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ABSTRACT

This paper presents an approach for representing and analyzing random motions and hazardous events in a simulated three-dimensional workplace, providing designers and analysts with a new technique for evaluating operator-machine interaction hazards in virtual environments. Technical data in this paper is based upon a project striving to reduce workers' risks from being hit by underground mining machinery in a confined space. The project's methodology includes human factors design considerations, ergonomic modeling and simulation tools, laboratory validation, and collaboration with a mining equipment manufacturer. Hazardous conditions can be analyzed in virtual environments using collision detection. By simulating an operator's random behavior and machine's appendage velocity, researchers can accurately identify hazards, and use that information to form safe design parameters for mining equipment. Analysts must be discerning with the model and not read more from the databases than what the simulation model was designed to deliver. Simulations provided an interesting approach to data gathering in that there was no need for live subjects and logistics – test sites and costs associated with experiments–became insignificant. Collisions versus speed, operators' size, and risk behaviors proved the versatility found in the data obtained from the model. Preliminary results show that response time significantly affects the number of collisions experienced by the virtual subject. Also simulation data suggests that more mishaps occur with hand-on-boom-arm risk behavior.

INTRODUCTION

Several injuries to operators of underground coal mining equipment have led an investigation of safe velocities of a roof bolter boom arm at the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL). Researchers considered studying actual mishaps but empirical data cannot be collected from the incidents. They also considered laboratory experimentation but the complexity and danger made experimentation impractical. Therefore, a computer-based, three-dimensional solid model simulation approach was used as the primary means to gather data on mishaps. In the model, mishap means two or more object properties interacting. Consequently, hazardous conditions were analyzed in virtual environments using collision detection.

The uncertainty or randomness inherent in the drilling task can be compared to someone drinking a can of beverage. The occurrence of lifting the can to one's mouth and placing it back onto the table top is considered a random motion, and one could easily visualize the path of that motion. To model the random motion, the sequence of someone drinking from a can of beverage would reoccur until the can is empty, and each motion-path would differ slightly even though the motions look alike. So the model would incorporate the randomness of the motion and path variance within that motion. Thus, for a machine and operator, the operator's various risk behaviors, motions of each risk behavior, and motion paths associated with each motion behavior and moving machine appendages have some degree of randomness. These random motions give the model a realistic representation of the operator's motions and behaviors found during any machine task.

A model that includes any random aspects must involve sampling, or generating random variate. The phrase "generating a random variate" means to observe or realize a random variable from some desired arrangement of values of variables showing their observed or theoretical frequency of occurrence.

Studies on workers job performance, machinery and work environment has identified miners' risk and hazard exposures while bolting [1, 2]. More than two dozen bolting related problems (including specific human behaviors) were recognized as potential situations that could lead to injury or exposing workers to injury. Approaches to avoid these situations were suggested and applied at mining operations to evaluate specific problems in roof bolting tasks. A field study conducted a human factors analysis of hazards related to the movement of the drill head boom of a roof-bolting machine [3]. Seven recommendations to increase the safety of roof bolting operations were developed.

BACKGROUND

Roof bolting is one of the most basic and the most dangerous elements of underground mining operations. It is the principle method of roof support in mines, which is essential to ventilation and safety.

After miner crews remove a section of the coal seam, bolting equipment operators install bolts to secure sections of unsupported roof. A bolter crew's typical work sequence includes: general preparation and setup, drilling a hole, and installing a bolt. The sequence repeats until a section's roof is secure. The roof bolter operator does his or her job in a confined workspace near moving machinery. This restricted work environment puts the operator in awkward postures for tasks that require fast reactions to avoid being hit by the moving machine parts. Restricted visibility due to a protection canopy and low lighting conditions further complicates the task. From 1992 to 1996 Health and Safety Accident Classification injury data base showed an average of 961 roof bolter operator incidents per year, making roof bolting the most hazardous machine-related job in underground mining.

To address safety issues, the Mine Safety and Health Administration established a roof-bolter-machine committee with members from the WV Board of Coal Mine Health and Safety, NIOSH, and roof bolter manufacturers. The committee studied 613 accidents and 15 fatalities that attributed to inadvertent or incorrect actuation of control levers while the operator was within the drill head or boom pinch-point area (see figure 1). One major outcome of this study was the realization that there is no data on safe speeds for booms operating close to workers in confined environments like an underground coal mine. The NIOSH, PRL is endeavoring to determine what boom speed minimizes the roof bolter operator's chances of injury while still doing his or her job effectively.

METHODOLOGY

A computer-based simulation approach was used to generate and collect collision data between the machine and its operator while dealing with many variables, such as, the operator's response time, knee posture, choice of risk behavior, anthropology and machine's appendage velocity.

Engineering Animation's software, Transom JACK, was the simulation tool chosen to develop a roof bolter model for simulation. JACK is a human-centric visual simulation software package. Jack's software architecture lets users extend it's simulation functionality by writing code with the Lisp programming interface and Jack Command Language (JCL).

The roof bolter model evolved from code developed in Lisp and JCL that creates random human motion, random motion goals for the hands and torso, and random motion of events reflecting operator's behavior. The behavior motion parameters are based on statistics of machine and human actions that could cause injuries or fatalities in a bolter's workspace. The highest percent of hazardous acts were found in two bolter tasks: drilling the hole and installing a bolt [2]. The model contains only the task of drilling the hole, because it involves more risk behaviors: (1) hand on the drill bit (see figure 2a), (2) hand on the boom arm (see figure 2b), (3) hand on the boom arm and then hand on the drill bit, and (4) hand off the boom arm and drill bit (see figure 2c). Also, video footage of a roof bolter operation, in an actual underground coal mine and a manufacturer's training video, were used to help develop the animated motions of the operator in the model.

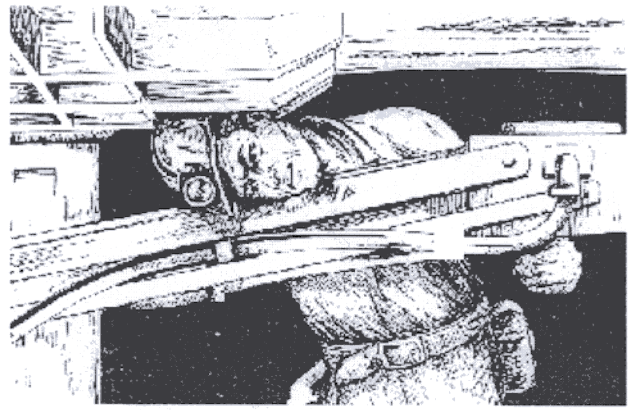

Figure 1. Artist concept of an operator caught within the boom arm pinch-point area.

The model allows investigators to experiment with response variable behavior (number of collisions between operator and machine) when manipulating the variables. Table 1 identifies all of the variables considered for the model. The operators' response times were withheld from the model because of proprietary issues and the complexity of programming this during simulation test runs. The response times were later used in the data analysis phase. During simulation runs, selected experimental conditions, shown in table 2, were held constant. The resulting simulation lets investigators generate, collect and analyze realistic data between a machine and its operator.

While watching animations produced by the software, the model seems to accurately depict random motions. The parameters used to generate random motions in the model need to be validated. If the model is valid then the decisions made with the model should be similar to those that would be made by physically experimenting with the roof bolter. Experiments on a full scale working mockup of a roof bolter boom arm are currently being conducted using human subjects to verify operator response times, human motion data, and field of view [4] relative to the bolter's boom arm. Because the model's validation stages are in progress, the results reflected in this paper include only preliminary simulation data.

RESULTS

The model can generate 96 different scenarios that mimic motions of the operator and machine during the drilling task. The scenarios are defined by varying four factors: four boom arm speeds [5], three operator heights, four risk behaviors and two knee postures. After the model generates motions, it records collisions that happen between the machine and its operator during a simulation test run. Distances between the operator's body parts and one or more of the six reference points on the boom arm are measured and recorded. The simulation's run time when the moving boom arm enters in the operator's viewing area is recorded. All information is collected every tenth of a second throughout a simulation test run. In the model's program, an output function sends each test run result to a computer file. In addition to recorded data, each file contains (1) a description of the test run scenario that characterizes which working behavior is in use, (2) whether the operator posture is leaning forward or is upright and (3) whether the operator is kneeling on one knee or on both knees. Table 3 shows the output file description. A typical test series consists of 600 simulation test runs.

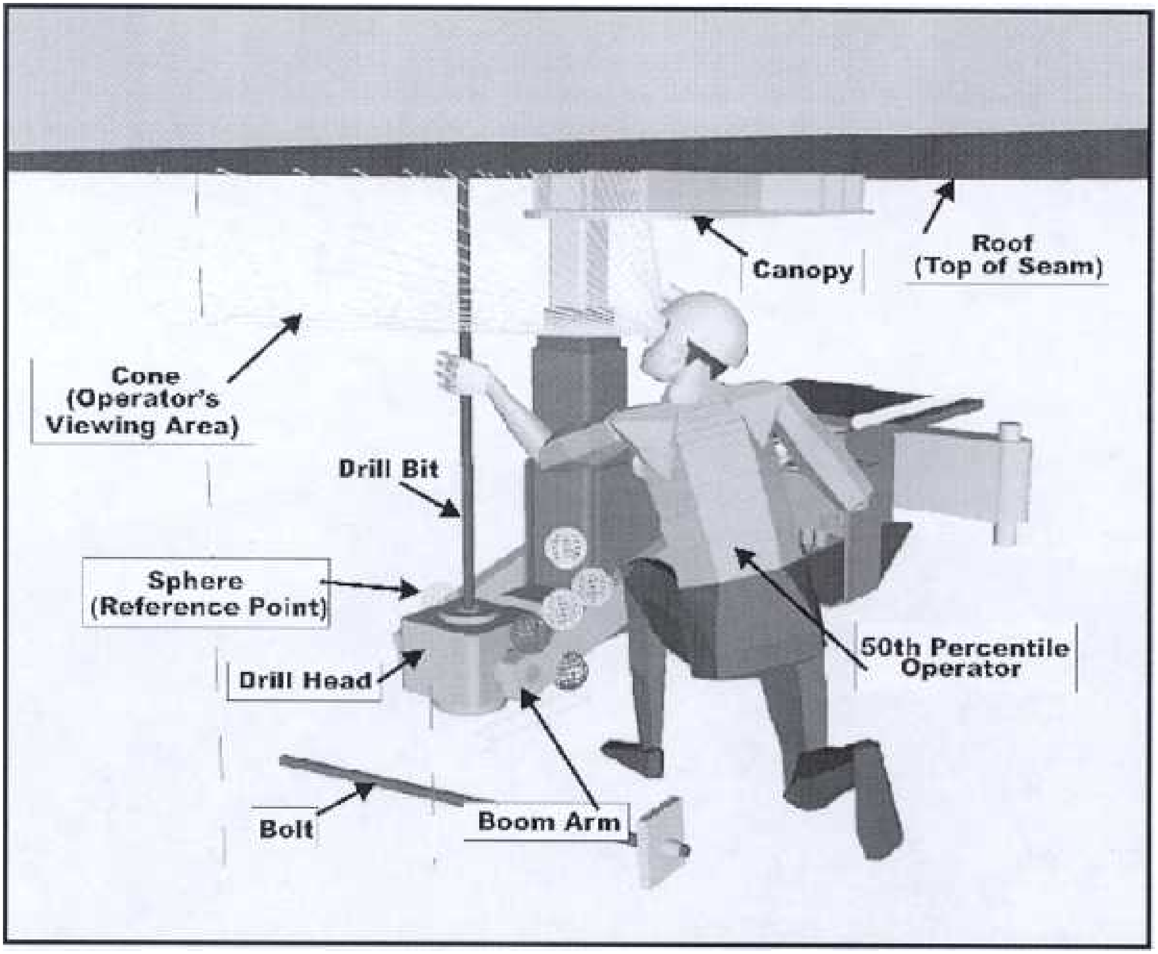

Figure 2a. Operator's risk behavior, hand on steel bit.