A PC-Based Monitoring System for Mine Hoisting

Michael J. Beus
Spokane Research Center, U.S. Bureau of Mines, Spokane, Washington USA

Frank T. Duda, Jr.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, Pennsylvania USA

Timothy J. Orr
Spokane Research Center, U.S. Bureau of Mines, Spokane, Washington USA

ABSTRACT

The technology to enhance safety and control features for mine shaft hoists is being investigated by researchers at the U.S. Bureau of Mines (USBM). The objective of the research is to prevent injuries and fatalities related to hoist and elevator operations. Monitoring and controlling mine hoisting operations will allow hoist operators, inspectors, and maintenance personnel to increase their awareness of potentially dangerous situations and provide controls for safer operations. Process simulation and visualization software, real-time data sensing, and advanced programming techniques are being applied to this problem. Development of reliable and cost-effective sensors and data acquisition interfaces to monitor hoist loads and detect slack rope conditions is underway. Three-dimensional design software was used to visualize mine hoisting to enhance understanding of hoist operations. Quick Basic and Visual Basic (an object-oriented Windows interface) are being used for acquiring and processing hoisting data. Testing and evaluation of components are underway at USBM testing facilities. The resulting system will allow hoist personnel to assess critical operating parameters, such as hoist position, speed, acceleration, conveyance load, and rope tension.

RÉSUMÉ

La technologie, pour réhausser la sûreté et traits controllés des hissages de puits dans les mines, est sous recherche par les ingénieurs du Bureau des Mines aux États-Unis. L'objectif des recherches est de prévenir les altérations de santé et dégâts mortels au rapport des hissages et élévateurs en mines. Les observations et le controllement des activitées de hissage en mine permettra les ouvriers, inspecteurs et le personnel de maintien, d'augmenter leur perception en situations potentielles et dangereuses, et fournir des mesures de control pour des travaux de meilleure sûreté. Un procédé simulateur et programme de visualisation, sensorisation de données en temps-actuel et techniques avancées de programmatique sur ordinateur sont appliqués ă ce problem. Le développement des censeurs exacts et coût-éffectifs est entrepris, ainsi que l'interface d'acquisition de données, pour observer l'éffet du chargement des hissages et de détecter l'état du câble en détente, pendant l'abaissement. Un programme de dessin proportionné trois-dimensionel a été utilisé pour etablir une réalisation visuelle de hissage en mines et pour réaliser la compréhension des hissages eux-même. Quick Basic et Visual Basic (an object oriented Windows Interface sur ordinateur) sont utilisés pour acquir les données sur hissages. La tenue des épreuves et les évaluations des éléments constitutifs sont commencées dans les établissements d'évaluation des U.S. Bureau des Mines. Le résultat permettra le personnel du hissage d'imposer les paramètres des procédures délicates; tel sont l'état du huissage, la vitesse, l'accélération, le transport et la tension du câble.

INTRODUCTION

Mine shafts are the "lifeline" of underground mining operations. A shaft (figure 1) provides access to the network of openings used to recover the underground resource and serves as an escapeway in case of emergency. As such, a shaft must be well designed and maintained for a long and reliable service life. Hoist and elevator systems for underground metal/nonmetal mines and coal mines must meet the requirements specified in the Code of Federal Regulations (CFR), Parts 57 and 75. The Mine Safety and Health Administration (MSHA) has been reluctant to require new safeguards for elevators and hoists without fully developed technology. However, in many cases, the mining industry and hoist equipment manufacturing companies cannot justify research and development expenditures.

Researchers at the U.S. Bureau of Mines (USBM) are conducting research to develop a PC-based monitoring, inspection, and control system that will increase awareness of proper functioning of mine hoists, warn of potentially dangerous situations, and provide controls for safer operations. According to MSHA data, many of the shaft-related accidents in the United States are associated with the hoisting cycle and maintenance operations (figure 2). For example, about 10% of all injuries in U.S. metal/nonmetal mines in the period between 1985 and 1992 were related to hoisting. Of these, almost all (>90%) were related to errors by operating (i.e., hoistman or cagetender) and maintenance personnel, as opposed to injuries caused by faulty or poorly maintained equipment.

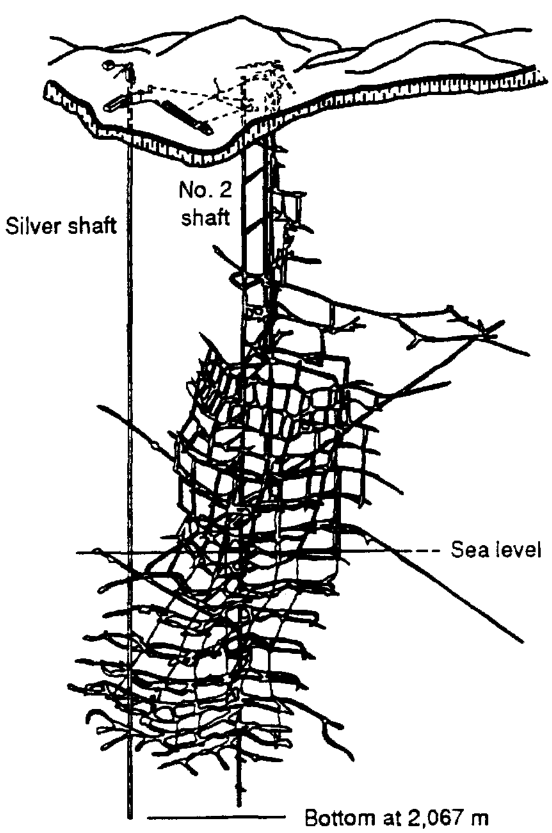

Figure 1. Typical shaft layout in deep metal mine.

From MSHA accident reports, personnel located in areas related to muck and material loading and unloading were particularly susceptible to injury or death. A relatively common occurrence was water inundation or muck hangup in the loading pocket or ore pass. Several fatalities have occurred recently in the United States and Canada from the sudden inrush of water and muck, washing loading-pocket operators into the shaft (MSHA, 1989). Another problem occurs when spillage or equipment falls to the shaft bottom, often severely damaging shaft hardware and requiring expensive downtime and hazardous repair work. Downtime for inspection, maintenance, and repair also significantly decreases the time available for muck hoisting.

In the past 10 years, several documented mine hoist and elevator accidents (Dames and Moore, 1977) have

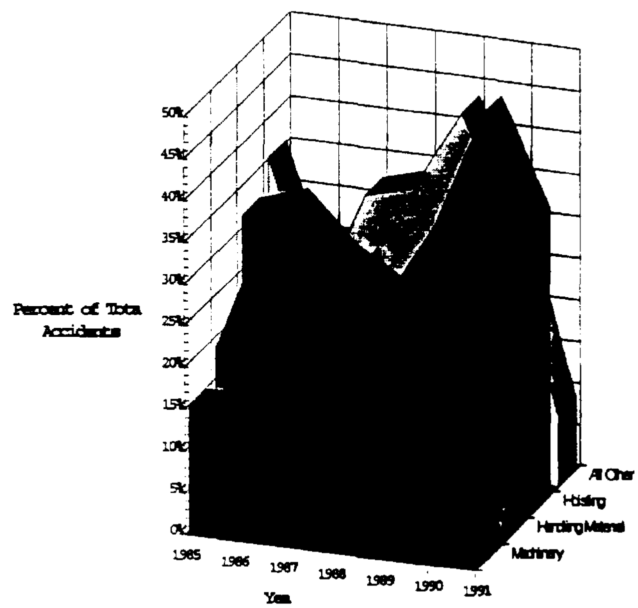

Figure 2. Shaft-related accidents in metal and nonmetal mines in the United States—1988-92.

also resulted from electrical, mechanical, and structural failures, despite MSHA requirements for periodic testing of hoist systems. All these accidents had the potential for injuring or killing miners, as did the accident at the Markham Colliery in the United Kingdom on July 30, 1973. With advances in computer technology, including process visualization, real-time data acquisition, sensors, and microcomputers, safer, more cost-effective inspection, monitoring, and control systems are possible. This paper will present some applications of computer methods and sensor development approaches to the mine hoist monitoring and inspection problem.

APPROACH

This research is being conducted at the Pittsburgh and Spokane Research Centers, in cooperation with the MSHA Technical Support Group in Pittsburgh. Components of various mine hoisting and elevator systems were assessed, including hoisting machinery, such as hoistroom controls, motors and gearboxes, and winders, and shaft infrastructure, such as support frameworks, guides, wire ropes, and skips and cages. Current technology was assessed to determine what conditions and equipment should be monitored, availability of adequate sensors, and how to process and act on the information.

Specific research tasks were defined as follows:

- Evaluate the complete shaft hoisting and materials handling process and facilities, including stations, loading pockets, and safety and control features.
- Develop a working computer model to simulate the hoisting process and delineate potential safety problems and targets for condition sensing.
- Assess currently available sensors and monitoring and process-control technology for hoisting personnel and materials in mines.
- Identify parameters to be monitored and modify or develop new sensors and data acquisition capabilities.
- Develop laboratory test facilities to conduct proof-of-concept testing.
- Develop software with hoisting process and subprocess graphics screens and collect, save, and evaluate sensor data.
- Conduct field evaluations and transfer technology to industry and MSHA.

TECHNOLOGY ASSESSMENT

Shaft hoisting technology, safety features, and standards have been assessed. Such work includes an evaluation of all safety features for hoists and elevators, existing safety standards for both hoists and elevators as well as current hoist and elevator monitoring systems and sensors (Farley et al., 1983; Barkland and Helfrich, 1988; Loynes, 1976; Cseff et al., 1981). Most monitoring and control systems have been developed and introduced in Canadian, British, and South African mines. However, indications are that cost-effective hoist monitoring systems are not widely used in the United States, particularly for smaller operations and for use with older hoisting equipment. Existing commercially available systems range in price from $50,000 to $250,000 and are largely customized to be site specific. Major cost items are sensors, data acquisition, and associated monitoring and control software.

It was concluded that research to improve sensor technology and increase information flow on operational status of the hoisting function is important. More cost-effective methods and software for automated inspection operations and sensors for determining conveyance loads, slack and tight rope, and conveyance position must be developed.

Software kits for developing personal-computer- (PC-) based data acquisition systems for enhancement and customization of current software were evaluated. State-of-the-art, factory-floor process control technology for monitoring and controlling schemes for mine hoisting operations were evaluated.

Figure 3 shows an example of a control screen layout of a deep-mine hoisting process using currently available technology. This screen incorporates cage or skip position, speed, and acceleration using various layouts of in-shaft processes. Figure 4 shows how the loading pocket may be set up and simulated, again using off-the-shelf software. However, it was deter-

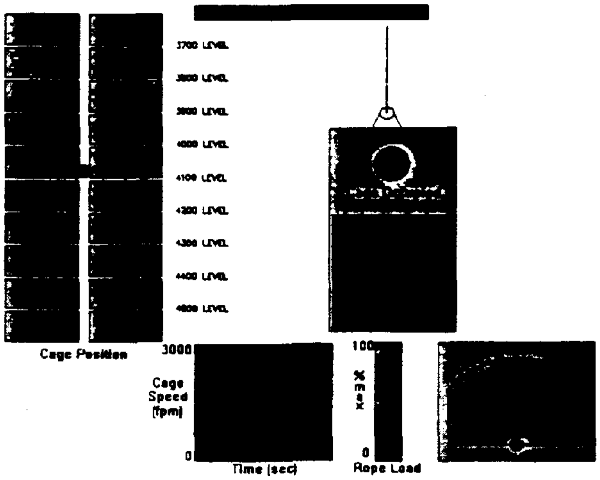

Figure 3. Control screen layout of deep mine hoisting process.

mined that existing software packages were still either too comprehensive or too expensive to be compatible with the requirements of the project. It was decided to develop in-house a public-domain data acquisition and process control software package customized for hoisting. Windows-based software appeared to offer the greatest potential for reducing cost and enhancing the user-friendly aspects of the interface between an operator and a PC screen. Powerful and comprehensive Windows-based data acquisition and process control software and hardware tools are available.

Sensor development has focused on determining conveyance position and load. Various sensors for monitoring skip or cage position and hoist velocity and acceleration have been evaluated. For example, onboard ultrasonic and a radar-based speed and distance detectors developed for the agricultural industry has been evaluated for determining the position of a skip in a shaft. A position sensor located on the conveyance eliminates the need to correct the position of the conveyance because of rope stretch. However, preliminary results indicate that these devices are not sensitive enough for accurate positioning, and the response time is insufficient for proper control.

Shaft conveyance load is identified as the other key element for enhancing hoist safety. Conveyance load monitoring in real time will detect slack or tight rope conditions resulting from shaft obstructions, rock movement, and misalignment. In addition, it will serve as a production monitor and warn of ore hangup in the skip or loading pocket. Current approaches favor inline load cells in the load path of the conveyance or load cells in the sheave wheel pillow blocks at the headframe. Both of these approaches have major disadvantages. Inline load cells may compromise the integrity of a wire rope, and they are costly and difficult to install, requiring a significant modification to the conveyance termination point. Pillow-block load cells weigh the total downshaft load, including the wire rope and acceleration loads. This makes determination of the net weight of the conveyance, and therefore overload conditions, difficult to determine, particularly in deep shafts where the weight of the wire rope becomes a significant part of the total load. This situation requires a very high-capacity load cell, the use of which would reduce sensitivity so that small but significant changes in the conveyance load could not be determined.

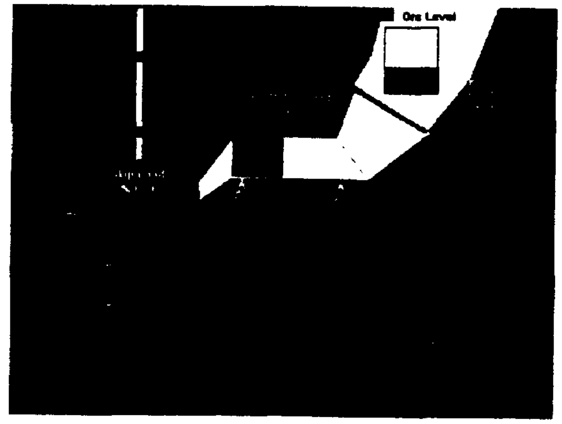

Figure 4. Simulation of loading packet with off-the-shelf software.

HOIST TEST FACILITIES

It was determined early on in the project that testing of new technology would be difficult to undertake in operating hoist installations. For this reason, a deep mine hoisting test facility was constructed at Spokane and a three-level elevator test facility was modified for research at the Pittsburgh Research Center. These test facilities are being used to evaluate position and load-indicator sensors, data acquisition systems, and software. The test facility in Spokane utilizes a 60-ft hoist tower to simulate the headframe and shaft, an 18-ft-deep "shaft" lined with concrete sections, a winding drum, sheave wheel assembly, and shaft skip conveyance (figure 5). A loading-unloading circuit to investigate skip loading and unloading operations has

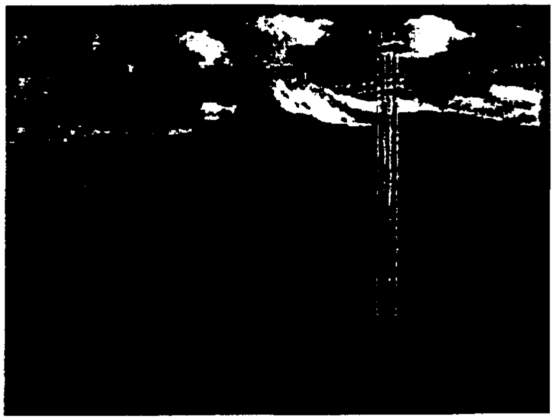

Figure 5. Hoist test facility at Spokane Research Center.

also been fabricated. A loading cartridge is equipped with balancing load cells to monitor the net weight of material in the cartridge prior to its discharge into the skip. Output from these cells and loading gate position sensors will control skip loading functions. A similar approach is used for skip discharge at the top of the headframe.

The hoist room components include a winding drum and gearbox, a motor-gearbox interface, a braking system, and a 50-hp dc motor. A digital motor controller allows sophisticated control of the dc motor through an interface to a PC. A ideal motor-velocity profile can be input using numerous parameters; the profile can be modified via feedback from sensors on the motor, such as an optical encoder, a digital tachometer, or armature current. The system is being further modified with a Simplex model Lilly hoist controller to back up the digital control system and duplicate hoisting installations currently in use.

The testing approach is aided by development of conceptual layouts in which all the features of a proposed monitoring and testing system and preliminary concepts for key sensor technology are delineated. A computer simulation of the Spokane shaft test facility was developed to allow researchers to visualize the hoisting process. This permitted delineation of target areas that might be of special concern and that would require additional sensors. An animated simulation of the test tower allowed various scenarios to be considered. The analysis also allowed computer evaluations of key structural components of the test frame and skip. Different skip and guide materials may be analyzed and the computed results correlated with the results of actual testing. For example, a more flexible guide rail alignment wheel may allow the skip to pass through tight spots with less resistance, a major cause of tight rope conditions. The computer visualization and simulation model of the test frame continues to be updated and is being used to simulate operation of the actual test hoist as features are added.

CURRENT PROGRESS

Sensors

A new approach to conveyance load sensing incorporates a design that is independent of the conveyance load path, and therefore does not compromise the integrity and safety of the wire rope. This concept is called a "flexcable" load cell. The device imbeds a slight curvature in the rope at the sensing point and is totally independent of the load-carrying function of the wire rope. A typical full bridge circuit measures bending strains on the conforming cell body as the rope is tensioned, providing the required output as pounds of tension at the conveyance termination.

Pillow-block load cells at the sheave wheel are used to verify loads from the flexcable load cell at the conveyance. Figure 6 shows a layout of the labor-

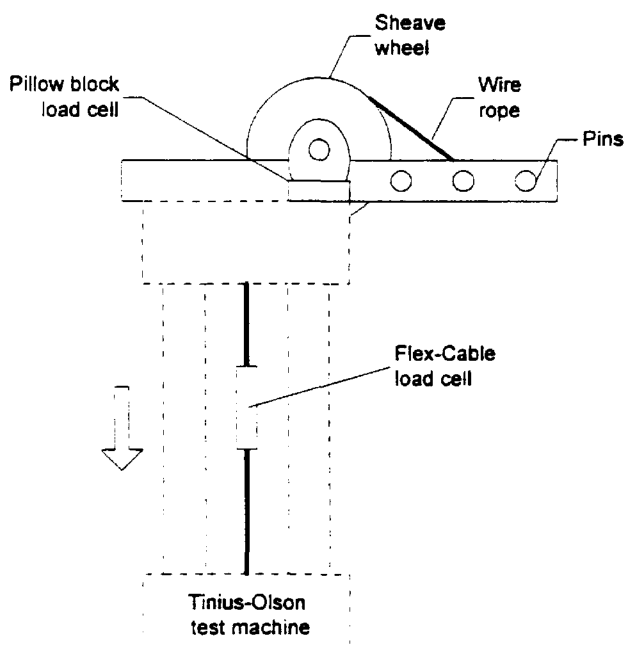

Figure 6. Layout of laboratory test setup to evaluate load cells.

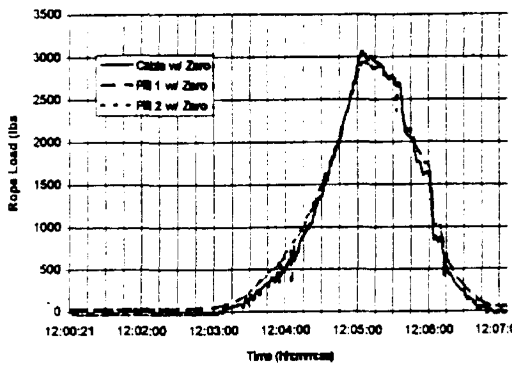

Figure 7. Comparison of results of pillow-block and flexcable load cell.

atory test setup. Results of this work show an excellent correlation between the pillow-block load cells and the flexcable cell. Figure 7 shows the results of the comparison using a laboratory test setup.

The design for conveyance position favors the use of an optical encoder mounted on a conveyance guide wheel. In addition, an encoder mounted on the winding drum and hoist motor monitors shaft revolutions and provides backup data for determining the same operating parameters. These devices provide sufficient data to establish conveyance position, and thereby velocity, and acceleration. These data are needed to develop the hoist speed curve, a shaft-hoisting parameter essential for monitoring and testing hoist safety features. This is considered a critical need by MSHA inspectors.

Data Acquisition

Data acquisition consists of a hybrid scheme incorporating both a "desktop' system for monitoring hoistroom functions coupled with an "onboard" system for downshaft monitoring.

The desktop data acquisition system utilized at the Pittsburgh Research Center consists of a 486 PC equipped with two ISA expansion cards and the appropriate signal conditioning. One expansion card provides A/D capability for 16 single-ended or 8 differential analog inputs at 12-bit resolution. The card can sustain a sampling rate of up to 100 thousand samples per second. The second expansion card is a counter-timer card that has five 16-bit counters that can be configured for frequency measurements and event count accumulations. Both cards have multiple digital I/O port capabilities. A eight-channel commercially available signal conditioner is used to make the sensor signal readable by the A/D board as well as to provide electrical protection.

At this time, the data acquisition system is being used to monitor dc hoist motor voltages and currents as well as signals from speed- and position-measuring sensors on the elevator. The sensors are hard wired into the signal conditioners. This system will be validated against the current monitoring system now used by MSHA inspectors.

Obtaining accurate and reliable data from a moving hoist conveyance in a deep shaft remains a key element of future efforts. A commercially available transmitter-receiver set was procured and installed at the Spokane Research Center for wireless transmission of load cell and encoder data from the test hoist. This unit provided a standard for evaluating prototype transmitter-receiver sets. The receiver, located at the headframe or in the hoist room, has been tested both as stand-alone equipment and with a "leaky feeder" antenna that extends the receiver's effective range. The leaky feeder antenna allows signals to be received around corners underground, such as around a rope raise and into an underground hoistroom.

A battery-operated, microcomputer-controlled signal processing board has been designed jointly by the USBM and McCoy Engineering Co., both of Spokane, WA. Functionally, this board processes data from various hoist sensor inputs and provides serial data output for a radio uplink from the conveyance to the hoist control room computer. Inputs are—

1. An analog load-cell input channel for monitoring loading of the hoist wire rope by the conveyance.

2. An analog input channel configurable for use with another load cell or with other sensors, such as accelerometers, linear potentiometers, or ultrasonic transducers.

3. A digital optical encoder input channel for monitoring the location of the conveyance in the shaft.

Analog sensor input data are sampled by the monitoring system at 100 ms intervals. This sampling rate allows data to be acquired about 10 times per second, which is adequate for evaluating satisfactory hoist operation and affecting timely control at a speed of 600 m/min or 10 m/s (1,800 ft/min or 30 ft/s). At the completion of each sampling period, this information is combined with an updated optical encoder pulse count and transmitted as asynchronous serial data over the radio modem. A secondary RS-232 serial port output of the processing board can provide the same information to a portable computer or terminal on the conveyance itself. The conceptual data acquisition and sensor package is shown integrated into a hoist and shaft conveyance monitoring system (figure 8).

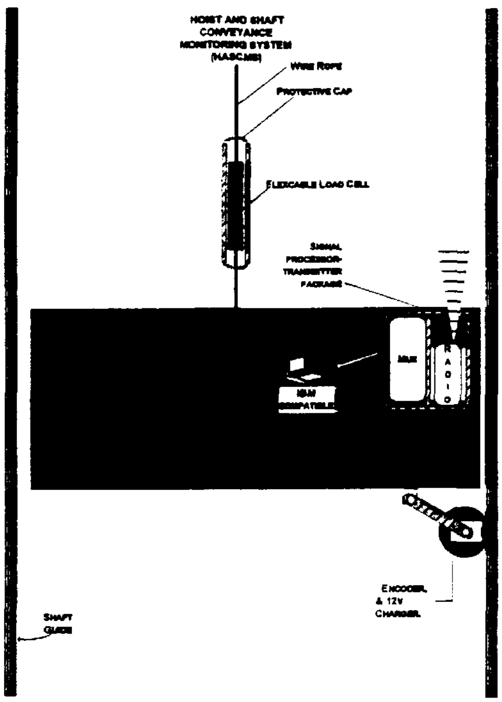

Figure 8. Hoist and shaft conveyance monitoring system.

Software

A user-friendly software interface to collect, save, analyze, and provide hoist control from sensor data input has also been developed. Visual Basic, an event-driven programming language, was selected. Instead of lengthy instructions taking weeks to write, this program is drawn. Subroutines are embedded in tool boxes of requisite functions by simple "point, click, and drag" programming. Subroutines are carried out in reaction to an event caused by either user input or internal actions. For example, events could be entered with a mouse click on a start button on the screen or input to a text box from a communications port on a PC.

Initial programming efforts resulted in a series of screens displaying hoisting data. The main menu includes eight buttons for displaying different data: "hoisting," "loading/unloading," "data-save," "calibration," "shaft inspection," "set operating limits," "set password," and "exit." The user can move anywhere in the system from either the main menu or the pull-down menus that exist in each window. For example, in figure 9, the "hoisting" window is shown with a mine shaft and conveyance represented, along with various operating parameters. The conveyance moves in accordance with position data input into the text box. Speed, acceleration, and conveyance weight are displayed as input into the text boxes. Another icon on this screen represents conveyance contents tied to warning conditions set in the operating limits window.

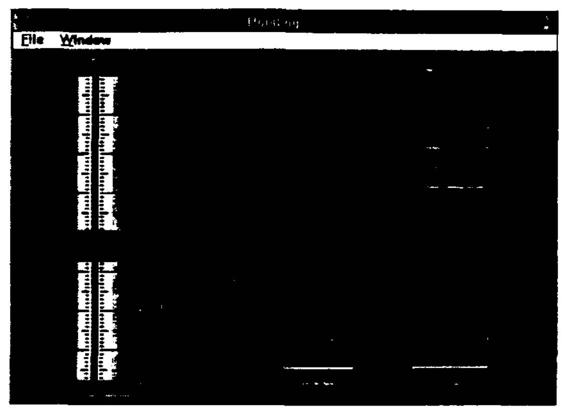

Figure 9. Computer screen showing shaft and conveyance simulation.

Updates and new capabilities are being incorporated as needed. For example, a menu bar is currently being incorporated into each process screen with a representative icon for different screens. Algorithms for time trends of rope load and conveyance speed with the effects of tight compartments from ground squeeze are also being considered. Coupled rock mass and set distortion data with slack and tight rope sensing can define potentially hazardous sections in the shaft.

SUMMARY

The major benefit arising from this research will be a reduction of injuries and fatalities related to hoist and elevator operations. Real-time visualization of hoisting processes will provide a hoist operator with a desktop tool for control of hoisting operations in a safe and efficient manner. By integrating this function into a broader framework of hoisting process control, the research will improve the health and safety of the work place.

REFERENCES

Barkand, T.D. and Helfrich, W.J., 1988.
Application of dynamic braking to mine hoisting systems. IEEE Trans. on Industry Applications.

Cseff, J., Forbes, W.J., Mills, A.W. III, Albert, L. and Penning, F.A., 1981.
Procedures for hoist and shaft inspection and maintenance. Vol. I. Systems description and Vol. II. Inspection and maintenance procedures (Contract J0100035, V.B. Cook, Inc.). USBM OFR 196(1)-82, 310 pp.; NTIS: PB 83-148049 and USBM OFR 196(2)-82, 140 pp.; NTIS: PB 83-148056.

Dames and Moore, 1977.
Safety analysis of United States shaft-sinking operations (Contract JO155174). USBM OFR 45-78, 289 pp.; NTIS: PB 282 289.

Farley, H.L., Fish, R.B., Jeffcoat, R.L., and Hoadley, D.L., 1983.
Slack and overload rope protection system (Contract JO199008, Foster-Miller Assoc., Inc.). USBM OFR 213-83, 327 pp.; NTIS: PB 84-143460.

Loynes, E., 1976.
Safe manriding in mines. Mining Technology, December, pp. 12-21.

Mine Health and Safety Administration, Health and Safety Analysis Center, 1989.
Shaft accidents in metal/nonmetal 1989, ADA (Accident data analysis).