Continuous Mining

A pilot study of the role of visual attention locations and work position in underground coal mines

By John R. Bartels, Sean Gallagher and Dean H. Ambrose

OPERATING LARGE MOBILE EQUIPMENT such as a continuous miner (Photo 1) is one of the most dangerous jobs that workers perform in underground coal mining. When underground coal is mined by the room-and-pillar method, rooms are formed by cutting into the coal bed (seam), leaving a series of pillars or columns of coal to help support the mine roof and create passages for the flow of fresh air. Generally, a completed room is 4.9 to 6.1 m (approximately 16 to 20 ft) wide and the pillar is 30.5 to 36.6 m (approximately 100 to 120 ft) wide. As mining advances, a grid-like pattern of rooms and pillars is formed, resulting in entries of horizontal mine passageways (Figure 1).

The Continuous Mining Process

Typically, to begin a room, the continuous miner engages in cutting (removal) a 3 m (9.8 ft) wide section of coal to a depth determined to be safe based on local geologic conditions and mining regulations—on average up to 6.1 m. Deeper cuts can be made (called extended-cut mining) with special permission from state and federal mining regulators.

After the cut coal is loaded onto haulage vehicles, the operator then backs the continuous miner out of the partially formed room, repositions the machine, and reenters to begin removing an additional 3 m section of coal to produce a wider entry. This process is repeated until a section of the seam is removed, forming a room approximately 12.2 m (approximately 40 ft) long and 6.1 m wide.

By law, roof support is required before continuing to extend the room's depth or cutting perpendicular to the room. Therefore, to allow other equipment to install roof support, the continuous miner is trammed (moved) to another location to begin cutting another room. Throughout the mining sequence, when forming rooms or tramming to another location, the machine operator, helpers, crew boss, maintenance mechanics and other equipment operators are put at risk by close proximity to the continuous miner machine and other hazardous situations associated with mining underground coal.

MSHA accident data from 2002 to 2006 indicate that the coal industry averages 6,407 accidents per year in underground mines. Of those total accidents per year, 21% (1,345) involve mobile face equipment, which includes continuous miners, roof bolters and haulage vehicles for underground mines; 4% (286) occurred while operating continuous mining machines. Unfortunately, in relation to this study, MSHA accident investigation reports do not contain sufficient information to aid in studying interactions between a machine and its operator. Consequently, a survey consisting of a questionnaire was used to gather pertinent information about operating a continuous miner in underground coal mines.

In the past, a continuous mining machine was

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Photo 1: **Operating large mobile equipment such as a continuous miner is one of the most dangerous jobs that workers perform in underground coal mining.**

Abstract: *Underground coal mine mobile equipment is often operated in a restricted workspace with reduced visibility. This puts machine operators in awkward postures for tasks that require awareness of their surroundings and fast reactions to avoid hazardous situations. Researchers conducted a pilot investigation that developed a method to gather visual attention locations and work positions used by machine operators while controlling the machine.*

operated and controlled by an operator seated in the onboard machine cab. New remote control technology allows operators more flexibility to position themselves to better view the work environment. Unfortunately, it has also allowed operators to position themselves in hazardous positions.

The use of radio remote control frees operators from the onboard cab and allows them to select any operating position within their line of sight. While cutting coal remotely, the operator typically takes a work position behind and to one side of the machine behind the last row of roof support. In high coal seams, where the machine is less of an obstruction, the operator trams the continuous miner using a remote control while walking near the rear of the machine. In low coal seams, the operator cannot see over the machine from the rear, so s/he trams the machine using a remote control while walking near the front of the machine.

However, operators tend to step alongside a moving continuous miner or beyond the supported roof for a better view while coal cutting or tramming. Adding to this hazard is restricted work space with reduced visibility. The work environment in found in low coal seams of 15.7 cm puts continuous miner operators and helpers in awkward work postures for the job, with tasks requiring quick reactions to avoid being struck by moving equipment.

Research has confirmed that modern mining practices and new technology have increased the risks involved in continuous miner machine operation. Bauer, Steiner and Hamrick (1994) report that the practice of extended-cut mining has increased operators' tendency to position themselves in hazardous locations. Additionally, Steiner, Turin and Hamrick (1994) state that an unforeseen consequence of remote control technology is that operators can position themselves in dangerous or hazardous locations which could result in a fatality or injury from possible roof falls, mine wall breakouts, pinch-points or other vehicle traffic. Finally, Lewis (1986) notes that low lighting conditions and restricted visibility found in many mines further complicate the tasks involved in operating equipment such as continuous miners.

The mining industry uses an operator guideline called *red zones* to help operators of remote continuous miners understand and avoid dangerous areas around the turning radius of the machine. While the concept of the red-zone technique, a pictorial go/no-go chart—developed by MSHA and the Virginia Department of Mines, Minerals and Energy (MSHA, 2004)—has been around for several years, fatalities and injuries continue to occur with moving machinery underground. The red-zone guide only addresses potential hazardous situations, ignoring the issue of what operators need to see and consequently where to position themselves in order to perform their jobs.

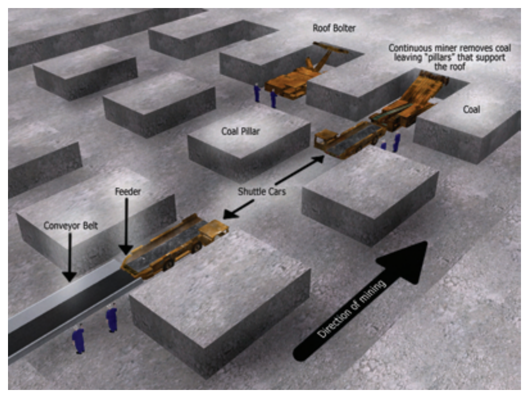

Figure 1: When underground coal is mined by the room-and-pillar method, rooms are formed by cutting into the coal bed, leaving a series of pillars or columns of coal to help support the mine roof and create passages for the flow of fresh air.

Human/machine interactions and behaviors should be considered in equipment design and work environment layout. After analyzing the data presented in this article, one can see that the practice of operators positioning themselves in a hazardous position in order to see visual attention locations (VALs) may be a major contributing factor to injuries.

A VAL can be defined as either a discrete point such as center of the cutting head or a general area that an operator visually scans such as the mine rib. Previous studies by Sanders and Kelley (1981) have provided a baseline of VALs that identified factors associated with cab-mounted operation of continuous miners. However, the information is not completely applicable to today's remote control operation. Approaches to determining operator VALs were also developed by Cornelius, Steiner and Turin (1998), who identified operator visual cues in extended-cut mining based on coal miners' experience.

The purpose of the study described here was to perfect a method of gathering information on work positions and VALs needed by operators during the cutting phase and while the continuous miner trams to a new location. This study precedes a future investigation using the developed survey that will recommend injury prevention interventions based on the influence of work positions and VALs on the risk of potential injury.

Table 1
Example of Questions

When you take a straight **cut** from where you are normally located, how often do you use the following as reference points?

Things 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			
Haulage vehicle inby bumper			
Haulage vehicle operator			
Floor at the face			
Roof at the face			
Right edge of drum			
Left edge of drum			
Center or other point on the drum			
Ribs on left side of miner			
Ribs on right side of miner			
Laser beam/spot			
Center line of entry			

Study Method
The Survey

A pilot survey was used to collect information on VALs from 12 continuous miner machine operators with experience ranging from 2 to 30 years at seven mine sites. A scripted interview technique was selected as the most efficient method of collecting and consolidating this information. The pilot study was used not only to collect information but also to judge the effectiveness of the questions in extracting the desired data.

The survey evolved through a series of discussions by individuals with years of mining research and continuous miner operator experience. Experienced operators have a wealth of knowledge, skills and abilities regarding machine job tasks, gained from years on the job. Researchers determined which phases of the continuous miner work sequence should be studied based on a combination of statistical information from MSHA's annual mine accident database, Sanders and Kelley's research (1981), and job task analyses for machine operators.

The survey covered two components of the continuous miner work sequence: 1) the cutting phase with 15 questions and 2) the tramming phase (movement from one location to another) with 16 questions. Each component was field tested at seven mine operations to evaluate effectiveness of questions and value of the data collected. In addition, during the mine visits, researchers arranged to go underground after the interview to observe the operator performing his job. These observations helped the researchers evaluate the data collected during the interview and validate the responses.

Key Mining Terms

Continuous miner: Mining machine designed to remove coal from the face and to load that coal into cars or conveyors.

Cutting: Operation of making openings across a coal seam.

Cutting drum: Rotating drum with carbide teeth that cuts the coal from the seam.

Extended cut: Cutting an entry that is more than 20 ft long without stopping to support the roof.

Face: Exposed surface of a coal or ore deposit in the working place where mining is proceeding.

Floor: Bottom of a coal seam or any other mineral deposit.

Haulage: System of hauling coal out of a mine (usually mobile vehicles or conveyor).

High/low coal: Coal seam of 48 in. or more is considered high; less than 48 in. is considered low.

Pillar: Column of coal or ore left to support the overlying strata or hanging wall in a mine, generally resulting in a *room-and-pillar* array.

Red zone: Area around an operating machine that should not be entered for safety reasons.

Roof: Rock immediately above a coal seam.

Roof support: System for preventing fall of roof in mines. Boreholes usually from 1 to 4 m (3 to 12 ft) long are drilled upward in the roof, and bolts of 2 to 2.5 cm (⅝ to 1 in.) or more in diameter are inserted into the holes and anchored at the top by a split cone, mechanical anchor or resin grout.

Room: Place abutting an entry or airway where coal or ore has been mined.

Room and pillar: System of mining in which typically flat-lying beds of coal or ore are mined in rooms separated by pillars of undisturbed rock left for roof support.

Seam: Stratum or bed of coal or other mineral; generally applied to large deposits of coal.

Section: Portion of the working area of a mine.

Tram: Moving a self-propelled mobile machine from one place to another.

Ventilation: Mine workings are usually subdivided to form several separate ventilating districts. Each district is given a specified supply of fresh air and is free from contamination by the air of other districts.

Water spray: Wetting of a surface while cutting to reduce airborne dust.

Note. *Originally compiled by the U.S. Bureau of Mines. Additional definitions can be obtained at www.infomine.com/dictionary.*

An operator must assimilate and process several VALs and machine feedback cues to safely control a continuous miner. The survey questions were designed to provide data not only on what the operator looks at and from what position, but also on why an operator uses certain visual cues and machine feedback cues to make decisions on how to operate the equipment and select a work location.

For example, questions addressed possible obstructions such as dust, water spray, light housings and the glare from light sources that might block the operator's view of vital VALs, and the operator was asked what he would do about these obstructions. Also, a series of questions dealt with initial work positions, operator postures and possible deviations from that initial position during the work sequence while operating the continuous miner.

Due to the restricted work environment and conditions such as low seam height, the operator may not always be able to see essential VALs. Experienced operators tend to substitute other cues when this happens. For example, the cutting drum on the continuous miner will make a task-specific sound or vibration, indicating that the machine is cutting into the roof or floor outside of a coal seam. This does not mean that the roof and floor become invalid VALs, but they are blocked from view in this instance. Because of this, the survey included questions about the machine feedback cues and how the operator uses this information to perform the job.

Underground mine configurations and coal removal plans vary at each mine operation based on mining preferences, seam height and local geology. Consequently, the cutting phase to complete a room can take four separate cuts, two longer cuts or even one cut if the continuous miner (full-face miner) is fitted with the cutting appendage wide enough to accommodate the planned width of the room. The method of hauling and loading coal is also wide-ranging, involving such options as continuous haulage systems, shuttle cars and front-end loaders.

Despite these variations, much of the information an operator requires in the way of visual cues to operate the continuous miner is the same. For this reason and to normalize the data, the survey used various illustrations that apply to a broad range of mining operations and mine environments as interview aids. The differences between mining configurations can be divided into three general layouts based on the type of haulage and width of the cut.

Other differences include a variation in the sequence of cutting patterns, such as taking the first cut on the left rather than on the right side of the new entry. The set of illustrations used at a particular site was based on a previsit interview with mine management to determine mining methods and cutting sequences used at that operation.

In particular, these illustration aids helped to identify the operator's work positions and the VALs specific to an area, a particular spot or other objects (people and machines) within that operation's work environment.

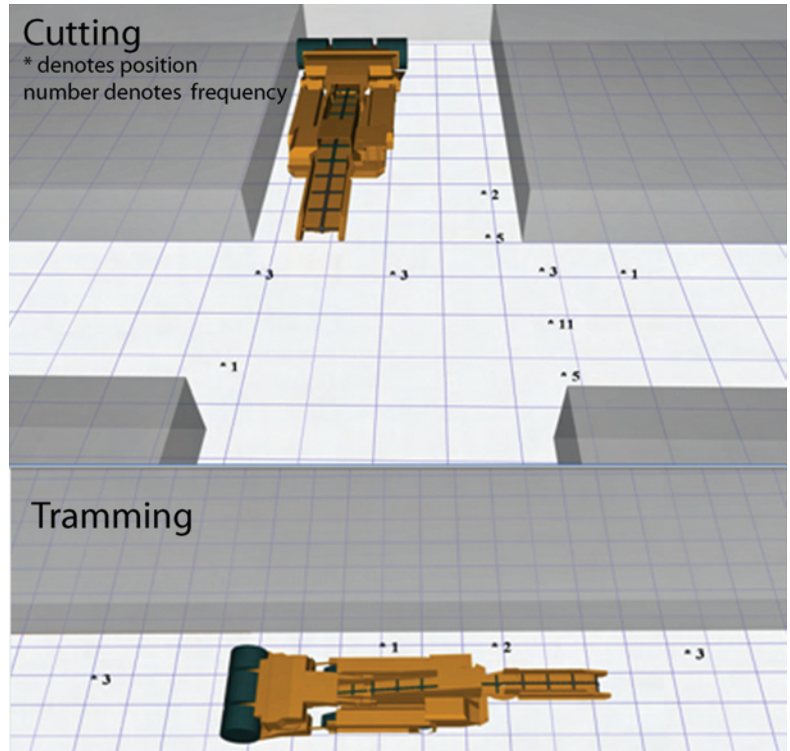

Figure 2: Work positions during cutting and tramming.

Interview Technique

The data were collected using a scripted interview technique following survey questions as the outline. The interviews were conducted at the mines during the shift change in aboveground settings such as the bath house or maintenance shop, since operators do not typically have enough time for interviews while working underground. In addition, through field trials of the survey, the aboveground locations proved to be convenient for conducting multiple interviews and confirmed how relaxed and focused operators were with their responses.

Each interview lasted about 1 hour and was conducted by two researchers, one who recorded while the other conducted the interview. The interviewer acted as a facilitator, so the other researcher recorded the responses in detail, because many questions were designed to lead the operator into comprehensive discussions rather than just a one- or two-word answer. This two-person approach allowed ample time to focus the interview and concentrate on understanding each operator's rationale in his decision making to process a lot of information for controlling the continuous miner.

Tailored to reflect the specifics of each mine visit, a series of colored, 3-D illustrations was prepared as a visual aid depicting that mine's sequence of tasks and underground coal mining equipment. These illustrations aided in the interview process and recording of the responses. It was obvious to researchers that the use of visual aids helped the operators explain where and why they positioned themselves, and identify discrete points or general areas they watched while operating the continuous miner.

In addition, the survey contained tables (such as

Table 1, p. 30), listing locations where the operator might look while controlling the machine and with what frequency (i.e., always, sometimes, never). These tables made it easier for operators to formulate their responses by identifying VALs that they would use and provided them the opportunity to discuss probable reasons for their choices. This information helped researchers determine the importance of the operators' choice in their responses associated with each VAL listed in the tables.

After completing each interview, responses were examined for possible adjustments to the survey. The first three interviews led to minor adjustments, such as rewording a question, changing question sequence, or modifying contents to clarify a table or an illustration. The changes were considered effective when the operators being interviewed no longer asked for clarification on the questions or had suggestions to make the questions clearer. These adjustments were made for clarity and flow of the interview and would not have changed responses from the three previous interviews.

Table 2

VAL Frequency Cutting

When you take a straight **cut** from where you are normally located, how often do you use the following as reference points?

Things you look at	How often		
	Always	Sometimes	Never
Edge of the machine on the side you are on	8	1	3
Center line of the machine	3	5	4
Back end of the boom	8	4	-
Cutting head bits	5	4	3
How far the boom swings	-	4	8
Spray nozzles	1	4	7
Haulage vehicle inby bumper	1	4	7
Haulage vehicle operator	3	7	2
Floor at the face	7	2	3
Roof at the face	11	1	-
Right edge of drum	4	8	-
Left edge of drum	5	7	-
Center or other point on the drum	2	8	2
Ribs on left side of miner	3	7	2
Ribs on right side of miner	5	5	2
Laser beam/spot	5	2	5
Center line of entry	9	3	-

When taking a straight **cut** from where you indicated you normally position yourself, do any of these things block your view of things you need to see?

Things that block your view	How often		
	Always	Sometimes	Never
Glare of machine lights	-	7	5
Machine light housing	-	2	10
Spray from nozzles	2	4	6
Steam from bits	1	1	10
Dust	8	3	1
Ventilation system (response reflects both or just one system used)			
Brattice	1	2	4
Tubing	3	2	3
Coal piles on machine	2	6	4
Bolter operator on miner bolters—not all mines use this machine	-	2	6
Do you ever turn the drum off for visibility	-	5	7

Data Analysis

The data revealed three types of cues an operator uses to control the machine: visual, audible and tactile. The operator responses indicated that VALs were the most important and that the other cues were used as substitutes when visual information was obscured or restricted. After an interview had been reviewed and analyzed, it was validated by observing interviewed operators performing their jobs. This verified that they were constantly 1) monitoring multiple VALs by scanning the work area; 2) checking machine feedback during operation; and 3) routinely observing the location of other workers and equipment in close proximity of the work area. In addition, it was observed that operator location could be dynamic, changing as the situation required. Figure 2 (p. 31) shows the frequency with which operators identified specific work positions during both the cutting and tramming tasks.

The VALs and the work positions that the operators considered vital were consistent from mine to mine. Table 2 summarizes data collected on visual attention locations for the cutting phase and Table 3 presents data for the tramming phase. VALs are defined as a general area around the machine, a specific point on the machine, or a mobile object such as another person or machine around the continuous miner machine. Some VALs are machine appendages associated with a direction of movement such as up/down, swing left, swing right or swing centered. Those VALs around the continuous miner that have movement—such as people and other machine operators—are defined as *mobile* to imply the possibility of moving in any direction.

Many VALs are the same for both the cutting and tramming phases, although the reasons for their importance may differ. For example, in the cutting phase, the tail of the continuous miner is watched while loading the haulage vehicle with coal. In the tramming phase, the operator watches the machine's tail to avoid hitting the roof when uneven floor causes the machine to undulate or when turning a corner to avoid striking the side of the coal seam.

As expected, the data showed that the line of sight to VALs plays a major role in the operator's decision on where to stand during the job. Observing operators underground proved to researchers that operators tried to select a work position which provided the best line of sight to VALs.

However, other factors also seemed to influence the selection of a work position such as equipment concerns or mine layout. An example of an equipment concern is the need to not run over the electrical cable that supplies power to the continuous miner. A mine layout example affecting work position is the requirement that operators stand close to a source of ventilation which supplies fresh air and removes dust from the work area. These factors limit which work positions an operator would use at a particular mine.

Results

An example of results from interview questions that helped to develop a list of VALs is shown in Tables 4 (p. 34) and 5 (p. 35). Operators were asked to indicate how frequently they looked at specific VALs. Other questions were more subjective, allowing operators to provide additional information that the survey had not covered. This combination of questions allowed for a prioritized list of VALs to be generated.

The data generated can be analyzed by various techniques with the goal of improving operator safety. The determination of operator work positions, for example, can be compared to Figure 3, which represents injury zones derived from the MSHA accident injury database. The zones are divided by the type of injury most likely to occur in that zone.

An example would be injuries in zone B, which would most likely be the result of a crushing accident by the tail boom. By comparing the frequency of injuries in a particular zone with the operator position frequency, recommendations can be made on preferred positions.

The data also permit the use of simulation tools to determine which VALs are blocked from the operator's view at any work position at a desired point in the mining cycle. The results gathered from 12 operators were used to determine operator positions in a simulated environment using a digital human model and simulation software. VALs were represented as individual points for a VAL that represented a specific point on the machine, or as a matrix of points for VALs associated with a general area. By representing areas as a matrix of points, the percentage of the area seen or blocked from the operators' view—from any perspective—could be determined. The operator could then be placed in any of the work positions determined from the data (Figure 4, p. 34).

Figure 5 (p. 34) represents the perspective view from the digital human's eyes of what the operator might see from any position. These perspective views allowed researchers to analyze the positions that the operator takes trying to see VALs while operating the machine. These views helped to reveal how limited an operator's field of view can be. The scanning feature of the software allows for an automatic determination of which VALs are seen or blocked from any position. This allows a numerical means of comparing one work position to another, which can then be compared to the accident injury zones.

To demonstrate, the operator's field of view improves on the left cut, but so does the temptation to move forward for a better view and, consequently, move underneath unsupported roof—which is not only illegal, but also unsafe. By comparing the operator's view at different positions, insight can be gained into the VALs the operator needs to control

Table 3

VAL Frequency Tramming

When you tram the miner from where you are normally located, how often do you use the following as reference points?

Things you look at	How often		
	Always	Sometimes	Never
Edge of the miner on the side you are on	5	-	-
Center line of the miner (paint or laser)	-	1	4
Any edge of the boom	2	3	-
Cutting head bits	4	-	1
Spray nozzles	4	-	1
Floor of the entry	3	1	1
Roof of the entry	4	1	-
Right edge of drum	3	2	-
Left edge of drum	2	3	-
Center or other point on the drum	3	2	-
Ribs on left side of miner	2	3	-
Ribs on right side of miner	3	2	-
Center line of entry	-	3	2
Back end of boom	3	2	-

When you tram the miner from where you are normally position yourself, do any of these things block your view of things you need to see?

Things that block your view	How often		
	Always	Sometimes	Never
Glare of machine lights	-	3	2
Machine light housing	-	-	5
Spray from nozzles	-	1	4
Dust	-	1	4
Ventilation system			
Brattice	-	2	1
Tubing	-	1	2
Coal piles on machine	-	1	4
Other machines	3	2	-
Other people	2	3	-

Figure 3: Operator injury zones derived from MSHA's injury database. The zones are divided by the type of injury most likely to occur in that zone.

Table 4
Most Important VALs Cutting

VAL	Area/spot/object‡	Direction of movement
Last row of bolts	area	-
Center line of entry	area	-
Center line of machine	area	-
Rib right side	area	-
Rib left side	area	-
Edge of machine right side	area	-
Edge of machine left side	area	-
Top of drum at center	area	up/down
Bottom of drum at center	area	up/down
Right edge of drum	spot	up/down
Left edge of drum	spot	up/down
Roof at right edge of drum	spot	-
Roof at left edge of drum	spot	-
Floor at right edge of drum	spot	-
Floor at left edge of drum	spot	-
Center line of machine at drum	spot	-
End of tail boom	spot	swing left/right/center
Roof at tail boom	spot	-
Floor at tail boom	spot	-
Cut depth mark added to machine	spot	-
Haulage machine (shuttle car, mobile bridge)	object	mobile◊
Operator of shuttle car/bridge/ram car	object	mobile
Face boss	object	mobile

‡ Area: specific area around the machine; spot: specific point on the machine; person: another worker around the machine.
◊ Mobile VAL is located near the continuous miner machine and moving in any direction.

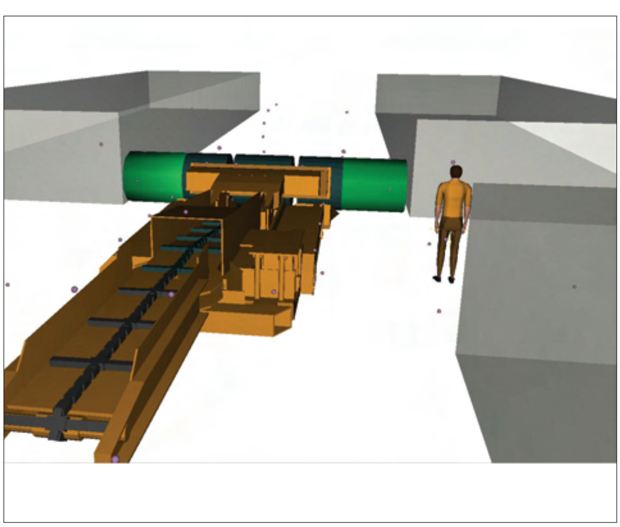

Figure 4: The data gathered permit the use of simulation tools to determine which VALs are blocked from the operator's view at any work position at a desired point in the mining cycle.

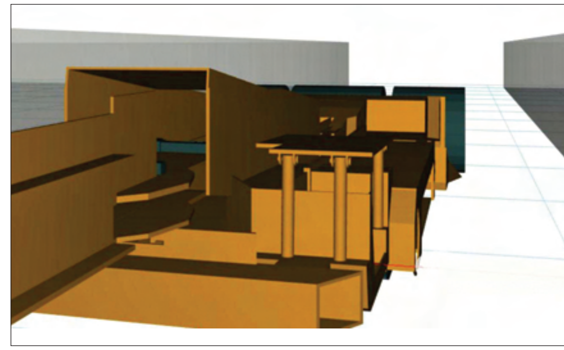

Figure 5: Operator's eye view, which allows the researchers to analyze the positions that the miner takes trying to see VALs while operating the machine.

the machine safely as well as positions where the operator could be at greater risk.

This information helped researchers to determine the importance of the operators' positions in their responses associated with each job task. Additionally, the information indicated the importance of the operators' choices in their responses associated with each of the VALs listed in the tables. Furthermore, it provided the operator the opportunity to discuss probable reasons for the choices made.

Discussion

The results of this pilot study showed that the method of data collection and analysis successfully identifies the work positions and the quality of information available to a continuous miner operator to control the machine safely. With the help of research tools such as computer models and simulations to evaluate visual data, the results of this article reveal that knowing the work positions and visual needs of operators in performing their job has the potential to improve both equipment design and machine operating practices. Additionally, Mason, Rhodes and Best (1979) report that the use of the operators' specific locations and visual perspectives as a training tool could help operators make better decisions on safe work position.

A 3-year study using the developed interview is currently underway to provide an in-depth examination of the VALs, operator positions and machine feedback cues that operators use for controlling a continuous miner. A larger number of interviews (70 to 100) are planned at mine operations throughout the U.S. to analyze the VALs, work positions and their relative importance to the machine operator.

Ranking the VALs will allow improved evaluations of each job phase for all mining configurations; however, a larger database is needed to do this. A larger database must have a better representation of operators and mining methods from a cross-section of underground mine operations in both eastern and western states. Additionally, the complex relationships between visual locations must be defined. For example, an operator on the right side of the machine might be able to imagine the VALs on the left side of the cutting drum if the right side of the drum is visible. Also, with a larger and more diversified database, comparing work positions and necessary VALs to injury data will be investigated. How these relationships apply in different situations, the operators' dependence on them, and potential control interventions adapted to machines to enhance VALs and optimize operator positions will be explored.

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 can see from a given work position and posture. Analysis techniques that determine which VALs an operator sees from a variety of positions in a computer simulation is shown to be potentially useful to the mining industry for design of work practices and section layout, and could impact equipment design or selection for improved worker safety through training. Based on the promising results of this study, an in-depth examination of operator cues and positioning is underway. ■

Table 5

Most Important VALs Tramming

VAL	Area/spot/object‡	Direction of movement
Center line of entry	area	-
Center line of machine	area	-
Rib right side	area	-
Rib left side	area	-
Edge of machine right side	area	-
Edge of machine left side	area	-
Roof at center of drum	area	-
Top of drum at center	area	up/down
Centerline of entry at 20 ft	area	-
Roof at 20 ft	area	-
Centerline at necessary stopping distance	area	-
Roof at necessary stopping distance	area	-
Floor at necessary stopping distance	area	-
Obstacles at necessary stopping distance	area	-
Right edge of drum	spot	up/down
Left edge of drum	spot	up/down
Roof at right edge of drum	spot	-
Roof at left edge of drum	spot	-
Floor at right edge of drum	spot	-
Floor at left edge of drum	spot	-
Center line of machine at drum	spot	-
End of tail boom	spot	swing left/right/center
Roof at tail boom	spot	-
Floor at tail boom	spot	-
Cut depth mark added to machine	spot	-
Other moving equipment	object	mobile◊
Mechanic	object	mobile
Face boss	object	mobile

‡ Area: specific area around the machine; spot: specific point on the machine; person: another worker around the machine.

◊ Mobile VAL is located near the continuous miner machine and moving in any direction.

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