this is not always readily visible, especially in lower seam mines. Other areas are not clearly defined to the operator. Research is being conducted to identify safe and unsafe zones for the operator. Since the mining environment is dynamic, it does not lend itself to implementing physical barriers to keep operators out of the unsafe zones; the operators must constantly process their position in relation to those unsafe zones. Remote control operation has required the continuous miner operators to divide their attention and process more information simultaneously. Defining and prioritizing what cues and feedback are most useful and how operators focus their attention leads to better operating decisions. This information can then be used to develop safe, realistic operating procedures allowing operators to focus on the most important feedback.

When analyzing human-machine systems, it is important to examine the components of the human and the machine within the work environment. The mining environment is a unique challenge. The work environment of a mine is very difficult to mold in comparison to a factory setting where the worker may gather designed and controlled information from machine displays. In the mining setting, the equipment designer can control how the machine functions, but not the surrounding environment. The environmental hazards in the mine cannot be removed by redesigning the system. This dynamic environment presents many hazards and information that must be continually monitored by the continuous miner operator.

## THESIS

The ability to process and utilize feedback information is an important component of the human-machine system. Safe and effective control of the system is dependent upon the worker properly sensing pertinent information and processing it to make the right decisions to control the system. Depending on the feedback or cues provided by the system or environment, the worker makes necessary modifications. Experienced miners have expanded their knowledge, skills, and abilities to perform safely and effectively. By identifying the specific feedback and cues used to perform their job, interventions and training methods can be designed to improve safety for all operators.

## SOURCES OF INFORMATION

There were a number of data inputs from earlier phases of this work which helped form the instrument used to collect information from miners to identify feedback and cues they use to perform their job. A preliminary task analysis questionnaire was developed when this project was initiated to identify general safety issues. In particular, the goal was to determine what aspects of this technology were problematic to the mining industry (Steiner *et al.*, 1994). Overall, workers had a positive attitude toward this technology. However, visibility for continuous miner operators and some aspects of maintenance were identified as common problems. Data obtained from this interview guide were used to identify what areas needed further examination and to devise a systematic approach to analyze this technology.

Subsequently, a work sampling technique was adapted to collect information on the needs of the workers doing specific tasks in the mining cycle (Steiner *et al.*, 1997). The goal was to learn what portion of time was spent by the operator on various tasks and where the operator was positioned in relation to the machines and other crew members during those tasks. At predetermined intervals, data were collected on where the operator was in the cycle, what task was being completed, where the machines and crew members were positioned, and in what direction the operator was looking. Operator position and direction of view data were needed to take an initial look at what visual feedback and cues were being used. Resulting observations revealed that the worker would sometimes stand in an unsafe area in order to see the cutting head of the machine during longer cuts. Also, turning a crosscut appeared to be the most variable and difficult task for the operator.

To more narrowly focus on some of the problem areas, another questionnaire was developed. The physical location of the operator during the turning task was an evident concern. During the work sampling, observational data were collected. However, due to the constraints of the environment, it was difficult to gather information from the operator which would explain exactly what the operator was looking at and why it was necessary to see that particular cue. Also, it was determined that operators were having difficulty seeing the mining machine throughout the cutting cycle. Thus, there was a need to identify what other types of feedback, such as audible and tactile, that were possibly used to compensate for the decreased visibility.

The questionnaire was developed to obtain answers which would provide insight into what specific types of feedback and cues an operator uses to safely and effectively perform the job. Also, the questions were designed to gain insight into what special skills, knowledge, and abilities were necessary to operate the continuous mining machine. Questions were mainly open-ended and focused on learning the specific actions and thought processes used to complete the tasks associated with the job. Using this questionnaire, a total of 32 continuous miner operators were interviewed at three different mines. The questionnaire was interactively administered at the worksite in a structured interview format.

While conducting the earlier activity sampling study, it was determined that cutting coal while turning a crosscut was the most challenging part of the cutting cycle. This is due to the difficulty associated with maneuvering the machine and positioning of the worker in a confined space. Questions concerning crosscut turning aimed to gain a better understanding of operator positioning during this task. Operators were asked questions to determine why they stand in a particular location, when and why they need to move from this position, and which cuts are most difficult to take and why. Other questions aimed to identify the information and feedback the operator used while operating the continuous mining machine. For example, the respondents were asked:

- *What is the most important feedback while mining a cut?*
- *During the last twenty feet of the cut, what in particular do you look at to stay on sight line?*
- *Do you have a problem with visibility when cutting?*
- *Have you had any problems with the lighting on your machine?*

Two questions were asked to gain insight into what skills were needed to operate the continuous mining machine:

- *If you were to teach me to operate a continuous mining machine, what would be the most important points you would tell me about taking a cut?*
- *What do you think makes one operator better than another?*

## FINDINGS

The responses formed a starting point from which to examine information input and processing of remote control continuous mining operators. Specific cues which primarily consisted of visual, audible, and tactile feedback used to complete the tasks were examined. Additional information was summarized and used to examine the skills and abilities needed to effectively operate the mining machine.

Responses concerning operating cues provide key information to understanding the many variables which the worker must process and balance while operating the mining machine. These factors play a major role to determine the best position for the remote control continuous miner operator. Often, equipment and mining plan layouts factor into this determination. For example, the continuous mining machine has thick cables running back from the machine which must be handled and repositioned continually throughout the cutting cycle. Another important factor of positioning related to the mining plan is determining the location which maximizes availability of fresh air and minimizes exposure to dust. The mining plan also determines operator positioning as it relates to the risk of being hit by falling roof and rib. In addition to all of these factors, the operator needs to be positioned where visibility is best.

Specific feedback supplied by the workers was categorized into three types of operating cues: visual, audible, and tactile. Their responses suggest that visual cues provided the most useful information. The operators must continually monitor the above mentioned items concerning their current location and when to move to a different position. Visual cues were necessary to keep the machine on line and to know when to terminate a cut, either in reaction to a geological problem or in compliance with the mine plans. Specifically they observe the color of the dust, sparks from the drill bits, and the angle of the cutting head. Workers used visual input to watch for haulage vehicles traveling to and from the working area and to monitor the level of methane present at the working section. At times communication between the crew was visual. For example, workers use their cap lamps as a means of communication.

Operators report that they listen for particular information too. For instance, they could identify a sound made when the cutting head hits rock which would indicate that they were cutting too high into the roof; a different sound determined when the cutting head hits the roof and the roof is about to fall. Another form of audible feedback was verbal communications. Information about hazards is provided by other workers on the section as well as workers from the previous shift.

Vibratory feedback was a common source used when operators rode on the machine. It was surprising to learn that the remote control operators still use this feedback. They can feel the vibrations of the machine by resting the remote control unit on top of the machine or leaning against the machine. However, this feedback is not encouraged since it can increase the operators' risk of being hit by falling roof.

Operators were asked to describe the most important points they would make if they were to teach the interviewer how to operate the machine. Responses consisted of some 'textbook' type information which reiterated what is learned in initial training such as protecting themselves from the roof and rib falls and watching for the moving equipment. Other responses revealed the 'tricks' that a miner might gain with experience such as, using particular reference points on the mining machine to measure distances for cutting and watching the direction of a haulage vehicle's wheels to know which way it is about to turn.

Continuous miner operators were also asked to describe what makes one operator better than another. Many of the responses in this category, unfortunately, turned out to be characteristics which would be difficult to measure, such as, desire to do a good job, leadership ability, good concentration, ability to pick up things quickly, and patience.

## DISCUSSION

Data collected from these remote control continuous miner operators helped to identify what information is important at various points in the mining cycle. An operator focuses attention at a given moment on the priority element, but then must quickly divert attention to something else. For example, when shuttle cars pull up to receive the next load of coal, the continuous miner operator must divert some attention to the moving vehicle and then must watch one direction to guide the machine cutting and loading the coal while also watching the opposite direction to know when the car is full.

At times, operators appear to be overloaded by the amount of visual information they need to monitor. Additionally, visibility can be poor due to the low lighting and concentrated dust in the air. The US Bureau of Mines previously conducted work to identify the most important visual attention locations for the continuous miner operator riding on board the machine (Sanders, 1981). This was one of the main concerns since visibility was limited by the canopy and compartment. The ability to see these visual cues has improved since the operator now can move around and get into a position to see what he needs to see. However, the lighting scheme on the mining machine is inadequate and there are additional visual cues that require attention because the operator has lost the protection of the compartment and canopy overhead, and must pay attention to potential hazards such as moving equipment and falling roof and rib.

Operator positioning plays an important role in receiving visual cues. This is not only due to operators moving to obtain a better line of sight, but since operators can be overloaded by visual cues and unable to divide attention to all the necessary places at given times in the cycle, it is common for operators to move to the other side of the machine to protect themselves from other moving equipment and falling pieces of roof.

Inexperienced remote control continuous miner operators focus more attention on how to operate the machine itself and have less attention to divert to watching the numerous cues that must be followed to ensure safety of the workers in the section. For example, one of the most difficult tasks for remote control continuous miner operators is to make a turn in the coal seam. For less experienced operators, performing this task may require full attention to be paid to the machine itself. Whereas, more experienced operators have found ways to make tasks somewhat easier and it affords them the attention necessary to focus on where they are positioned in relation to the moving equipment, the supported roof, and where other workers are positioned. Some problems can be solved through equipment redesigns for improved lighting schemes or technology enhancements for methane and dust control. However, other solutions which help to minimize or eliminate the need for operators to divide their attention to multiple resources in this complex environment, may be more challenging to resolve.

New operators receive on-the-job training. For the most part, there is no formal training program for operating the machine in this complex environment. Their initial ability is limited to the effectiveness of the operator doing the training. This study is an initial attempt to identify important cues used by expert continuous miner operators. It is hoped that a better understanding of these cues will lead to modifications in work methods, equipment, and training that improve miners' safety.

## REFERENCES

Sanders, M.S. (1981). Determining what needs to be seen and what can be seen from underground mining equipment. In *Ergonomics-Human Factors in Mining* (pp. 56-69). Information Circular IC 8866. U.S. Department of Interior, Bureau of Mines.

Steiner, L.J., Turin, F.C., and Hamrick, C.A. (1994). Ergonomic and Statistical Assessment of Safety in Deep-Cut Mining. In *Improving Safety at Small Underground Mines* (pp.124-132). Special Publication 18-94. U.S. Department of Interior, Bureau of Mines.

Steiner, L., Turin, F., and Cornelius, K. (1997). A Method for Evaluating System Interactions in a Dynamic Work Environment. In B. Das and W. Karwowski (Eds.), *Advances in Occupational Ergonomics and Safety II* (pp. 603-606). IOS Press and Ohmsha.