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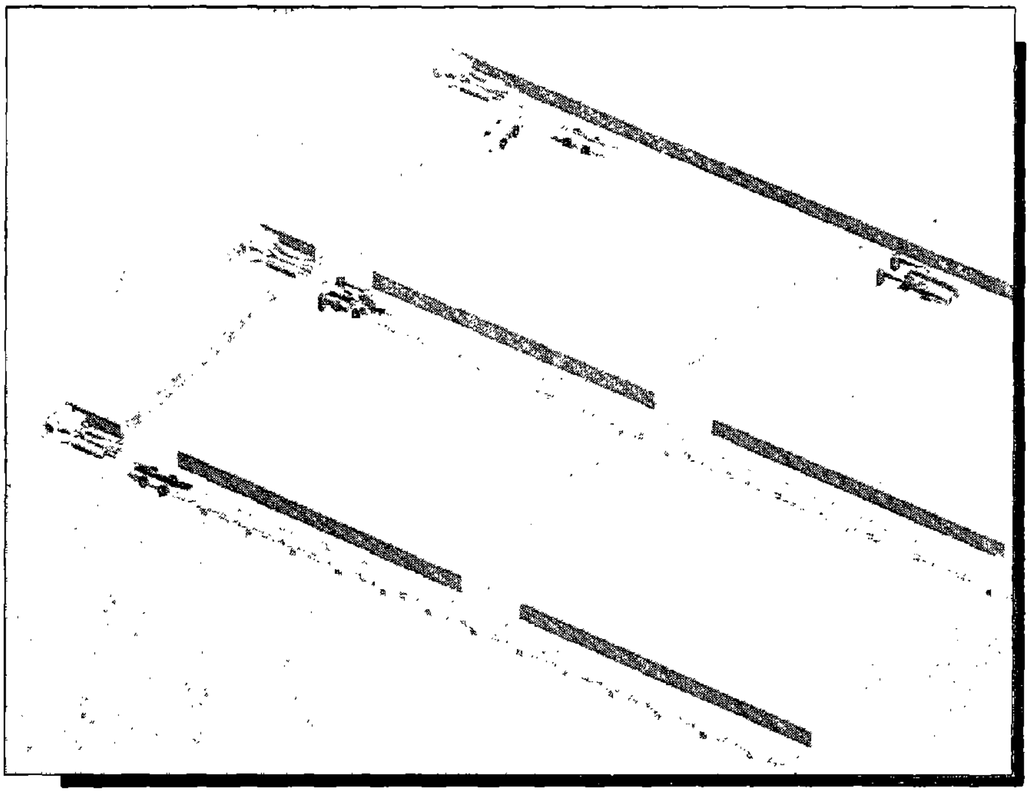
Computer Graphics Simulations Comparing Reduced Exposure Mining Equipment—Shuttle Cars Versus Continuous Haulage Systems

By Dean H. Ambrose



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Cover: 3-D computer graphics simulations compares productivity between reduced exposure mining system shuttle car and continuous haulage systems concepts.

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The U.S. Bureau of Mines recently developed computer graphic simulations to characterize mining scenarios, specifically for room-and-pillar mining operations in a 3-entry longwall development section. These simulations compare productivity between computer-assisted shuttle car and continuous haulage system concepts. One of the continuous haulage system concepts has bolting capabilities that supplement its haulage function. Simulations showed the continuous haulage system to be more time efficient than the shuttle car system. Researchers can reuse the simulation code (e.g., mining rates and equipment capacities can be changed) should investigators care to compare production of other mining scenarios. Using computer graphics simulation, researchers found computer model design modification flaws and mining scenario conceptual errors. The fundamental rationale for using three-dimensional computer graphics is to cheaply, easily, and quickly obtain information about the operation and design of a current or proposed mechanical coal or metal/nonmetal mining system. This report documents the computer graphic model and simulation developments and discusses some of the results and observations from the simulations.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	Mg	megagram
ft	foot	Mg/min	megagram per minute
ft/min	foot per minute	min	minute
h	hour	pct	percent
in	inch	s	second
m	meter	st	short ton
m/min	meter per minute	st/min	short ton per minute

1

COMPUTER GRAPHICS SIMULATIONS COMPARING REDUCED EXPOSURE MINING EQUIPMENT—SHUTTLE CARS VERSUS CONTINUOUS HAULAGE SYSTEMS

By Dean H. Ambrose[1]

ABSTRACT

The U.S. Bureau of Mines recently developed computer graphics simulations to characterize mining scenarios, specifically for room-and-pillar mining operations in a three-entry longwall development section. These simulations compare productivity between shuttle car and continuous haulage systems concepts. One of the continuous haulage systems concepts has bolting capabilities that supplement its haulage function. Simulations showed the continuous haulage system to be more time efficient than the shuttle car system. Researchers can reuse the simulation code (e.g., mining rates and equipment capacities can be changed) should investigators care to compare production of other mining scenarios. Using computer graphics simulation, researchers found computer model design modification flaws and mining scenario conceptual errors. The fundamental rationale for using three-dimensional computer graphics is to cheaply, easily, and quickly obtain information about the operation and design of a current or proposed mechanical coal or metal/nonmetal mining system. This report documents the computer graphics model and simulation developments and discusses some of the results and observations from the simulations.

[1]Electrical engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The U.S. Bureau of Mines (USBM) is staying on the leading edge of innovation by exploring the use of three-dimensional (3-D) computer graphics to examine new technologies and designs for reduced exposure mining systems (REMS). 3-D computer graphics have been available for some time; however, using them for mining equipment design and evaluation through computer model building and simulation is relatively new.

3-D computer graphics have three different application areas: modeling, simulation, and analytical interpretation. Modeling is the process of building a representation of an object by visualizing, understanding, and interpreting the geometric features of designs. These features include appearance, shape, size, and interference or clearance with other objects. Modeling in a 3-D computer environment often replaces building a physical model.

Simulation involves representing in some surrogate media the operation and control of a device. It often uses analysis tools such as kinematics (all geometric and time-based properties of motion) and dynamics (all force equations required to cause motion). Applying 3-D computing eliminates the immediate need for building and testing a physical prototype. If researchers had to conduct similar tests in the mine, it could be hazardous for personnel and cause interruptions to scheduled production.

Interpreting analytical results involves using 3-D capabilities to simultaneously display the geometry of a "part" and analytical results, e.g., shades of color that represent real-time temperature changes in a part. The purpose of such a display is to better understand the analytical results and their effect on the object(s) or its individual parts. Common examples of analyses interpreted this way include finite element techniques applied to airflow, stress, and heat.

USBM uses CimStation, scientific visualization software developed by SILMA, Inc. CimStation is a base system for designing and simulating automated devices. It is based on an object-oriented, open-system architecture that allows easily expandable and customized system functionality. Features include discrete event simulation, task-oriented programming, concurrent device programming, device mechanism modeling, computer-aided-design, -engineering and -manufacturing interfaces, kinematic and dynamic simulation, collision detection and avoidance and user-friendly interface menus. The software runs on Silicon Graphics Computer Systems 3-D computer graphics workstation.

USBM's reduced exposure mining research is divided into several major areas. The status and activities of each specific research area are beyond the scope of this report, but may be found in other references (*1-6*).[2] The objective of one project under the research program is to assess the use of automation technology for making improvements far beyond capabilities of current commercial mining systems. These studies involve examining the fundamental objectives of mining with the specific aim of designing and testing safer mining methods and systems that take advantage of specific capabilities of available automation technology, using 3-D computer graphics.

The USBM's 3-D computer graphics effort consists of four ongoing tasks: (a) create models of mining equipment, (b) create models of mine environments, (c) create simulations, i.e., use the environments and models in mining scenarios by programming a sequence of operations, and (d) with computer graphics simulation, study mining scenarios to examine machine or equipment interactions. Investigators will use these models and graphic simulations to examine navigation and guidance technology, computer systems and hierarchical architectures for real-time machine control, automated technologies adaptable to mining equipment, conceptual machine designs, and novel mining techniques.

The fundamental objective for using 3-D computing is to cheaply, easily, and quickly obtain knowledge about the operation and design of a current or proposed mechanical coal or metal/nonmetal mining system. Previous USBM research successfully developed a computer graphics simulator for a continuous miner model (*7*). The simulator provides investigators with a realistic test for experimental software that mimics the control functions of a continuous mining machine. This work serves as a base from which researchers can generate other models or simulators with little effort.

The most recent development of the USBM includes computer graphics simulations that characterize mining scenarios, specifically for room-and-pillar mining operations in a three-entry longwall development section. The purpose of these simulations is to enable industry or USBM to evaluate face haulage systems considering the capabilities of REMS. Specifically, the simulations compare productivity of shuttle car systems to continuous haulage systems. The REMS mining machines are conceptual in nature and are not yet commercially available. One of the continuous haulage system concepts has bolting

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

capabilities that supplement its haulage function. This report documents the computer graphics model and simulation developments and discusses some of the results and observations from the simulations. A video tape of the computer graphics simulations discussed in this report can be obtained by contacting the author.

ACKNOWLEDGMENTS

The author wishes to thank Stanley C. Suboleski, professor, Department of Mining Engineering, Pennsylvania State University, University Park, PA, for the technical descriptions of the mining process and mine plans; from the Pittsburgh Research Center, USBM, Darryl J. Esprit, computer engineer, for 3-D computer-graphics generated mine equipment models; Suresh K. Bhatt, mining engineer, for continuous haulage system information and simulation interest concerning the haulage project; Timothy J. Matty, electronics technician, for information regarding REMS machine behavior; and Joy Technologies, Franklin, PA; Fletcher Co., Huntington, WV; and Westfalia DM Enterprises, Washington, PA; for providing information on their mine equipment.

MODEL DEVELOPMENT

Researchers made a computer graphics model of a mine environment that portrays a three-entry longwall development section. Researchers also modeled the following commercially available mine equipment: Joy 14CM continuous miner, Fletcher automated dual head roof bolter, Joy 10SC shuttle car, Westfalia DM Enterprises (WDME) belt bender continuous haulage system, and WDME continuous haulage system modified with a dual head roof bolter. All equipment models for the simulations represent REMS machine concepts. Following is a detailed discussion of each model.

CONTINUOUS MINER

The continuous miner model (figure 1) represents a Joy 14CM9-10D. The model contains six parts: main-frame, right and left trams, gathering head, conveyor, shearer, and stab-jack. Four of the continuous miner model parts are tools: gathering head, conveyor, shearer, and stab-jack.

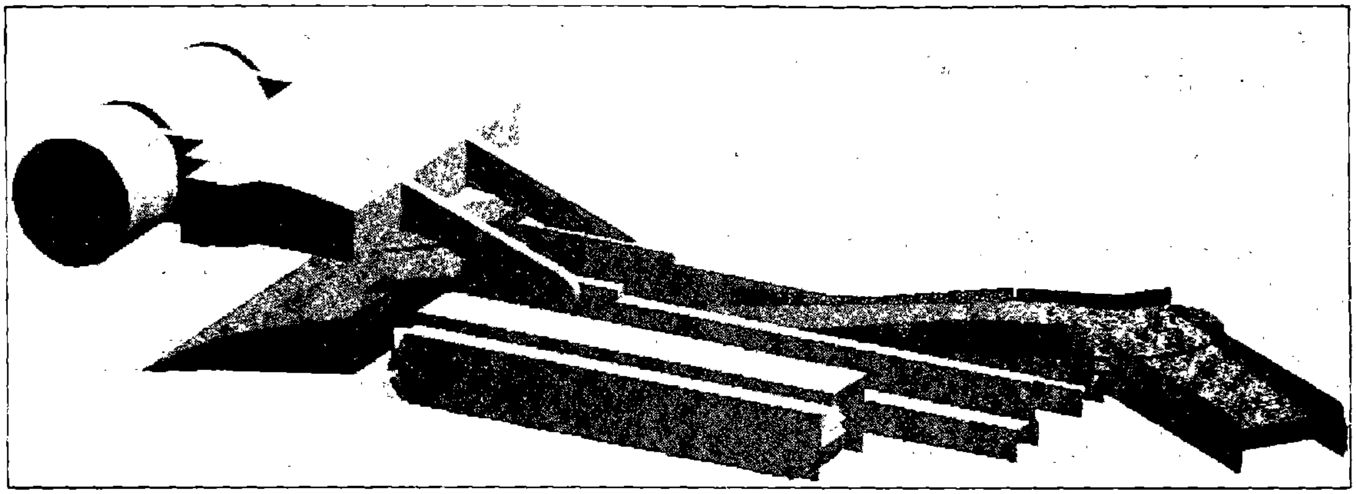
Using mine machine models in simulation requires "tools" that, when used together with the model, accomplish several tasks. A tool is a driven mechanical device (e.g., shearer) attached to the model (e.g., continuous miner) by which objects (e.g., coal) can be acted upon. Most tools contain moving parts; the simulation software, CimStation (*8*), requires kinematic descriptions (all geometric and time-based properties of motion) of each part. Modeled objects included as tools are not capable of kinematic motion until the software redefines them to produce kinematic motion. CimStation provides a "create tool" menu allowing the user to set and manipulate the parameters of each part of the tool. The parameters include *open* and *close* settings to limit the motion of the tool, *duration* to set the time (in seconds) for the tool to move from fully closed to fully open, *delay* to set the time (in seconds) for the part to begin moving after it is signaled, and *servoable* to set the parts' intermediate positions, if desired.

The continuous miner's conveyor and shearer were the only tools used in the simulations. The conveyor contains two moving parts: conveyor support and conveyor tail. The conveyor support controls the tail's elevation, which spans 6.5° between up and down. The conveyor's tail has a 86.63° swing side to side. At 42.65°, the conveyor tail aligns its center-line to the conveyor support's center-line, and is in effect "centered." The shearer contains one moving part: a boom with cutter drums attached. The shearer spans 44.52° between up and down, which mimics the full motion of the cutter drums. Also, 5° sets the cutter drums at the ground level, referencing to where the tram chain links touch the ground. Setting the shearer to 0° places the cutter drums 24.13 cm (9.5 in) below the ground level. The shearer was set between 5° and 30° to enable a cutting height of 1.524 m (5 ft). The cutter drums' diameters are 91.44 cm (36 in) and the cutting width is 3.048 m (10 ft).

ROOF BOLTER

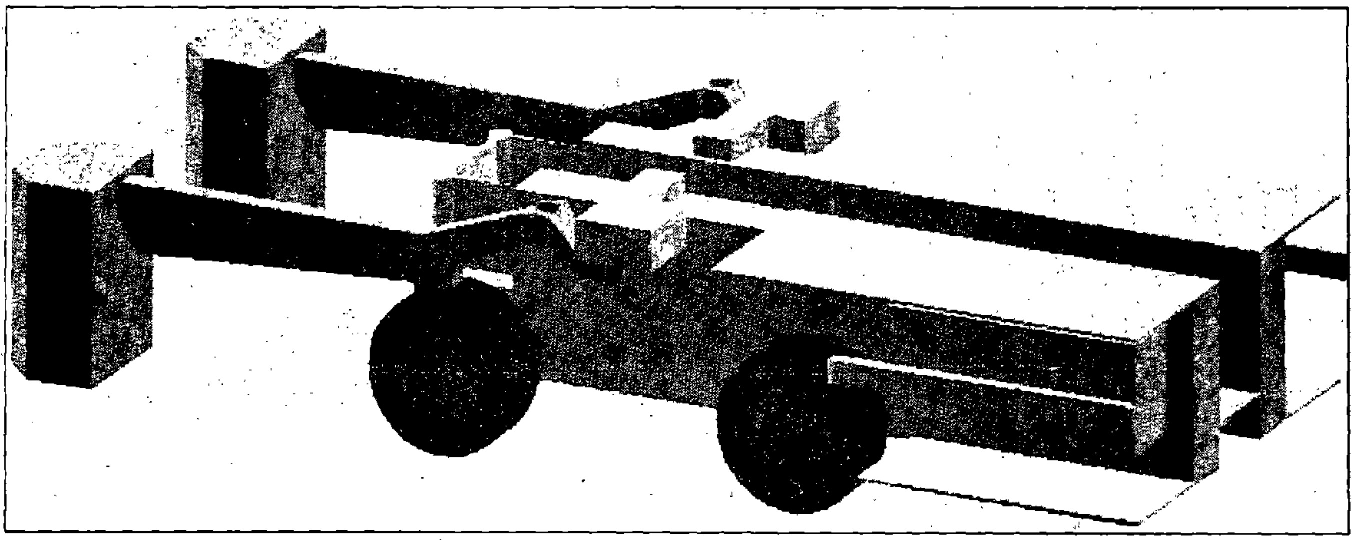
The roof bolter model (figure 2) represents a Fletcher Model HDDR dual head roof bolter with walk-through chassis. The model contains three parts: chassis, boom-arm assembly, and outrigger assembly. Two of the bolter model parts are tools: boom-arm and outrigger. The boom-arm assembly is the only tool used in the simulations. It contains three moving parts: pivot assembly, boom-arm, and drill platform. The pivot assembly swings 45° between open and close, but it controls the boom-arm swing of 3.048 m (10 ft) from either side of center. The boom-arm elevation has a 6° span between open and close, which provides a 40.64-cm (16-in) sump.

Figure 1



3-D computer graphics model of continuous miner.

Figure 2



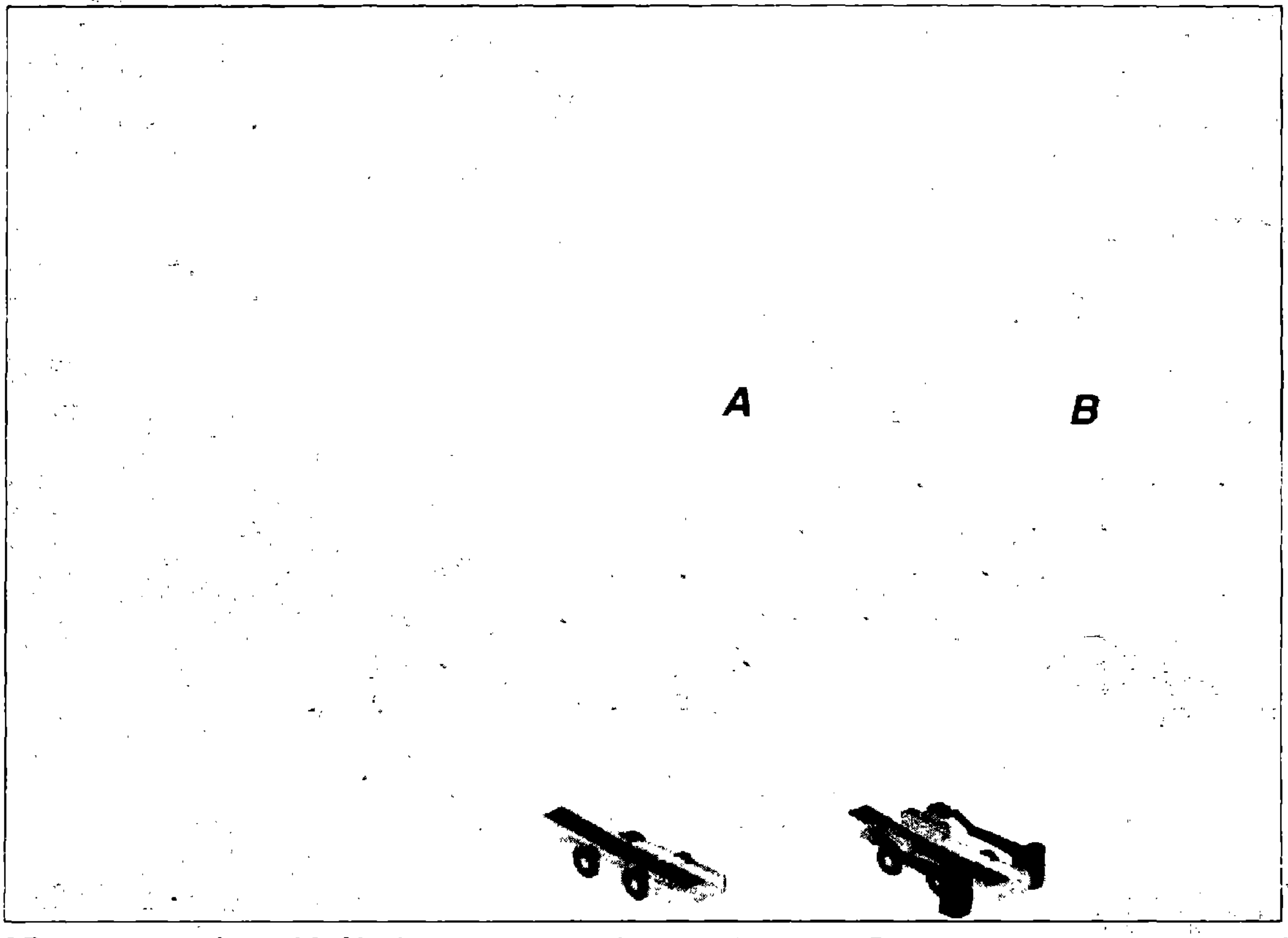
3-D computer graphics model of roof bolter.

CONTINUOUS HAULAGE SYSTEMS

A Westfalia DM Enterprises (WDME) belt bender continuous haulage system (figure 3*A*) and a WDME continuous haulage system modified with a dual head roof bolter (figure 3*B*) represents the continuous haulage system models. The continuous haulage system model contains two main parts: feeder-breaker car and belt-bender assembly. The feeder-breaker car consists of a chassis transported by a wheel assembly and housing a coal-breaking mechanism that reduces the coal size for easier transportation on the belt-bender system. The continuous haulage system consists of belt-bender sections that are connected to form a conveyor train of a length suitable to a particular mining technique. The discharge tail located on the last belt-bender section is the only tool on the continuous haulage system. The discharge tail angle is fixed at 45° to unload coal onto the main belt haulage system. The total length of the continuous haulage system is 77.724 m (255 ft).

The modified WDME continuous haulage system with bolter operation is identical to the WDME system discussed previously, except for the bolting capabilities. The bolting tool is the boom-arm assembly found on the roof-bolter model. Researchers copied just the tool assembly and attached it to the feeder-breaker car. The tool

Figure 3



3-D computer graphics model of haulage system: A, continuous haulage system; B, continuous haulage system with roof bolting function.

duplicates the roof-bolter functions. The ability to interchange a tool of one model onto another illustrates one benefit of using 3-D computer graphics modeling to explore ideas.

SHUTTLE CAR

The shuttle car model (figure 4) represents a Joy-310SC32A-3. The model contains three parts: chassis, conveyor system, and wheel assembly. The conveyor system is the only tool on the shuttle car and is one moving part that elevates at one end. The conveyor elevation spans 18° between open and close so that, when opened, it provides a 1.524-m (5-ft) elevation from the floor.

MINE ENVIRONMENT

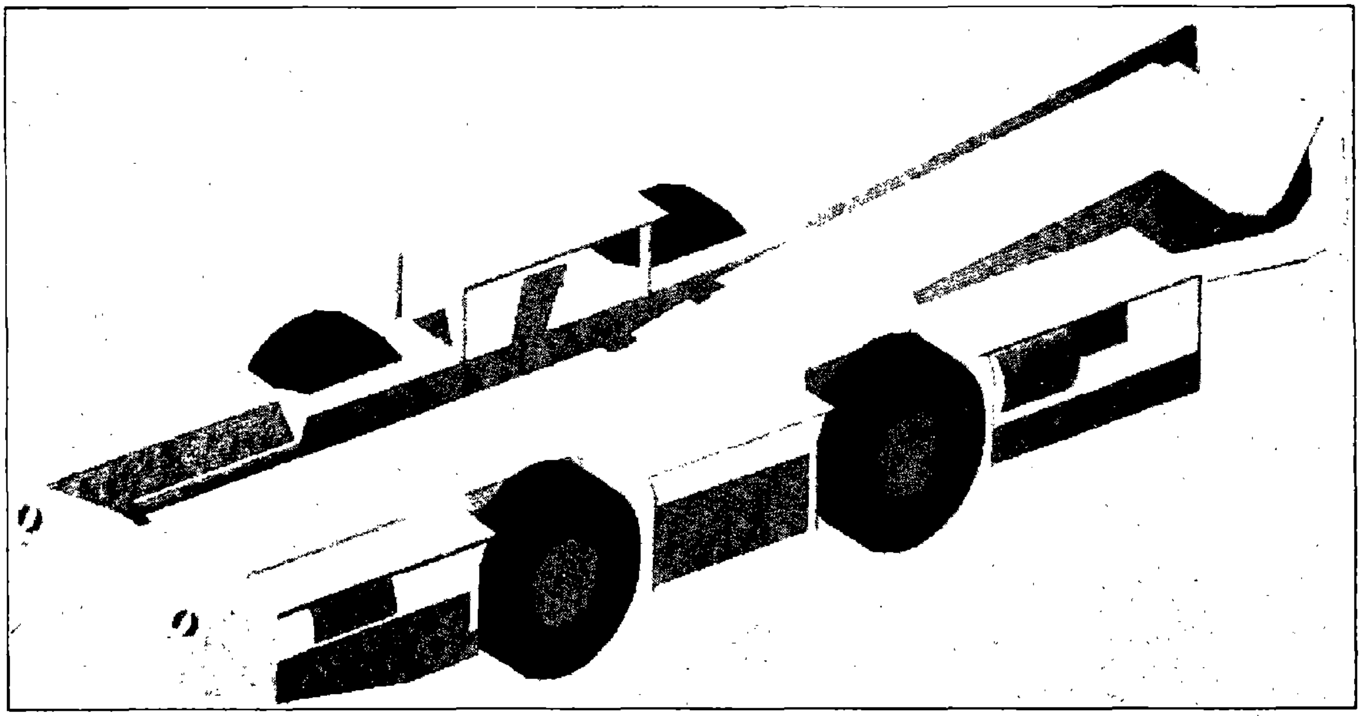
Researchers modeled a room-and-pillar mine environment representing a three-entry longwall development section. The entries are 6.096 m (20 ft) wide, and the pillars were constructed using solid rectangles that are 24.384 m (80 ft) by 30.48 m (100 ft).

The 1.524-m (5-ft) coal seam being extracted during the simulations was programmed to disappear as coal extraction progressed. To accomplish this, researchers modeled the primary coal seam as a series of blocks and used the "collision detection" capabilities of the software. The coal blocks were constructed and sized to fit the sump and shearing displacement of the cutter drums. This resulted in three coal blocks layered in such a way to allow the sump action to start from either top or bottom of the coal seam. Researchers programmed any collision between cutter drum and coal blocks to activate code that "hides" the coal being extracted.

Mining the crosscuts begins with a traditional three-pass cutting approach that forms the corner of the crosscut. To depict the process of beginning the crosscut in greater detail, researchers represented the extraction process using smaller coal blocks than those used in the primary coal seam. For the first 6.096 m (20 ft) of the crosscuts, the coal seam was modeled using 0.3048-m (1-ft) cubes as opposed to 0.6096 m high by 0.6096 m deep by 3.048 m wide (2 by 2 by 10 ft) blocks used in the primary coal seam. As the continuous miner's extraction process completes different cut angles and sump advances, the cutter drum collides with and hides smaller coal blocks, which enables investigators to see more realistic mining activity.

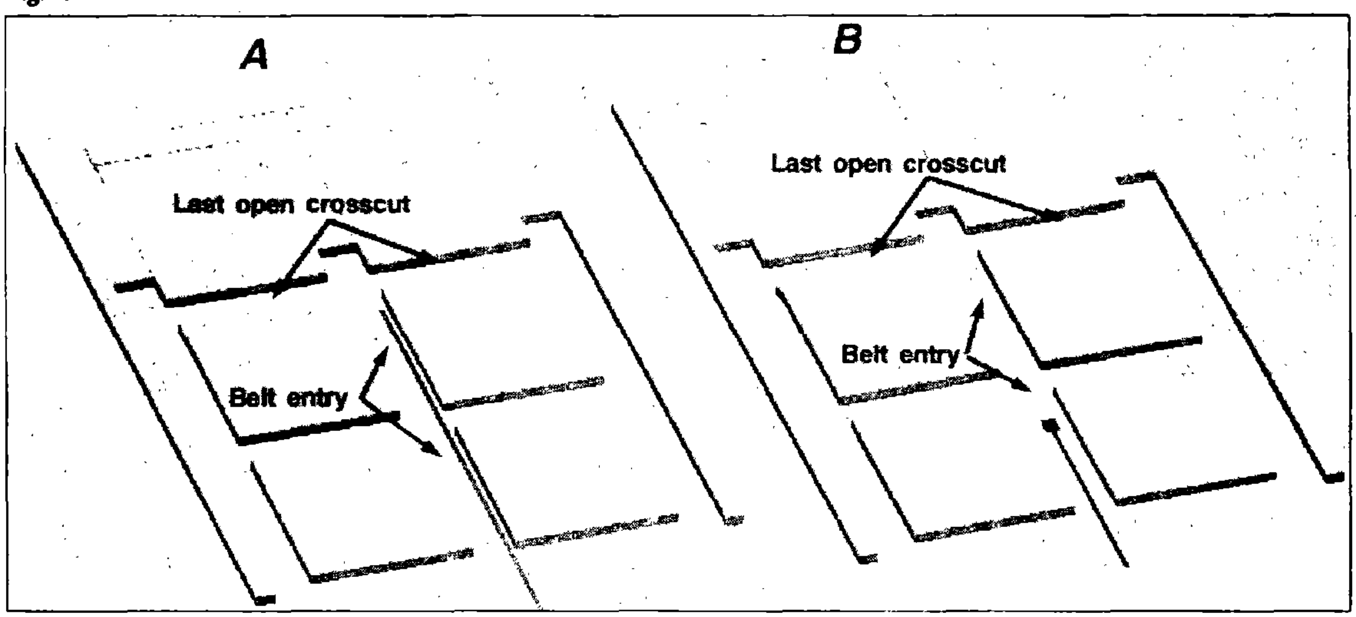
The main belt (figure 5A) and main belt with a discharge dump (figure 5B) are also part of the modeled

Figure 4



3-D computer graphics model of shuttle car.

Figure 5



3-D computer graphics model of room-and-pillar mine environment: A, With a main belt; B, with a discharge dump and main belt.

environment, but both are used in different simulations. The main belt is 121.92 cm (48 in) wide and 45.72 cm (18 in) above the floor and positioned to the right side of the belt entry. The main-belt and discharge dump is positioned 6.096 m (20 ft) from the open crosscut and in the middle of the belt-entry, which causes a one-way to the dump.

SIMULATION DEVELOPMENT

Researchers simulated three individual mining scenarios. All scenarios represent room-and-pillar mining that uses continuous mining equipment. Scenario 1 simulates a continuous miner in a mining operation loading onto a continuous haulage system. Scenario 2 simulates a continuous miner in a mining operation loading onto shuttle cars. Scenario 3 simulates a continuous miner in a mining operation loading onto a continuous haulage system that has roof bolting capability.

In addition to allowing investigators to visually follow the mining process, the simulation displayed the mining operations' elapsed times in hours and coal production in short tons. Compiling time and tonnage was one of the major tasks of the simulation.

Machine speeds used in the simulations are averages that were recommended by experts who study mine operations to assist mine operators in planning. These speeds yield accurate times for simulating machine trams and other event sequences (e.g., events used for the bolting simulations). The machine tram speeds used in the simulations incorporate an average allowance for cable handling.

Because of the unknowns surrounding some mining delays in the scenarios, such as gas checks (except those before roof bolter operation), ventilation checks, or curtain installations, these delays are not part of the simulations. Further studies are necessary to examine the impact of other mining delays on the mining process in each scenario. Researchers could use the results of these studies and simulate various ground control and ventilation concepts for analysis.

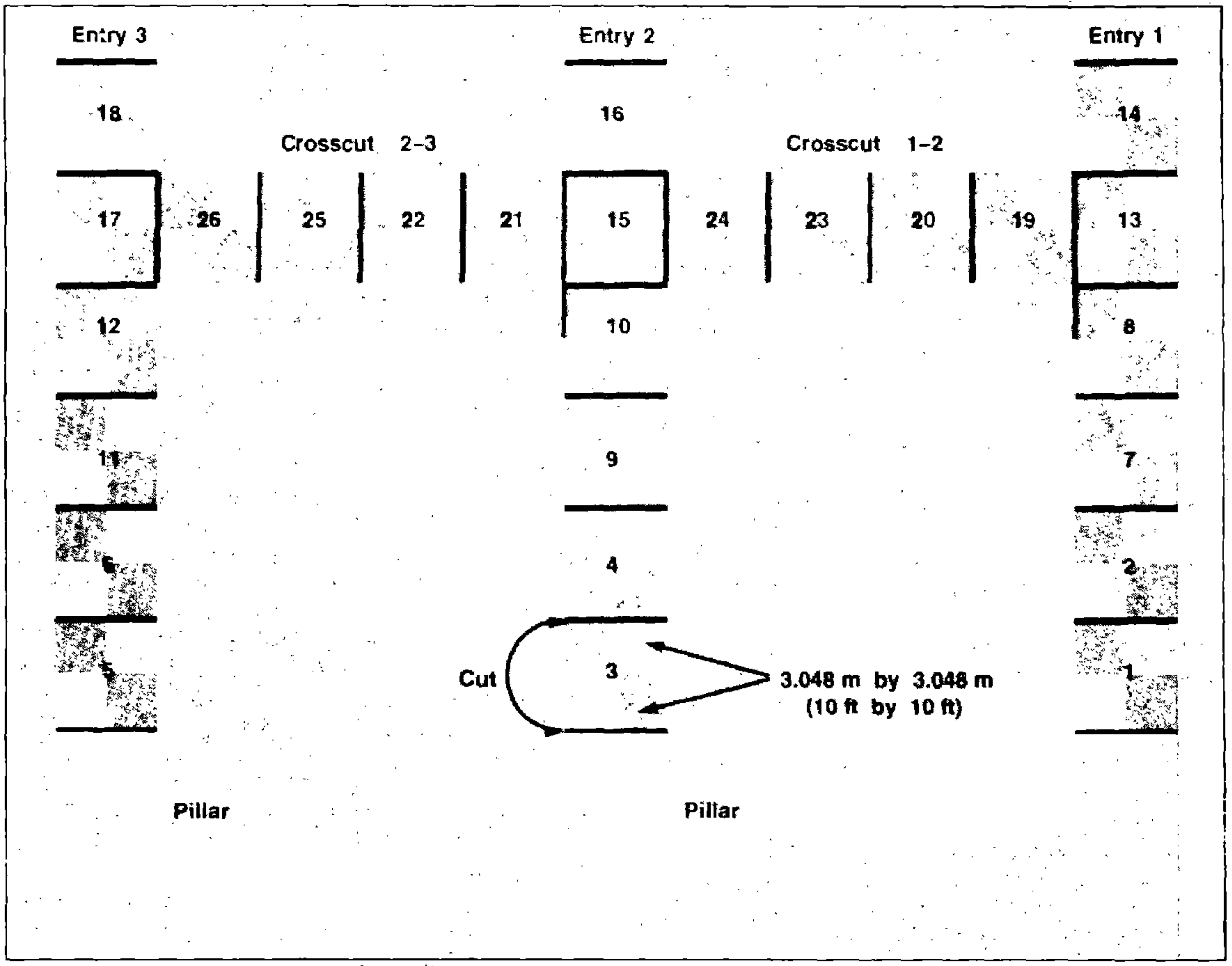
The starting point for all simulations is after the continuous miner has trammed into the cut and stopped at the right side of the face. Because of the limited reach of the continuous haulage system, the main belt must be moved every open crosscut length, not every two lengths as with the shuttle car system. This belt-move is not included in the simulations, but is discussed in the Analysis section of this report. Each of the scenarios are discussed below.

SCENARIO 1

The first coal mining scenario consists of a continuous miner, a continuous haulage system, and two roof bolters. This scenario illustrates a REMS operation that makes a 12.192-m (40-ft) advance with a series of cuts using a continuous haulage system. The cut pattern for this scenario is illustrated in figure 6. The sequence for simulating the mining operation begins with the sump, shear, and cusp removal (sump-shear-trim) cycle. The continuous miner sumps forward 60.96 cm (24 in) into the seam, shears up or down, and trims the floor or roof. The continuous miner's sump speed is 2.438 m/min (8 ft/min) and shear speed is 3.048 m/min (10 ft/min). The mining rate for one cycle is 3.81 Mg (4.2 st) in 57 s. The continuous miner's loading rate is 8.165 Mg/min (9 st/min). This rate is sufficient to unload coal onto the continuous haulage system without slowing the mining rate. The continuous miner continues the sump, shear, and trim until it reaches a cut depth of 3.048-m (10-ft) deep. After mining for 3.048 m (10 ft), the continuous miner "sets over" which takes 67.2 s. Setting over is when the continuous miner backs out of one side to a position about 6.096 m (20 ft) outby the original position of the cut and begins to mine the other side of the entry. During all set-over maneuvers, the continuous miner performs a cleanup pass as it goes to the other side of the entry. The mining cycle for the cut is repeated, but now the left-side cut continues for 6.096 m (20 ft). In effect, a 3.048-m (10-ft) slab cut is extended by a 3.048-m (10-ft) box cut as the continuous miner continues to mine on the left side for a total of 6.096 m (20 ft). After completing the cut on the left side, the continuous miner sets over to the right side that takes 91.2 s. The box-cut, extended slab-cut pattern is then repeated until the cut is completely mined. Finally, the continuous miner trams to the next entry. The continuous miner's tram speed is 7.62 m/min (25 ft/min). The cycle repeats until all the cuts in the cut pattern have been mined.

The continuous haulage system simply follows the continuous miner into and out of the various cuts. The continuous haulage system tram rate matches the tram rate of the continuous miner during the cutting cycles. In effect, there is no delay associated with the continuous haulage system taking positions behind the continuous miner. During the simulation, the continuous haulage system takes up various positions behind the continuous miner to allow the continuous miner to move and unload coal without interfering. While the continuous miner sets over, the continuous haulage system will take up an unobtrusive position but will immediately catch up with the continuous miner before the mining cycle sequence begins. The continuous haulage system's tram speed is 15.24 m/min (50 ft/min). Because of the characteristics and abilities of the

Figure 6

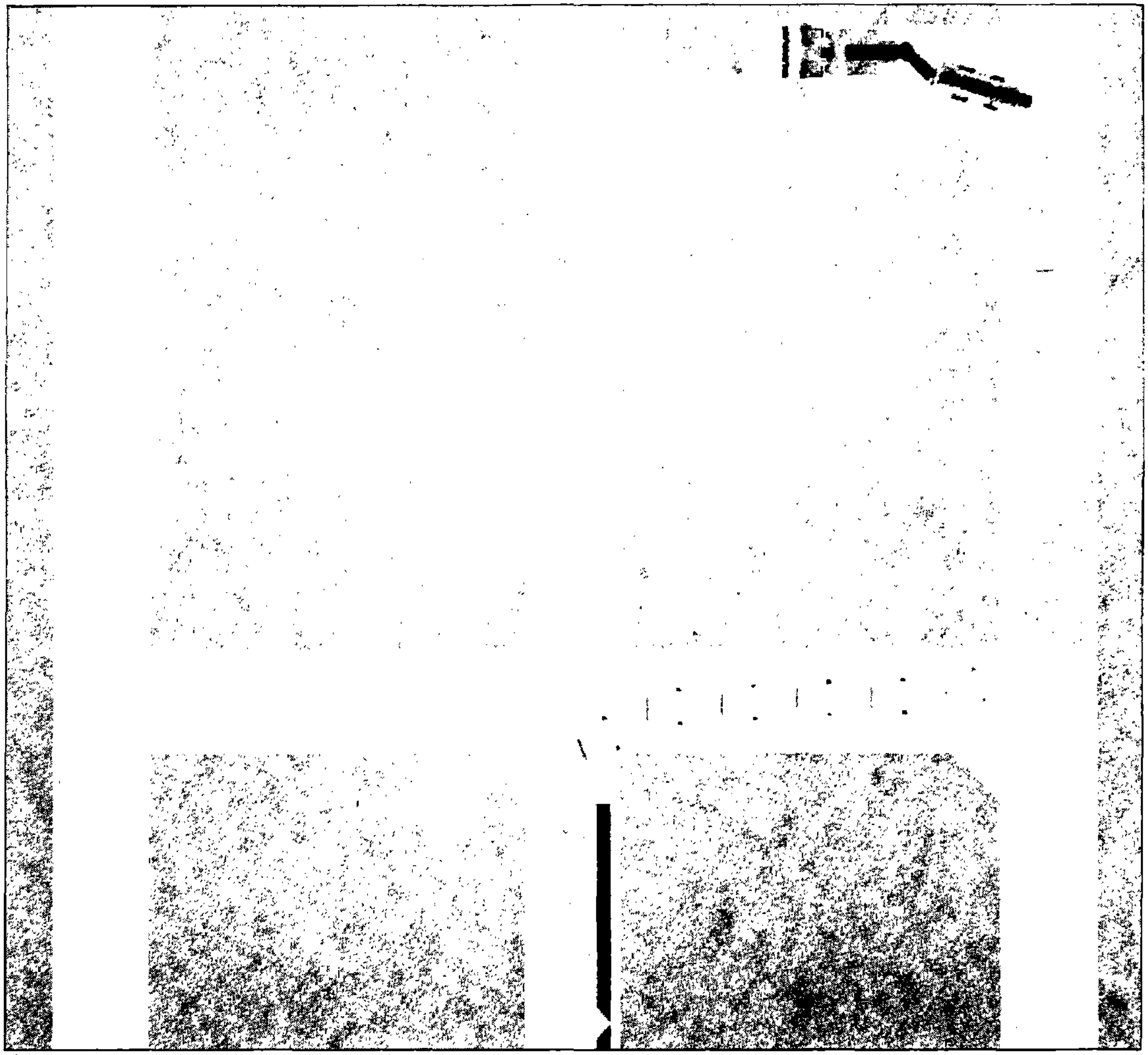


Cut pattern for scenarios 1 and 2. (Discolored areas within the cut separates 3.048-m by 3.048-m (10-ft by 10-ft) sections of the coal seam.)

continuous haulage system used in the simulations, the continuous haulage system will "snake" through the entries and crosscuts to unload coal onto the main belt haulage system (figure 7).

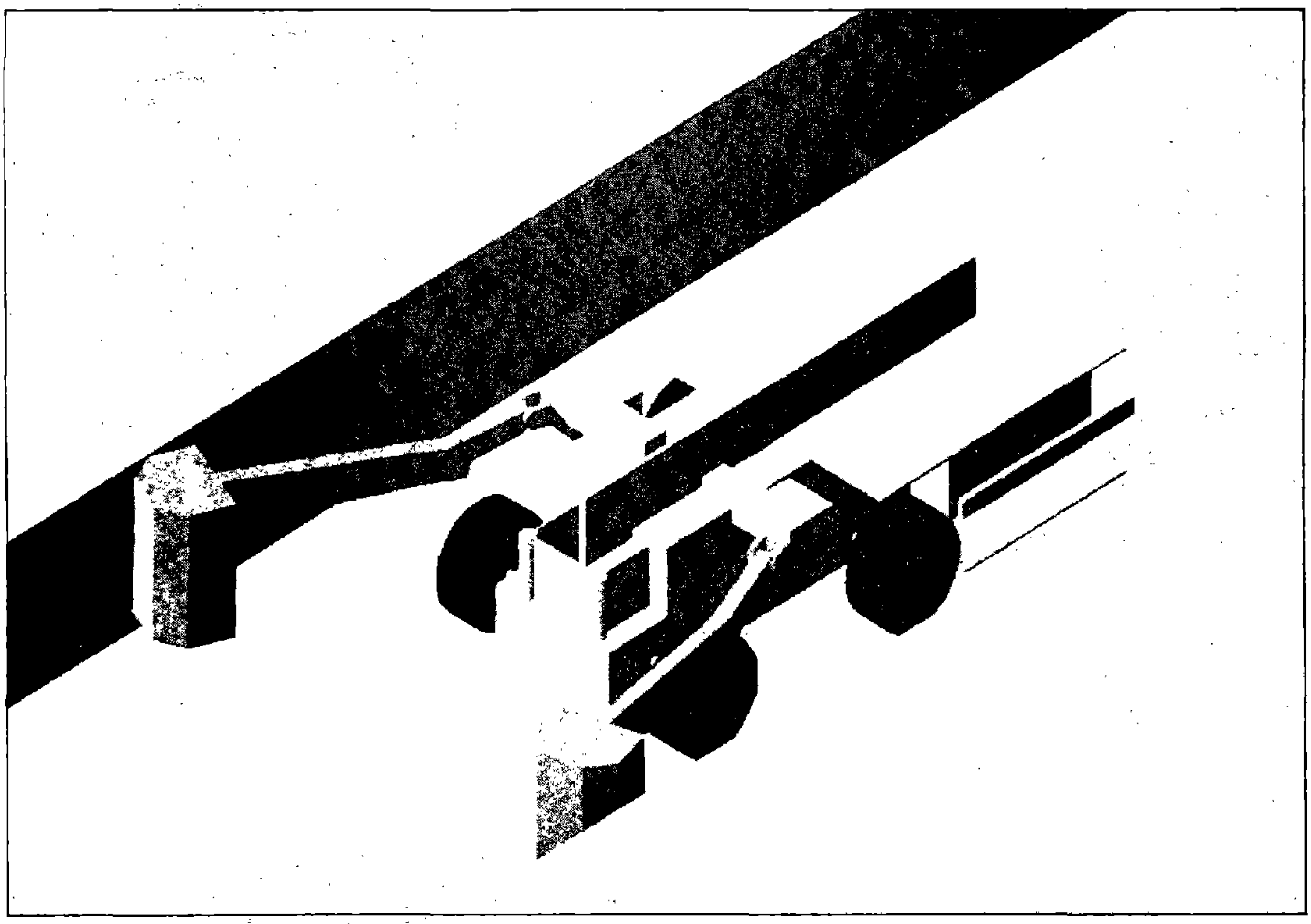
Bolter 1 is assigned to entries 1 and 2 and to crosscut 1-2. Bolter 2 is assigned to entry 3 and to crosscut 2-3. The roof bolter's cycle begins with the completion of a cut. The bolter trams from its waiting point into the cut. The bolter's tram speed is 27.43 m/min (90 ft/min). The bolter takes position for bolting the first row of bolts and performs a methane check, which takes 40.8 s. A sequence of events used for the bolting simulations and times are (a) position bolter, set for outside bolt holes, and set automatic temporary roof support, 30 s; (b) place steel head and drill (figure 8), 61.2 s; (c) lower boom and remove steel head, 4.8 s; (d) insert and tighten bolt, 42 s; (e) set for inside bolt holes, 8.4 s; (f) place steel head and drill, 61.2 s; (g) lower boom and remove steel head, 4.8 s; and (h) insert and tighten bolt, 42 s. This sequence is repeated until all rows have been bolted the length of the cut on 1.219-m (4-ft) centers. The bolter then returns to a waiting point.

Figure 7



Continuous haulage system as it "snakes" through entries and crosscuts.

Figure 8



Roof bolting outside bolt holes.

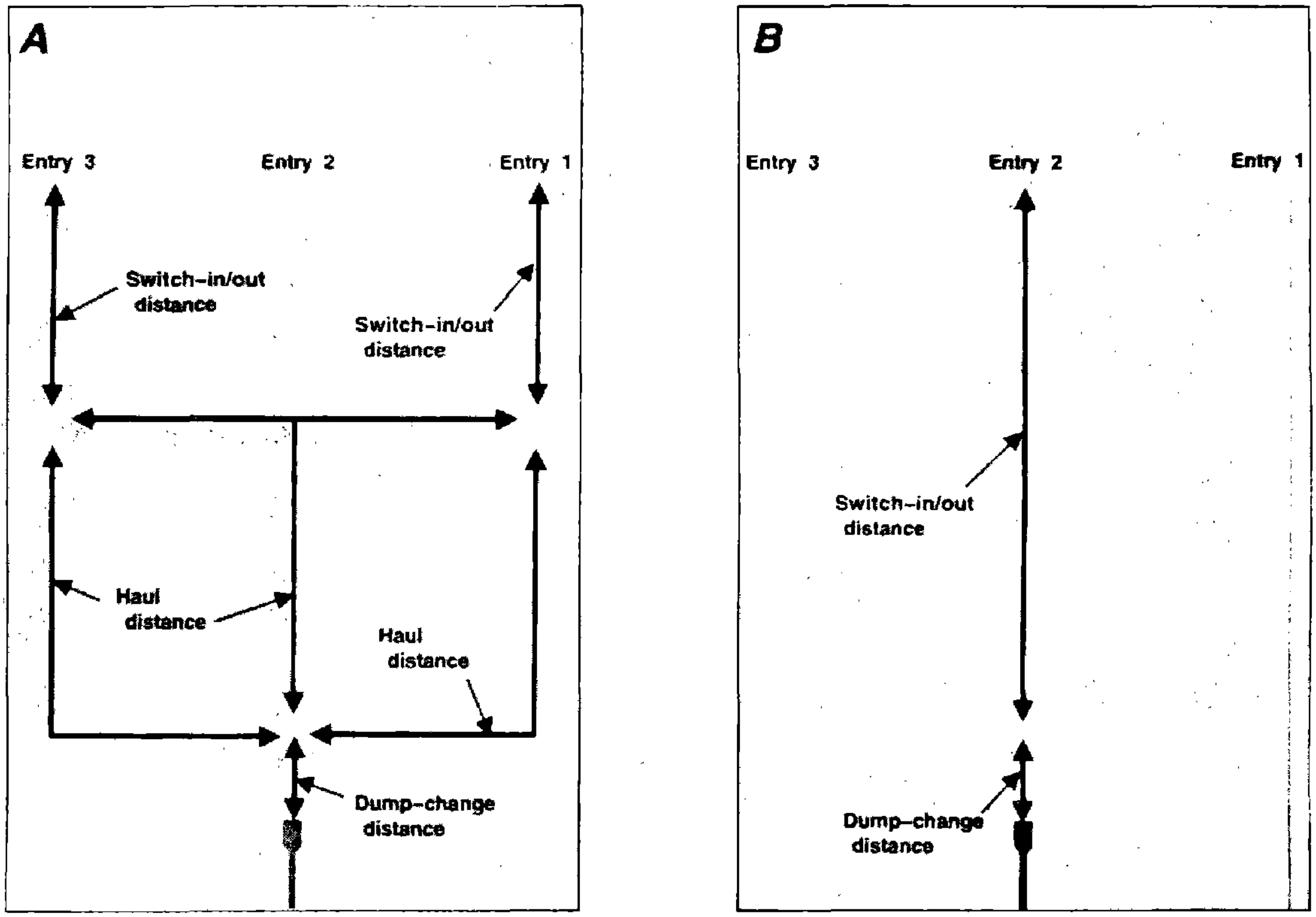
SCENARIO 2

The second mining scenario consists of a continuous miner, two shuttle cars, and two roof bolters. Its purpose is to illustrate a REMS operation that makes a 12.192-m (40-ft) advance with a series of cuts using a shuttle car haulage system. The cut pattern for this scenario is also illustrated in figure 6. The sequence for simulating the mining operation begins with the sump-shear-trim cycle. The description and mining rates are identical to those in scenario 1. Scenario 2 uses two bolters whose bolting description is identical to scenario 1.

The shuttle car route consists of three segments: (a) switch-in/out distance, (b) haul distance, and (c) dump-change distance. The haul distance for entries 1 and 3 (figure 9*A*) is the portion over which each car travels an independent route. In the other two segments, only one car can travel at a time. However, for entry 2 (figure 9*B*), only one car can travel at a time in any of the segments. A change point is a "check location" where the car waits if another mining vehicle is blocking the travel distance or intersection. Another major task of the simulation is determining delays at all change points.

The two shuttle cars' haulage cycle begins with the first car tramming to the cut. The shuttle car tram speed is 91.44 m/min (300 ft/min), but the last 12.192 m (40 ft) to the dump or to the miner, the speed is 83.82 m/min (275 ft/min). The first car follows the continuous miner and the car is loaded with 5.67 Mg (6.25 st). After it is loaded, the car travels to the first change point and clears it. Next, the second car trams into the cut, takes position behind the continuous miner, and the mining sequence continues. Meanwhile, the first car continues to the dump change point; if the dump point is clear, the car travels to the dump. The dump discharge time is 45 s. As the empty first car returns, it checks at each change point to determine if another vehicle has to clear, waiting if necessary. After the second car is loaded, it travels to the dump to unload and returns to the continuous miner making checks at each change point. When either car

Figure 9



Shuttle car routes: A, Routes for entry 1 and 3; B, route for entry 2.

arrives at the continuous miner, the shuttle haulage cycle repeats.

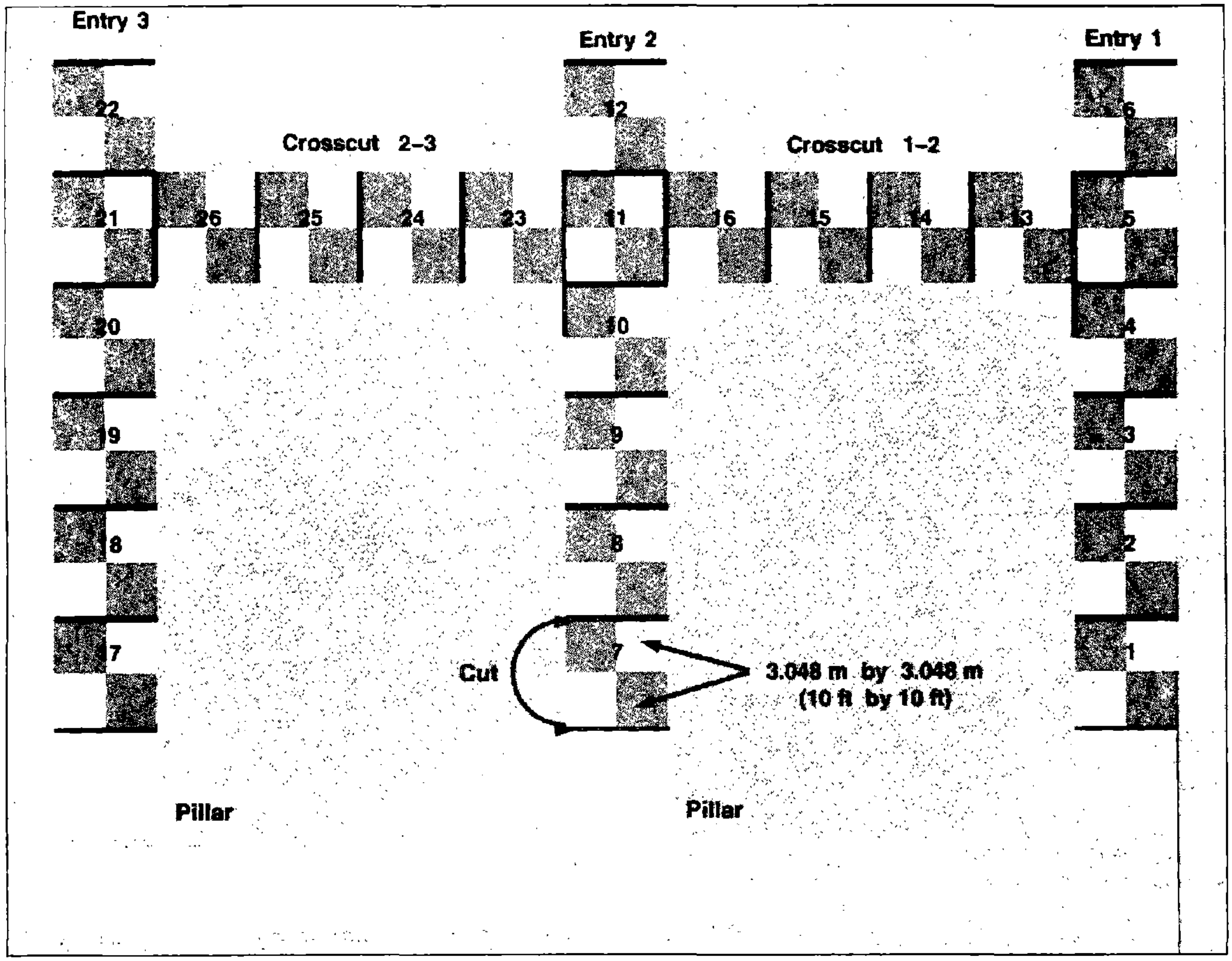
Shuttle car capacity varies with the seam thickness, seam density, and width of car. The car capacity used in the simulation was 5.67 Mg (6.25 st); current maximum safe hauling capacity specified by the manufacturer of shuttle car used in the simulation is 13.61 Mg (15 st). Should investigators care to examine another scenario with increased shuttle car capacity, simple changes can be made to existing simulation code and rerun the simulation.

SCENARIO 3

The third mining scenario consists of a continuous miner, a conceptualized continuous haulage system modified with bolting capabilities, and two roof bolters. This scenario illustrates a REMS operation that makes a 36.576-m (120-ft) advance with a series of cuts using a continuous haulage system equipped to perform bolting tasks. The cut pattern for this scenario is illustrated in figure 10. The sequence for simulating the mining operation begins with the sump-shear-trim cycle. The mining rates are identical to those in scenario 1. The continuous miner continues the sump-shear-trim cycle until all the cuts in the cut pattern have been mined.

The continuous haulage system simply follows the continuous miner into and out of the various cuts as discussed in scenario 1. However, when the continuous haulage system positions 6.096 m (20 ft) inby, it begins a bolting cycle. A sequence of events used for the bolting simulations and times is as follows: (a) set for outside bolt hole, 8.4 s; (b) place steel head and drill, 61.2 s; (c) lower boom and remove steel head, 4.8 s; (d) insert and tighten bolt, 42 s; (e) set for inside bolt hole, 8.4 s; (f) place steel head and drill, 61.2 s; (g) lower boom and remove steel head, 4.8 s; and (h) insert and tighten bolt, 42 s. This sequence is repeated every 1.219 m (4 ft) for a length of 24.384 m (80 ft). The continuous haulage system's

Figure 10



Cut pattern for scenario 3. (Discolored areas within the cut separates 3.048-m by 3.048-m (10-ft by 10-ft) sections of the coal seam.)

bolter device has artificial intelligence (a concept) to follow a bolting plan of 1.219-m (4-ft) centers and keep track of the bolt hole locations.

Roof bolters were not originally included in the plan for scenario 3. However, during the scenario's development, it was discovered that the continuous haulage system's bolting operation could not finish the last 9.14 m (30 ft) of the entry unless the continuous miner was moved out of the way. Without adding delay to the mining operation, researchers decided to simulate the use of roof bolters for the last 12.19 m (40 ft) of the entry. Subsequently, the continuous haulage system's bolting operation completes only 24.38 m (80 ft) of the 36.576-m (120-ft) entry.

ANALYSIS

Scientific visualization software, e.g., CimStation, is effective for realizing images of familiar objects. It is equally effective for translating the abstract multidimensional data sets derived from computer simulations into informative animated sequences. Because of the enormous amount of visual information being presented in computer graphics simulations, it was necessary to review the simulations many times. During the reviews, researchers made changes to the scenarios to achieve better understanding and accuracy of the mining techniques. Following are some observations from the three simulations and results or changes.

SCENARIO COMPARISONS

Mining scenario comparisons are summarized in table 1. All scenarios mined the same amount of coal, 2,000.376 Mg (2,205 st). Scenario 1 productivity is 1062.3 Mg/unit-shift (1171.3 st/unit-shift) compared to scenario 2, 732.5 Mg/unit-shift (723.5 st/unit-shift) and scenario 3, 859.5 Mg/unit-shift (947.4 st/unit-shift). Because of the limited reach of the continuous haulage system, the main belt must be moved every open crosscut length, not every two lengths as with the shuttle car system. Consequently, the belt-move adds more time to the continuous haulage systems. Belt-move time takes from 2 to 8 h, depending on the efficiency of the mine workers. This time is not included in the total time displayed by the simulations. However, for comparison purposes and its importance to the overall mining time, researchers included a belt-move time of +4 h in the table.

SLAB CUT EXTENSION

Applying new mining techniques to mining systems that enhance mining operations can be easily examined using computer graphics simulation. A new technique illustrated in all three scenarios is using slab cut extension. During a traditional mining cycle, the slab cut advances only 3.048 m (10 ft) and the continuous miner sets over and begins another box cut. However, mining cycle enhancement is illustrated in the scenarios by mining an additional 3.048 m (10 ft) on the left side slab cut. Technically, what makes this possible is the use of machine-mounted dust scrubbers that remove air contaminated with gas and dust. This mining technique was not used in prescrubber days because the line brattice was carried a few feet from the rib of one side of the entry to no farther than 3.048 m (10 ft) from the face.

DISPLAYS HELP ANALYSIS

More vehicle delays were observed during scenario 2 than any other scenario, because the shuttle cars waited often for the other car to clear the change point or dump change point. Researchers wanted to be sure the time-delay tracking code worked. Therefore, they drew upon the times saved by the simulation code and displayed them after making simple changes to the display portion of the simulation code. This demonstrates how easily changes can be made in computer graphics simulations, e.g., additional displays to provide information for more analysis. The display provided times that accounted for each shuttle car delay, which indicated that the time-delay tracking code works.

MACHINE ROUTING

During scenario 2's development, researchers were concerned with the optimal haulage routes. For example, during scenario 2's simulation of entry 2, researchers tried combinations of the number of routes and shuttle cars. After experimenting with two shuttle cars and one haul route, researchers found this solution was optimal because other solutions increase total mining time. This is a good example of how computer graphics simulation can be used to improve mining time by analyzing machine routing.

DETECT COLLISIONS

During scenario 3, collisions were detected between the continuous miner tail and the bolter device attached to the feeder-breaker of the continuous haulage system. Researchers unsuccessfully attempted to eliminate the collisions by relocating the bolter device on the feeder-breaker, but minimize them. Other possible options included using a new bolter device design for the feeder-breaker, or attaching the existing bolter device onto one of the belt-bender sections behind the feeder-breaker. These findings demonstrate how computer graphics simulation can help find design flaws or conceptual errors.

Table 1.—Mining scenario comparisons

(Total coal production in all scenarios is 2,000.376 Mg [2,205 st])

Scenario and haulage type[1]	Productivity, Mg/unit-shift	Productivity, (st/unit-shift)[2]	Time, h[3]	Main-belt move, h	Time with main belt move, h
1: Continuous	1,062.3	(1,171.3)	15.06	+4	19.06
2: Shuttle cars (2)	656.4	(723.5)	24.38	0	24.38
3: Continuous with bolting capability	859.5	(947.4)	18.62	+4	22.62

[1]All scenarios use one continuous miner and two roof bolters.
[2]Unit-shift, 8 h; productivity does not include main belt move.
[3]Total elapsed time to complete mining scenario.

SUMMARY

Researchers successfully developed 3-D computer graphics simulations using models of underground coal mining equipment. The equipment models are representations of the following mine machines: Joy 14CM continuous miner, Fletcher automated dual head roof bolter, Joy 10SC shuttle car, and Westfalia DM Enterprises (WDME) belt bender continuous haulage system. All equipment models for the simulations represent conceptualized REMS machines. One of the models is a modified WDME continuous haulage system having bolting capabilities that supplement its haulage function. Researchers developed three simulations: two sequences simulating a continuous miner in a room-and-pillar mining operation loading onto continuous haulage systems and one loading into shuttle cars. The purpose of these simulations was to allow investigators to visually follow the mining process and examine and compare the safe use of different mining techniques and equipment. The simulations feature a display showing the mining operations' elapsed time in hours and coal production in short tons. Determining mining delays and compiling time and tonnage were major assignments for the simulations.

After reviewing the simulations several times, researchers made changes to the scenarios to achieve better understanding and more accurate representation of the mining techniques. Three-dimensional computer graphics simulations will help researchers resolve complex safety and worker health safety and worker health problems as they relate to technological comparisons or simply understand mechanisms. Also, computer graphics model simulations will serve as a technology transfer tool to present complicated mining concepts in an easily understandable format. Following are some conclusions of this work:

- Applying new mining techniques to mining systems that enhance safe mining operations can be easily examined, e.g., slab cut extensions and machine routing decisions.
- Changes are easily made in computer graphics simulations, e.g., adding displays to provide additional information for more analyses.
- Interchanging modeled parts of one model to another illustrates the benefit of using computer graphics modeling to explore safety ideas, e.g., attaching a bolting device from a modeled roof bolter to a continuous haulage system to reduce worker exposure from bolting operations.
- Collision detection helps find design flaws or conceptual errors, e.g., collision between the continuous miner tail and the bolter device attached to the feeder-breaker of the continuous haulage system.

Mining scenario comparisons revealed that scenario 1 productivity is greater than scenario 2 by 38 pct and scenario 3 by 19 pct. Shuttle car's haulage operation time is more than either continuous haulage operations. Because of the unknowns surrounding some mining delays in the scenarios, such as gas checks (except those before roof bolter operation), ventilation checks, or curtain installations, these delays are not part of the simulations. Further studies are necessary to examine their impact to the mining process in each scenario. Further options may include applying simulations to try various ground control and ventilation concepts for further analysis.

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