Table 1. Variables considered in the simulation model

Independent variables	
operator's anthropometric scale [9, 10, 11, 12, 13, 14] • 5th, 50th and 95th male percentile subjects	operator's random body motion • motion with some degree of randomness
initial work posture • operator's posture, one or two knees • randomly lean forward 0 to 30 degrees • position from the boom 0 to 20 cm closer	operator's optimal viewing area • ±40 deg vertical and ±35 deg horizontal to either side of the normal line of sight [4]
operator's response time • includes perceptual time, decision making time, and reaction time or motor response time (get out of the way)	risk behaviors associated with drilling • operator places hand on the steel bit {1,0}, places hand on the boom arm {0,1} or both hand on bit and then arm {1,1} or hand off both {0,0}
mine seam height typical for machines' model [1] • 114.3cm, 152.4 cm, and 182.8 cm	machine control panel configuration • piano key and joystick controls
protective canopy height • same height as the seam or removed	speed of boom arm and drill head • 17.78 cm/sec, 25.40 cm/sec, 40.64 cm/sec and 55.88 cm/sec
Dependent variables	
• *collisions* between the operator and selected machine appendages	
• *distances* between operator's body parts to reference points on the machine	
• *time-event-signal* when the operator sees the moving boom arm	
[1] Recommended by Fletcher & Co., Huntington WV, manufacturer of the Roof Ranger bolter.	

An important phase of data analysis is to create a database of each test series. This requires several steps. First, count the number of collisions ('raw') that occur in each test run. Second, determine the number of collisions ('avoid') in each test run that the operator could have avoided by using a predetermined human response time, taking 250 msec or 400 msec [6, 7, 8] to get out of the way of a moving boom arm once seen. Third, calculate the collision totals to be used for evaluation by taking the difference between 'raw' and 'avoid,' resulting in collisions (see table 4, 'hit') represented as four scatter plots (figures 3a, 3b).

A scatter plot gives strong support for using regression analysis. Regression analysis shows the relationships between independent variables and one dependent variable, such as taking into account the values of the five factors in the model and predicting collision trends. With one independent variable (speed), the regression analysis plots a line of "best fit" through a scatter plot of independent-dependent (speed-collisions) value pairs.

Along with regression analysis, a nesting technique is used on each collision database to group factors together, forming relationships that, when plotted, give meaningful trends. For example, a collision-versus-speed plot for a desired risk behavior would be depicted by three separate lines. Each line is identified by the operator's height, which includes both response times and knee postures. For each test series, unique collision-versus-speed plots were created using nesting techniques and varying the levels of the risk behavior. Simulation data regressions for a 114.3 cm (45 in) coal seam height and a 152.4 cm (60 in) coal seam height, are graphed in figures 4a, 4b through 8a, 8b.

Analysis of the databases reveals what happens when 'variables' change as they relate to the interactions between the operator and the machine:

- number of collisions versus boom arm speeds,

the significance of the

- operator's response time,
- knee posture,
- choice of risk behavior, and
- anthropology.

Table 2. Simulation Test Chart

Machine	Machine Controls	Mine Info	Test Velocity	Test Subjects N = 50 each
Type:	Configurations:	Seam Height (cm)	Experiment Speed 1	Male Percentile 1
Bolter	Piano Key (pk) and Joystick (js)	114.3, 152.4 and 182.8		Male Percentile 2
				Male Percentile 3
			Experiment Speed 2	Male Percentile 1
				Male Percentile 2
				Male Percentile 3
			Experiment Speed 3	Male Percentile 1
				Male Percentile 2
				Male Percentile 3
			Experiment Speed 4	Male Percentile 1
				Male Percentile 2
				Male Percentile 3

Each factor level is held constant for each test speed and subject combination.

PLANNED TESTS:	pilot -	experimental -	research
Test series 1: pk, 152.4 cm	X	X	X
Test series 2: pk, 114.3 cm	X	X	X
Test series 3: pk, 182.8 cm	-	E2	E2
Test series 4: js, 152.4 cm	-	E1	X
Test series 5: js, 114.3 cm	-	E1	X
Test series 6: js, 182.8 cm	-	E2	E2

(4 speeds) X (3 subjects per speed) X (50 observations per subject) = 600 total observations per test series.

X: original testing; E1: 1st test expansion; E2: 2nd test expansion