# WORK SAMPLING APPLIED TO A HUMAN FACTORS ANALYSIS OF MINE WORKER POSITIONING

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Growing concern from labor unions, regulatory agencies, and industry about the safety of a prevalent underground coal mining method which utilizes remote control has prompted human factors field evaluation of mining activities. Remote control operations were implemented with little consideration given to human-system interactions. Ideally, collecting and analyzing information *prior* to implementing new technology would have helped to address potential problems. One such problem that operators and other mine personnel are faced with is the question of where they should safely position themselves to avoid injury while remotely operating machinery. To determine work methods employed by machine operators before and after implementation of the new method, work sampling techniques have been used to provide data about positioning of face crew members at different points in the mining cycle. This data provides information for optimal positioning, leading to safer operating procedures and identifying training shortfalls.

## INTRODUCTION

As with many industries, mining companies implement new technologies as they are developed to increase productivity and reduce costs. These technologies require evaluation to determine what unintended effects these new methods, machinery and interfaces have on mine workers. Extended cut mining, the primary method for coal extraction and mine development, uses remote control technology to allow the operator of the cutting machine to cut up to twice the horizontal distance than was permitted by manual on-machine operation. The mining industry readily adopted widespread use of the new method due to its productivity enhancements and its promise to keep operators farther from the hazards of unsupported mine roof. As such, the mining machine operator is no longer exposed to the shock and vibrations of the machine and is free to move about the worksite to facilitate

visibility of the task. This same freedom has at times, exposed the operator to new hazards such as moving equipment and unpredictable roof and rib conditions.

Growing concern about extended cut mining was expressed by the United Mine Workers of America (UMWA), Mine Safety and Health Administration (MSHA), state regulatory agencies and mining companies due to its possible contribution to several mining fatalities occurring from 1988 to 1995 (Bauer *et al.*, 1997). Since available data on non-fatal injuries is insufficient to provide information about root causes or details of operators' actions, it was not possible to relate safety issues directly to extended cut mining and the specific tasks that were performed. Why operators choose to position themselves in particular areas that may increase the risk of injury could not be determined. Analysis of continuous miner operators/helpers/trainers fatalities from

1988-1995 reveal that 33% are from roof falls and 23% from being crushed by the machine and other moving equipment. These incidents are a result of poor operator positioning.

## THESIS

This paper discusses the application of a quantitative engineering task analysis tool, work sampling, supplemented by qualitative interview data to determine whether operators position themselves in unsafe areas while operating machinery because of the length of cut permitted. Data from the sampling reveals the feedback operators need to effectively operate machinery remotely. This method could also be used to predict hazards associated with method and equipment changes in the design phase before implementation.

## SOURCES OF INFORMATION

A previous work sampling study performed by Bureau of Mines researchers revealed that continuous miner operators were standing in positions that were not recommended by their standard operating procedures because of their inability to observe operations effectively from the recommended positions (Love and Randolph, 1992). This study was not concerned with extended cut mining *per se*, but rather with remote control mining. The study suggested that in comparison to taking cuts straight on, there was more operator position variability when turning the machine to begin a crosscut. Unfortunately, the number of observations was insufficient to draw conclusions. The study clearly showed that there are substantial differences between operator's actions and the company's safe operating procedures (SOP). However, further investigation of SOPs developed by mine companies revealed that detailed operator location information was lacking and it was difficult to make more specific comparisons of the work sampling observations and the SOP.

Interviews were conducted with 155 miners at 7 mines to examine general safety issues in extended cut mining (Steiner *et al*, 1994). The interview data revealed that most mine workers were in favor of extended cut mining. However,

operators again expressed concern about the safety of their location (especially when turning the machine), their inability to see the machine's cutting head in some situations, ineffective lighting on the machine, and difficulties with performing certain maintenance tasks.

In order to determine the work methods employed by continuous mining machine operators and the effects of extended cut mining methods, more detailed work sampling techniques were developed. Work sampling or activity analysis was appropriate in this situation because the tasks were easily defined, not highly repetitive, and cycle times were of proper duration (Kirwan and Ainsworth, 1992). Fixed interval sampling was used to document work methods and exposure to hazards (Keyserling, 1997). Due to the inherent variable conditions in underground mining, direct task observation in the field was essential. To specifically determine what effects extended cut mining had on miner operators' habits, mines were identified that had not yet implemented extended cut technology, but were preparing to start. It was determined that useful information could be collected using work sampling techniques by examining mines both before and after implementing the longer cuts. The activity analysis was adapted to collect data regarding the face crew's location at different points in the mining cycle, since operators and other crew members are faced with the question of where they should safely position themselves while machinery is being operated remotely. The most important factors influencing position were visibility, geological conditions, ventilation, positions of other mine workers, and moving machinery. The optimum location for an operator to stand may differ depending on the length of cut, type of cut, and a number of other variables.

The goal of the work sampling method was to identify differences in operator positioning in standard versus extended cuts providing insight to the habits of the operator and reasons for differences in habits. In particular, it was necessary to determine what cues and information were used by operators to decide where to stand at what point in the mining cycle. The locations of workers and equipment at the face area were

recorded along with the direction the operators were looking and at what stage they were in the mining process. Based on the observations made, verbal descriptions from the operator were recorded immediately following the observations to explain any unusual actions or safety discrepancies the operator performed during the observation periods.

Case studies were conducted at two mines identified by MSHA as having applied for extended cut approval but were still in the approval process. The work sampling process was applied both before and after extended cut operations were approved and implemented. Observations were taken over several days with the same continuous miner operators and helpers for each condition so data were comparable. This reduced operator variability and the observer effects. Observations every three minutes prompted by a programmable beeping source. Fixed interval sampling was used at this rate due to the relatively slow changes in operator position and the extensive amount of data being collected. Videotaping of operator activities is virtually impossible in this environment due to low lighting and visual obstructions by machinery and people. Data was collected on graph paper pre-drawn with mine dimensions and machines. Operator positioning was recorded with respect to the mining machine. Zones were defined before field evaluations to make recorded positioning less vague (Figure 1).
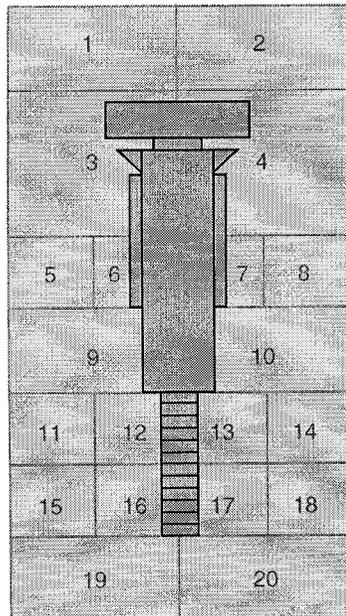


**Figure 1.** Miner Operator Zones Defined With Respect to Mining Machine.

The type of data collected included: who was in the activity area, where they were located with reference to the machines, what they were doing according to previously defined activity codes, operator's direction of view, and any

discrepancies or violations observed. Data was collected over a four-day period for mines both before approval was granted for extended cut and again several months after approval was granted to allow for sufficient learning time. The sampling covered 30 cycles in the pre-approval status (15 cycles at each mine) and 24 cycles in the post approval status (10 and 14 cycles at each mine). Researchers were also interested in whether management would provide training or institute additional safety precautions as a result of their change to extended cut mining.

## FINDINGS

Several comparisons were made including operator differences between mines both before and after extended cut approval, operator positioning differences within mines but based on extended lengths of cuts and shorter lengths of cut, and operator positioning during the first twenty feet of the cut and the final twenty feet of the cut. These comparisons are made to determine whether taking an extended cut changes the actions of the operator and if it is necessary for operators to stand in particular positions in order to effectively operate equipment.

Large differences were not evident among individual operators between the before and after extended cut approval conditions. In fact, operators preferred to stay in the same position, #10, with reference to the machine during the first twenty feet of the cut regardless of the permitted length of cut. Zone #10 is an area 7' by 8' located at the right rear corner of the machine (Figure 2). During turning operations, operators stay in zone #10 unless they are in the first cut of turning the machine towards the left (with the cable and ventilation set up on the right side of the entry). In this case, one mine's operators stand in zones 9 and 11, sacrificing fresh air and visibility of the mining cable for better visibility of the cutting head when aligning the first cut. Turning a crosscut appears to be the most variable and difficult task for operators regardless of length of

cut. The first two cuts of the crosscut were critical and required the most skill. Operators tended to stay further behind the machine during longer cuts. Operators are not allowed by law to go past the last row of roof supports. The longer cuts place the
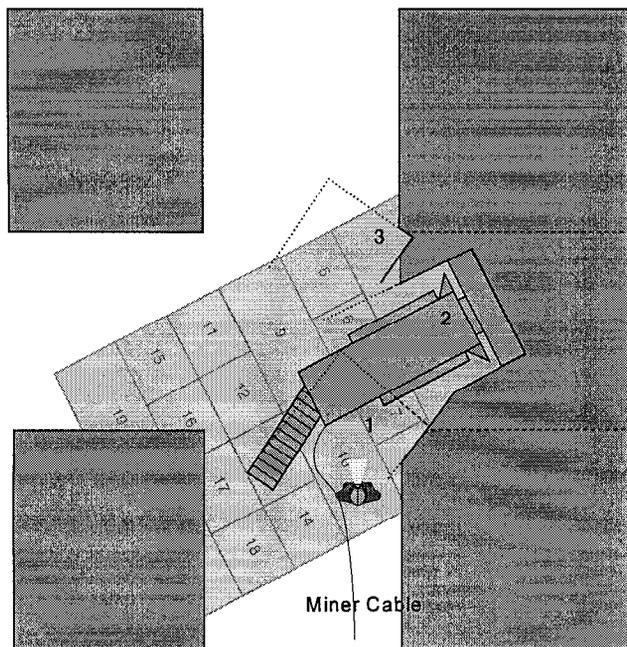


**Figure 2.** Continuous Mining Machine in Cut Two of a Right Crosscut

machine away from the operator but the operator is not allowed to follow the machine into the cut. In this case, he has no choice but to operate from a further distance. Several safety discrepancies were observed including backing out the equipment while standing too close, failure to check for methane, standing in pinch points between the machine and the rib, and accidently going beyond roof supports.

## DISCUSSION

The observations helped to define the preferred location of operators while mining straight ahead and while turning. Operators prefer zone #10 when the mine is set up with the ventilation and mining cable on the right side. The mirror image is also true. Operators tend to place themselves in one particular spot for the entire sequence unless there are unusual tasks that need to be performed. Operators prefer zone #10 because it allows them to receive the vibratory and auditory feedback they need to determine if the cutting head is in rock or coal. Also, because operators were used to riding on the deck of the machine, and they may prefer to stay rather close to that original location. The lighting scheme on the machine influences operator positioning since the lighting is still designed for on-deck operation. This is a major problem for the operator. If the lighting were redesigned to illuminate the necessary visual attention locations, the operator would have more freedom for positioning. The operator also likes to stand in fresh air and be able to attend to the miner power cable. If the miner or the haulage operator runs over the cable, power can be cut off to the machine causing production delays. Though operators have chosen this position for many reasons, it is not necessarily the safest with respect to human factors considerations. While operators have definite position preferences, those preferences may be based mostly on habit. In several mines visited after the work sampling study was completed, operators were observed standing two to three feet behind the machine (zones 18, 19, 20 and beyond) when cutting coal, and said they were able to operate effectively. In this work sampling study, operators were effectively operating from behind the machine when they were legally required to do so. This suggests that it may be possible for more skillful operators to stay further back from the machinery and unsupported top and still operate effectively. It also suggests that less skillful operators can be trained to stand in safer zones thus reducing the exposure to crushing injuries and roof falls.

Since most fatalities occur when the operator goes beyond the last row of roof supports or when the operator is pinned between the machine and the rib, it is critical that operators avoid those locations. The injury data show that operators of remote control machines are more likely to be injured by being struck by the machine than by roof falls. Being struck by the machine usually happens while taking the first twenty feet of the cut. Being struck by unsupported roof usually occurs while taking the next 20 feet of the cut. The main threat to safety in extended cut mining resides in the use of remote control technology. The majority of injuries occur during the turning operations, i.e., during the first twenty feet of the cut. This study highlights the difficulty

of taking turns, the danger of using remote control while in close proximity of the machine, the types of sensory feedback operators need, and suggests reasons for operator preferences and habits.

The data collected has prompted some changes to be implemented and others are in the research phase. The information has been used at these mines to develop more explicit safe operator procedures for continuous miner operators and helpers. NIOSH is currently using this data to
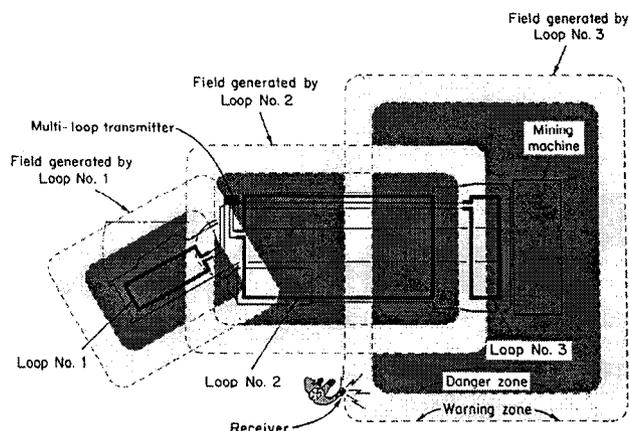


**Figure 3.** HASARD Two-Zone Operator Warning System

develop and test a device, HASARD (Hazardous Area Signaling and Ranging Device), to warn operators when they get too close to mining equipment (Figure 3). HASARD is an electronic warning system that warns operators at three levels: a safe zone, a caution or warning zone, and a danger zone. In the warning zone, operators can make a decision to step back into the safe zone or continue moving closer to the mining machine into the danger zone which will shut down the tramming function of the machine. The feasibility and practicality of this system from a human factors perspective is being determined at this time. HASARD can also be used to train new equipment operators to form safe habits and learn to rely on feedback while staying a safe distance from the machine. Although HASARD will not prevent miner operators and helpers from going under unsupported top, it will address the issue of being pinned between the rib and the mining machine. Also, the machine's lighting scheme needs to be

redesigned to improve illumination of critical areas. Some of the pinning/crushing injuries and roof fall injuries are a result of operators trying to see what they need to see. Improved illumination could help to reduce these injuries as well. The engineering technique adapted to identify risk factors in mining could be applied in many manufacturing situations where a change in work methods and equipment is forthcoming. This information could help to predict problems and prevent injuries before implementation of the proposed change.

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