Evaluation of Work Positions used by Continuous Miner Operators in Underground Coal Mines

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ABSTRACT

Operation of underground coal mine mobile equipment is usually done in a restricted workspace with reduced visibility. This work environment puts machine operators in awkward postures for tasks that require awareness of their surroundings and fast reactions to avoid hazardous situations. Using experienced equipment operators as a source, researchers conducted an investigation that developed a method to gather data on the needs and practices of machine operators while controlling the machine and the reasons for needing particular operational cues. The method used was an interview technique including a survey questionnaire and visual aids. The data gathered defined operator cues and work positions for the cutting and tramming phases of remote controlled continuous mining machines used in underground coal mines. Analysis techniques to determine which cues an operator sees from a variety of positions utilizing a computer simulation is shown to be potentially useful to the mining industry for design of work practices and workplace layout and could impact equipment design and selection for improved worker safety. Conclusions indicate that the survey was a good research tool to collect data and helped investigators understand important visual cues. Using this information, researchers were able to analyze the visual cues an operator can see from a given work position and posture.

INTRODUCTION

Operating large mobile equipment such as a continuous miner (Figure 1) is one of the most dangerous jobs that workers perform in underground coal mining. Throughout the mining sequence, whether cutting coal or tramming (moving equipment) to another location, the machine operator, helpers, crew boss, maintenance mechanics, and other equipment operators are put at risk from close proximity to the continuous miner machine and other hazardous situations associated with mining underground coal. Restricted workspace and reduced visibility of hazards compound the danger of operating a continuous miner. Mine Safety and Health Administration (MSHA) accident data from 2002-2007 indicate that the coal industry averages 6,517 accidents per year in underground mines. 20% (1,362) of those total accidents per year involved mobile face equipment that includes continuous mining machines, roof bolters, and haulage vehicles for underground mines. An average of 4% (266, 2 fatal) of those total accidents per year occurred while operating continuous mining machines.

Figure 1. Continuous miner

Unfortunately, MSHA accident investigation reports do not contain sufficient information to aid in studying interactions between a machine and its operator. Experienced operators have a wealth of information on what is needed to operate equipment and why operators choose certain operating positions. Consequently, in-mine observations and a survey, consisting of a questionnaire and visual aids, were used to gather pertinent information about operating a continuous mining machine in underground coal mines.

METHOD

Investigators used a scripted interview survey method and visual aids to gather information on work positions and visual needs of the operator during both the cutting and tramming (moving to new location) phases of mining. Surveys were followed by direct observation of the operators during mining operations. The data gathered was compiled into a database and used to develop computer simulations of work positions and visual cues used by operators. This information was then used to develop computer-based analysis tools that could be used to develop or to identify new safety interventions.

Survey Development

The survey collected information on operator position and visual cues from 77 operators of continuous mining machines with experience ranging from 2 to 30 years. Operators representing 39 separate underground coal mine operations in Alabama, Colorado, Illinois, Kentucky, Maryland, New Mexico, Ohio, Pennsylvania, Virginia and West Virginia were interviewed.

A survey using a scripted interview technique was the most efficient method of collecting and consolidating this sort of information. The survey was developed through a series of discussions with individuals having years of mining research and continuous miner operator experience, and by using pilot interviews to refine the survey questions. In addition, researchers determined which phases of the continuous miner work sequence should be studied by analyzing statistical information from MSHA's annual mine accident database, from Sanders and Kelley's (1981) effort defining visual cues for mining machine cabs, and job task analyses for machine operators conducted by NIOSH.

There are a number of visual cues and other machine feedback cues that operators must assimilate and process to safely control a continuous miner. The survey questions were designed to provide data on what the operator looks at and from what position, and on why the operator uses certain cues to make decisions on how to operate the equipment and select a work location. For example, questions addressed possible obstructions that might block the operator's view of vital cues, such as dust, water spray, light housings, and the glare from light sources, and asked what the operator would do about these obstructions. Another series of questions dealt with initial work positions and postures of the operator and possible deviations from that initial position during the work sequence while operating the continuous miner.

Previous studies of deck mounted operator cabs in continuous mining machines, shuttle cars, and scoops by Sanders and Kelley (1981) and Eger, Salmoni, and Whissell (2004) contain cue data from machine operators. Despite the change in operating method from inside a cab to remote control, Sanders and Kelley's work contains a number of cues that are still valid for today's remote control operation of continuous mining machines. Information from the new survey (an example question dealing with cues is shown in Table 1) would provide information such as operator's work positions and reason(s) for choosing a position.

Table 1. Example questions

Guides you look at….	How often….		
	Always	Sometimes	Never
Edge of the machine on the side you are on			
Center line of the machine			
Back end of the boom			
Cutting head bits			
How far the boom swings			
Spray nozzles			
Right edge of drum			
Left edge of drum			
Center or other point on the drum			
Haulage vehicle inby bumper			
Haulage vehicle operator			
Floor at the face			
Roof at the face			
Ribs on left side of miner			
Ribs on right side of miner			
Laser beam/spot			
Center line of entry			

*partial list for one of the three studied configurations

The survey evolved through a series of discussions with individuals having years of mining research and continuous miner operation experience. Experienced machine operators are a valuable source of information on machine job tasks. They have a wealth of knowledge, skills, and abilities gained from years on the job. The interview approach was the best method of compiling this knowledge. Researchers conducted three pilot interviews with machine operators. After completing the pilot interviews, the responses were examined for possible adjustments to the survey. Only during these pilot interviews were minor adjustments made to the survey such as rewording a question, changing the question sequence, and clarifying visual aids. These adjustments were not likely to have changed the responses obtained from the pilot interviews, but would contribute to clarity in future interviews.

Survey Structure

The survey covered two components of the work sequence: (a) cutting phase (15 questions) and (b) tramming phase (16 questions). Illustrations representing 1 of 3 possible mining configurations were employed as visual aids. Each illustration showed a section layout of a mining work area. The mining configurations illustrated were mobile haulage, continuous haulage, and full face layouts. Each component of the survey was field tested at 7 mine operations to evaluate the relevance of the questions to mining machine operators.

Continuous mining machine (CM) operators were interviewed one-on-one or in groups of up to 4. Meeting locations varied and included underground near the working face area, above ground in a conference room, or in the maintenance shop. Interviews took approximately 1-1.5 hours to complete. The participants were asked to respond to the questions verbally and to mark certain answers on a series of illustrations representing the mining configuration at their mine. In addition, researchers arranged with the mine management to go underground after the interview to observe the operator doing their job. The positions the operator used and areas frequently looked at during an 8-hour shift were noted by the researcher on illustrations identical to those used during interviews. These observations of the CM operator were used to validate the responses researchers obtained during the interview.

DATA ANALYSIS

Cue Ranking

Operator cues, operator position location, and their frequency of use were tabulated for each mining configuration using data from the interviews. Cue ranking was based on rankings provided by operators combined with the frequency of the cue's occurrence in the answers to open-ended questions. An example of the rankings for the various mining configurations is presented in Table 2, which shows a partial list for the mobile haulage configuration. There is significant overlap in the top six cues for all three mining configurations. Overlapping important cues include roof at the face, edge of drum, ribs, center line of entry, center line of entry, and cutting head bits.

Table 2. Example of cue ranking for a mobile haulage configuration

Importance	Mobile Haulage Configuration
1	Roof at the face
2	Right edge of drum
3	Ribs on right side of miner
4	Edge of the machine on the side you are on
5	Center line of entry
6	Cutting head bits
7	Floor at the face
8	Laser beam/spot
9	Back end of the boom
10	Center or other point on the drum
11	Center line of the machine
12	Left edge of drum
13	Ribs on left side of miner
14	Spray nozzles
15	Haulage vehicle inby bumper
16	How far the boom swings
17	Haulage vehicle operator

*partial list for one of the three studied configurations

Figure 2 illustrates the operator positions and their frequency of use for the mobile haulage layout. The most frequent operator positions are 4, 5, and 6, which together account for 48% of the positions taken. Positions 9 and 10, on the left side of the miner, provide the best viewing. They are not regularly used because they are located in return air, not in fresh air. They are used only when ventilation layout dictates. Position 8, in the center of the entry, was used primarily to determine how the mining machine lined up with the center of the entry. Position 8 cannot be used while a haulage vehicle is present. Similar results were found for the other mining configurations and various postures at these positions, depending on the height of the coal seam.

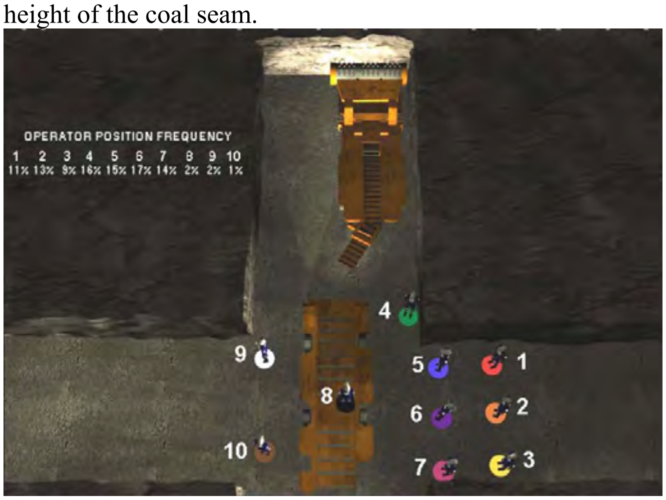

Figure 2. Available operator positions in cutting mobile haulage configuration.

Simulation Modeling

Researchers used computer simulation tools to determine what was blocked from the operator's view at any of the work positions and postures. The operator position and posture data was used to define virtual human operator positions in a simulated environment. In the computer simulation, a matrix of points was used to define the desired visual area. Visual cues could be represented as individual points for a cue that represented a specific location on the machine, or as multiple points for cues associated with a general area such as a rib. By representing areas as a matrix of points, the percentage of the area seen or blocked from the operator's view, from any perspective, could be determined. The virtual operator could then be placed in any of the work positions and postures, and the matrix scanned by the simulation software (Figure 3). The scanning automatically determines which visual cues are seen or blocked from any position, and allows a numerical means of comparing one work position to another. The positions can then be compared to MSHA's data on accident injury locations.

Figure 3 Simulated operator with visual cue matrix

Perspective views from the digital human's eyes of what the operator might see from a given position (Figure 4) allowed researchers to analyze the positions and postures of CM operators. The perspective views reveal how limited an operator's field of view can be in various positions, postures, and mining configurations. For example, the operator's field of view improves the further into the section he or she moves. This creates the temptation to move forward for a better view, even though doing so may place the operator in an unsafe and illegal position, such as underneath unsupported roof. By comparing the operator's view at different operator positions, researchers gained insight into the cues CM operators need to control the machine safely, as well as positions where operators may place themselves at greater risk.


Figure 4. Perspective view of simulated operator

Data tables showing (a) the visible percentage of the areas an operator wants to see from the operator positions in standing, kneeling, or squatting postures and (b) the average percentage of individual visual cues visible from all of the operator positions were developed for each of the individual mining configurations. Comparing the survey and observation data with visibility data from the simulations shows that CM operators most frequently selected positions that provided access to the cues they most wanted to see. The most blocked visual cues are the left edge of the cutting drum and the floor at the face, while the least blocked visual cues are the haulage vehicle operator and the center line of the machine. Interventions need to be concentrated at the most blocked cue locations.

From a safety standpoint, the safest positions to stand are farthest from the mining equipment, under supported roof, in fresh air, not near the ribs, and out of the way of tripping hazards and haulage equipment. Positions 2 and 6 best fit these requirements, but are only used 30% of the time (Figure 2).

DISCUSSION

The main thrust of this research is to identify the cues that are most significant to the operators. Interventions can then be developed to enhance these cues so that operators are more likely to choose a safe working position.

The methods of data collection and analysis used in this study successfully identify both the work positions and the quality of information available to a continuous miner operator. With the help of research tools such as computer models and simulations to evaluate visual data, the results of this study reveal that knowing the work positions and visual needs of operators in performing their job can have the potential to improve equipment design, machine operating procedures, and the areas where interventions would be the most effective.

Eger et al. (2004) report that the use of the operator's specific locations and visual perspectives as a training tool could assist operators in making better decisions on safe work positions. Operators should be trained to position themselves in safe locations, but they must be able to operate the equipment effectively from those locations. Operator position selection was determined to be based on the need for operational cues and by the dictates of the mining environment. The safest positions were only selected 30% of the time, which implies that improving other factors could make safer positions more attractive to operators. Data comparing the most important operator cues with the frequency of a selected operator position can now be compared to accident frequency and location.
The ranking of the visual and machine feedback cues allowed improved evaluations of each job phase for the most common mining configurations, and helped better define the complex relationships between visual cues and operator positions. The improved understanding of cues used by operators can further help the development of interventions.

The database of survey and observation information provides a good representation of operators and mining configurations from a cross-section of underground mine operations in both eastern and western states. The generated database of position frequency allows a comparison of the operator-selected work positions with a map of injuries derived from the MSHA injury database. How the relationships between cues, position selection, and injury occurrences apply in different phases of the mining cycle can be used to propose changes to machines to enhance operator safety and effectiveness.

Based on the promising results of this initial study, an in-depth study to develop interventions to improve safety of operators is underway. Results indicate that the survey and underground observations were a good combination and technique to develop a database of important visual cues and locations an operator wants to see from a given work position and posture. An analysis technique that determined how much of a particular area an operator sees from a variety of positions and postures in a computer simulation was shown to be potentially useful. The mining industry now has a tool to design work practices and section layout. The study could also influence equipment design or selection for improved worker safety through training.

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