

Analyzing Factors Influencing Struck-By Accidents of a Moving Mining Machine by using Motion Capture and DHM Simulations

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

National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Lab

ABSTRACT

Remote operation of continuous mining machines has enhanced the health and safety of underground miners in many respects; however, numerous fatal and non-fatal continuous miner struck-by accidents have occurred. In an effort to prevent these injuries, NIOSH researchers at Pittsburgh Research Laboratory studied the workplace relationships between continuous miner operators and various tramming tasks of the equipment using motion capture data, operator response times, and field of view data to evaluate the factors influencing operator-machine struck-by events (contact with a solid object) in a virtual mine environment. It is not feasible (nor ethical) to use human subjects to directly evaluate factors that precipitate such injuries. However, use of motion analysis data and digital human models can facilitate analysis of struck-by accident risk by allowing investigators to manipulate factors that influence injury. Factors included in this study included machine speed, direction of escape, the direction the operator was facing relative to the machine, work posture, distance from machine, and operator anthropometry. Close proximity to the machine, high machine tramming speeds, a right-facing orientation and operator positioning near the tail all resulted in high risk of being struck.

INTRODUCTION

The use of digital human models (DHMs) to analyze



Figure 1. Continuous miner operator by tail.

workplace hazards and improved workplace design are becoming more prevalent among human factors and ergonomics professionals (Badler et al., 2002; Brown, 1999; Chaffin, 2002; Colombo and Cugini, 2005; Ferguson and Marras, 2005; Zhang, X. and Chaffin, D.B., 1996). These DHMs can be driven by human motion analysis techniques,

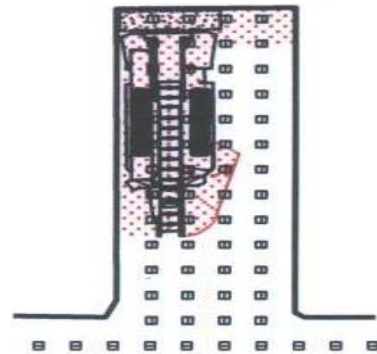


Figure 2. Red Zone around a continuous miner.

providing a means by which human-machine interactions can be analyzed. One particular advantage of DHMs is that they can be used to evaluate the risks associated with hazardous tasks (or interaction with potentially hazardous machinery) without risk of serious injury to a person. An example of this type of situation is one where struck-by or caught-between accidents might occur when a worker is operating tramming (moving) machinery.

The Mine Safety and Health Administration (MSHA) reports that both fatal and non-fatal remote-control continuous miner (figure 1) accidents from 1999-2006 are averaging 254 per year during routine mining activities with the majority of accident victims working within the turning radius of moving continuous miners. The mining industry uses an educational aid called "red zones are no zones" (MSHA 2006) to help operators of remote control vehicles, such as continuous miners, to understand which areas around the machine to avoid (figure 2). However, fatalities and injuries still continue as results of contact with moving machines.

MSHA is interested in reducing injuries and fatalities attributed to the operation of continuous mining machines (Clark et al., 1998, Colley et al., 2006). As recently as February 2006, MSHA posted on its website information regarding protection of continuous miner operators by using

proximity warning devices to help recognize the red-zone strategy.

In an effort to better understand the influence of these issues on the risk of injury, it was decided that a DHM using motion capture of operator movements would be a useful methodology. The purpose of this investigation was to analyze factors influencing struck-by accidents during tramming of a continuous mining machine using DHM simulations driven by actual human motion analysis using a variety of human subjects, postures, facing orientations, environmental constraints, and mining machine operational characteristics.

METHOD

Motion Analysis Data

Ten male subjects aged 32-59 years were recruited from local mines to perform realistic movements in a laboratory setting (figure3) that mimic getting out of the way of a moving



Figure 3. Laboratory test setup; a subject finishes a trial run.

continuous mining machine. Experienced operators were used because they are accustomed to the unique movements and

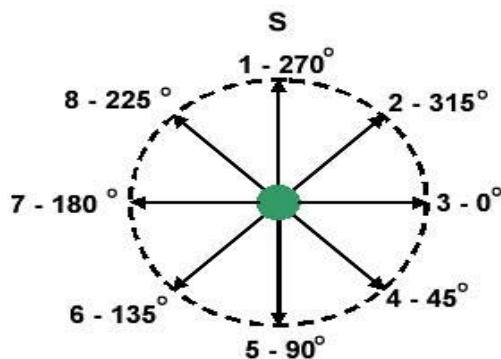


Figure 4 . Test area layout showing path number and orientation in degrees.

postures required in the mining. The subject's motions were measured by recording them using Motion Analysis Corporation's (MAC) motion tracking and capturing system. MAC is an optical system that uses infrared sources and cameras to track reflective markers placed on a test subject.

From measured infrared reflective characteristics, each marker position and orientation is computed by EVaRT, specialized MAC software that converts and records this information for future analysis.

Human motion data were obtained for various operator work postures and escape paths (directions) typically used when operators are tramming mining equipment such as continuous miners. The capture session was conducted for a posture of kneeling on both knees, a squatting posture and a standing posture that represented seam heights of 36-, 48- and 60-inch, respectfully. At a given signal, a test subject moved from a starting location (see figure 4, solid circle) as quickly as possible along a given path (numbered 1 thru 8) labeled on a carpet in the test posture. The sequencing of path direction was randomized for each subject. Prior to each path movement, the subject's orientation was either facing the signal source (a researcher controlled light) or with the signal source to the subjects left or right side. The signal source also emitted an infrared signature allowing it to be captured with the motion data. When a light signal source at 'S' was turned on it cued the test subject to move. The subject stopped moving once he crossed the outer portions of the dash-circle (figure 4) on the carpet (figure 3). Each subject completed 216 trial runs to accommodate the variables of operator's work posture, facing orientation, and escape path direction.

Development of Human-machine Model and Simulation Data Collection

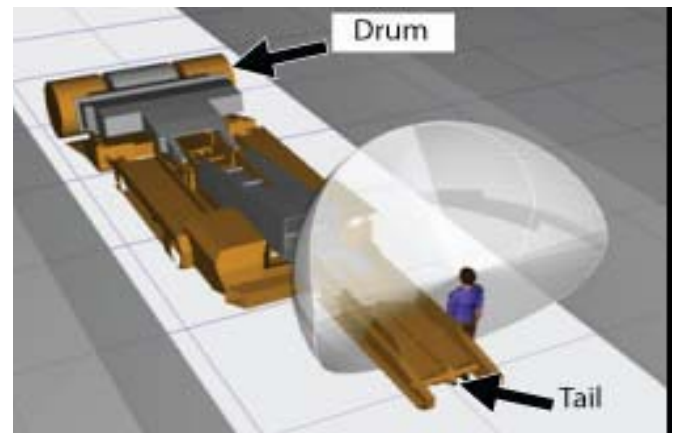


Figure 5. Model contains a continuous miner model, DHM as operator and DHM's peripheral vision views

A human-machine model (figure 5) was developed to measure parameters that would be used to predict struck-by events when the operator moves out of the way of the moving machine. The parameters included: (1) the time when the machine first begins to move, (2) the time when the operator first begins to move, (3) the time when the operator is struck-by an object, (4) name of the object that struck the operator (pan, boom drum), and (5) the operator's distance from the machinery when struck-by an object. Struck-by means a collision occurs between the operator and machine or the mine wall. The data collection in this process uses captured