Predicting System Interactions in the Design Process

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INTRODUCTION

Almost every process has a predecessor, and studying the predecessor helps to define needs and shortcomings to be addressed in the new design. It also suggests what information is needed by the users in order for them to be able to operate safely and effectively. The end users of a system can provide important feedback to better evaluate the current and proposed designs. When new technology is introduced into a system, mishaps may occur before it is realized that human-system interactions were not considered adequately in the design process. A systematic methodology to evaluate the causes of these injuries and to develop remedial recommendations can enhance safety. This paper illustrates how such an approach was used to assess remote machine operation in underground coal mines.

The dynamic work environment of underground mining with its unpredictable geologic anomalies can result in numerous hazards. Many of these hazards, including mine roof collapse, occur near the working face where coal is being extracted. The face area is also where the most intricate interactions of people and equipment occur. For these reasons, a high priority has been placed upon minimizing hazards to the workers at the face. A remote control operation was introduced to provide a safer working distance from these hazards. As the remote control technology began to be widely used for extended cut mining operations, new issues became evident. It was essential to develop mechanisms for mines to evaluate these issues in order to predict and reduce injuries.

Mining methods and equipment changes must allow for the ability of workers to adapt to changes in their dynamic mining environment. Consideration should be given to how the worker will use familiar information to make decisions in now unfamiliar situations. There will be both intended and unintended consequences [Merton, 1949]. Designers try to anticipate and eliminate surprises, but it is impossible to eliminate them all. How, then, will the new system affect the tasks to workers which are currently accustomed? As suggested below, this question may be addressed and more of the unintended outcomes predicted with a planned design process which includes strong human factors input to determine interactions and behaviors of participants.

METHODS

A simple system or product design process involves several stages, proceeding from general to specific. It starts with the definition of a need and a plan to produce a solution, and ends with a final product to monitor and evaluate. The process is iterative and each stage can be revisited at any time to improve the design of the system. It is critical to integrate human factors into each stage of the process [Chapanis, 1996]. Emphasis should be given to the human-machine-methods-environment interface from the onset. Regarding extended cut mining, the authors have investigated changes to interfaces in order to determine what impact the new process has on the worker's ability to adapt to the dynamic work environment. The following questions need to be answered: What effect does the equipment change have on the operator and other workers in the face area? How do work methods change due to equipment change and relocation of the operator? Several analytical methods were used to answer these questions.

Literature Review

An examination of the literature about new mining equipment and methods revealed that most concerns with the implementation of the extended cut method lay in the areas of ground control and ventilation rather than in the use of remote control technology. These centered upon regulatory compliance and production enhancements. There was little evident concern for specific operator needs. This review led to a better understanding of the system and guided development of methods that could be used to target human factors problem areas.

Injury Analysis

An important aspect of research to assess the safety of extended cut mining has been the examination of injury data. Injury rates at mines with approval from the Mine Safety and Health Administration (MSHA) to do extended cut mining, were higher than those at mines without approval but fatality rates were lower. Mines with extended cut approval had higher injury incident rates for incidents that involved a worker being struck by or against something, incidents related to the handling of materials, and injuries involving a slip or fall [Bauer et al., 1994]. However, it was not possible to compare characteristics of incidents that occurred when an extended cut was being taken to those of shorter standard cuts because of the limitations in the data. The implication to be drawn from this is that reporting methodologies should be changed to reflect changes in technology.

As a corollary, an exploratory study was initiated at two mines following the occurrence of fatal injuries to machine operators working within an intersection during extended cut mining. Although the injury data analysis had significant limitations, the results of those efforts combined with exploratory study findings provided insights that were used to develop more specific mine site research.

Interviews

An interview guide was developed to identify general safety issues, and specifically, to determine what aspects of this extended cut technology were problematic to the mining industry. Topics included mining experience, work methods and procedures used, incidents and injuries, manual materials handling, control layout and design of equipment, visibility, ventilation, operator protection, maintenance, and general safety. Overall, the workers had a positive attitude toward this technology. However, visibility and some aspects of maintenance were identified as common problems. It was learned that major differences exist in the specific type of problems encountered at each mine, making a generalized solution impractical.

A subsequent questionnaire was administered at mines in a particular geographical area in order to more narrowly focus some problem areas. The physical location of the operator during the turning task was an evident concern. The questionnaire also revealed a less than optimal illumination scheme on the continuous mining (CM) machine used in extended cut mining. Further research found that no changes had been made to the lighting systems on the machines since remote control was introduced.

Activity Analysis/Structured Observations

Information was collected using work sampling techniques by examining mines both before and after implementation of longer cuts. The goal of this activity analysis was to identify differences in operator positioning in standard vs. extended cuts. Operators and other personnel at these mines are faced with the question of where they should position themselves while remotely operating machinery. The optimum location for an operator to stand may differ depending on the length of cut and a number of other variables, and the most important issues were identified as visibility, roof condition, ventilation and avoidance of moving machinery. The locations of workers and equipment at the face area were recorded along with the direction the operators were looking in and at what stage they were in the mining process. Specific cues used to operate equipment remotely were also investigated.

RESULTS

Activity analysis helped to define the specific problem areas where human factors research could help. It also pointed out specific tasks that were affected by the change from on-board to remote control operation. Before remote operation, there was no question of where the operator would be since he had to operate from the compartment on the deck of the miner. But with remote control operation, the operator could be in several locations and exposed to other moving equipment, variable and adverse roof and rib conditions, and an unsupported top.

Among the operators observed and interviewed, it appears that continuous mine operators choose their position at the start of the cut and tend to stay in that position regardless of the length of cut. At times, the operator would need to relocate to perform unusual tasks and would sometimes stand in an unsafe area in order to observe the longer cuts. Turning a crosscut appeared to be the most variable and difficult task for operators regardless of length of cut due to the difficulty associated with maneuvering the machine and positioning of the worker in a confined space.

All operators thought that they were more productive with extended cut mining and most of them liked to use the remote control which provided them with the freedom to move about the face area. Operators remarked that there was not much difference in going from shorter to longer cuts but that going from on-board operation to remote control operation was difficult. Concern from operators centered mostly around where they should position themselves while operating remotely and still be able to see critical operating cues. Along with visual cues, operators used many audible and tactile cues including sounds of the cutting head and machine vibrations when hitting rock or coal.

CONCLUSIONS

It was evident that operators had adapted to the visibility and positioning difficulties of remote control operation but, in some cases, at the expense of health and safety. If this system change from on-board to remote operation had been investigated from a more global view including technical as well as human factors issues, some of these issues could have been resolved prior to implementation. It would have been easy to predict such problems as the visibility restrictions and that the illumination system on the remote mining machine would need to be changed. Many industries other than mining can use this approach to evaluate current and new designs. If human factors issues are ignored until after major design decisions have been made, it is difficult to make more than minor changes. Simply put, the earlier human factors get involved in a design process, the better, and the safer the outcome will be [Chapanis, 1996].

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