THE PENNSYLVANIA STATE UNIVERSITY
Department of Mineral Engineering

Mining Engineering Section

STUDY OF THE HUMAN FACTORS ASPECTS OF AN AUTOMATED CONTINUOUS MINING SECTION

Prepared for
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by
Robert L. Frantz
Robert H. King

FINAL REPORT
on
Grant No. S0144115

March 31, 1977

OF EARTH AND MINERAL SCIENCES
Park, Pennsylvania

REPORT DOCUMENTATION PAGE

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle
Study of the Human Factors Aspects of an Automated
Continuous Mining Section

5. Report Date
March 31, 1977

6.

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
Department of Mineral Engineering
The Pennsylvania State University
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University Park, Pennsylvania 16802

10. Project/Task/Work Unit No.

11. Contract or Grant No.
S0144115

12. Sponsoring Organization Name and Address
Assistant Director--Mining
Bureau of Mines
Department of the Interior
Washington, D. C. 20241

13. Type of Report
Final

14.

15. Supplementary Notes

16. Abstract

This report is a part of the project "Study of the Human Factors Aspects of an Automated Continuous Mining Section".

The report covers three phases:

Phase I Assessment of the Impact of the Automation Technology on Mining Health and Safety.

Phase II Estimation of the Cost-Effectiveness and Productivity of Automation.

Phase III Prediction of the Psychological and Organizational Impacts of Automated Mining.

The investigation determines that the automation of a continuous mining section will improve the health and safety of the miner; will increase section productivity and decrease mining costs; will result in a more attractive and desirable working environment, and will result in a greater rate of return on capital investment.

17. Originator's Key Words
Automated Continuous Mining, Human Factors,
Underground Mining.

18. Availability Statement

19. U. S. Security Classif. of the Report

20. U. S. Security Classif. of This Page

21. No. of Pages

22. Price

MINING ENGINEERING SECTION
DEPARTMENT OF MINERAL ENGINEERING
THE PENNSYLVANIA STATE UNIVERSITY

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DISCLAIMER NOTICE

"The views and conclusions in this document are those of the authors and should not be interpreted as necessarily representing the official policies of the Interior Department's Bureau of Mines or the U.S. Government."

CERTIFICATION OF THE ABSENCE OF PATENTS AND INVENTIONS

This statement certifies that at the contract report date, no inventions have been developed from Contract SO-144115. Consequently, no patents are pending.

Robert L, Frantz, Project Director

Robert King, Project Engineer

FOREWORD

This report was prepared by The Pennsylvania State University, College of Earth and Mineral Sciences, Department of Mineral Engineering, University Park, Pennsylvania, under USBM Contract No. SO-144115. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center, with Mr. James Ault serving as the technical project officer. Mr. Howard Parkinson was the program coordinator. Mr. J. A. Herickes was the contracting officer for the Bureau of Mines.

ACKNOWLEDGEMENT

The authors would like to acknowledge the cooperation of the National Mine Service Company personnel, in particular Mr. Don Freed, who cooperated fully with the authors and furnished much needed information about the Automatic Extraction System. The technical guidance supplied by Howard Parkinson was also invaluable in the completion of this report.

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ABSTRACT

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The report covers three phases:

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The investigation determines that the automation of a continuous mining section will improve the health and safety of the miner, increase productivity and decrease mining costs, result in a more attractive and desirable working environment, and result in a greater rate of return on capital investment.

Chapter 1
INTRODUCTION

Scope of Work

The objective of this study is to analyze safety and production aspects of automated underground coal mining through the engineering analysis of an automated continuous mining section. The divisions of the study are:

Phase I	Assessment of the Impact of the Automation Technology on Mining Health and Safety.
Phase II	Estimation of the Cost-effectiveness and Productivity of Automation.
Phase III	Prediction of the Psychological and Organizational Impacts of Automated Mining.

The true measure of the value of innovation or improvement, such as automation in mining, is the extent to which it permits a mine to expand and approach its "theoretically possible" capacity in a safe, economical, and environmentally desirable working arrangement.

State of the Art

There have been a limited number of attempts to achieve automated or remote control of major functions in mining operations over the years. These are documented in the bibliography references presented at the end of this report, and include the much publicized, but presently inoperative, Joy "Push-button Miner" and the presently operating 15-mile one-way surface rail coal transportation system in the Muskingum Mining complex of the American Electric Power Company.

Other operations of less magnitude include the use of remote sensing and controlling devices in coal preparation plants, mine ventilation and atmospheric environment monitoring systems, fire detection equipment and coal conveying systems. At least one major coal equipment manufacturer is known to have developed a sequential cutting cycle for a continuous miner that did not find successful commercial application. In recent years the development by nearly all major mining equipment manufacturers of control consoles for remotely operating continuous miners had been well received by the mining industry, particularly in low vein and retreat mining circumstances. The development of means for communicating and processing large volumes of data from underground sources appears to be achieving success more readily than the science of monitoring and auditing mobile machinery and mining systems functions. However, substantial gains are being made in this area. Reportedly it is possible to utilize a video screen and computer console to monitor the fixed electrical machinery of a mine and a wide range of environmental conditions underground from a central location. The unit utilizes a single visual display unit and depicts the equipment status information in the form of a "mimic" diagram. Voice-communication facilities are provided throughout the system. The arrangement consisting of several hundred monitoring stations can control virtually any electrically driven stationary equipment, such as conveyors, pumps, fans, or crushers; perform environmental monitoring, and reportedly troubleshoot breakdown through computer analysis. Computer printouts of delays with reasons can be made available. The operational reliability or functional desirability of the specific system is not known to the authors.

The major research effort supported by the U.S. Bureau of Mines to develop a compatible group of underground mining equipment suitable for automated and remote-controlled operation has been previously documented and will not be repeated here. The summary and conclusions regarding these current research efforts are appended at the back of this report (Appendix C).

Mining Extraction Concepts

This study selects the Automated Extraction System type machine (AES) currently being constructed by the National Mine Service Company (see Appendix B for specifications) for a U.S. Bureau of Mines research contract as the type of extraction concept to be projected into the fully automated and remotely controlled production mode of operation for straight-ahead entry mining. It is presumed that turns, such as crosscuts, and place changes encountered in the normal mining sequence will require manual assistance and will be performed concurrent with the service functions.

It is recognized that other equipment manufacturers are currently performing various levels of research and design on similar types of extraction systems. The National Mine Service Company prototype machine is currently undergoing above-ground tests and is more advanced in its development for potential production evaluation.

The ancillary mining services will also be mechanized and automated to the extent considered economically feasible, commensurate

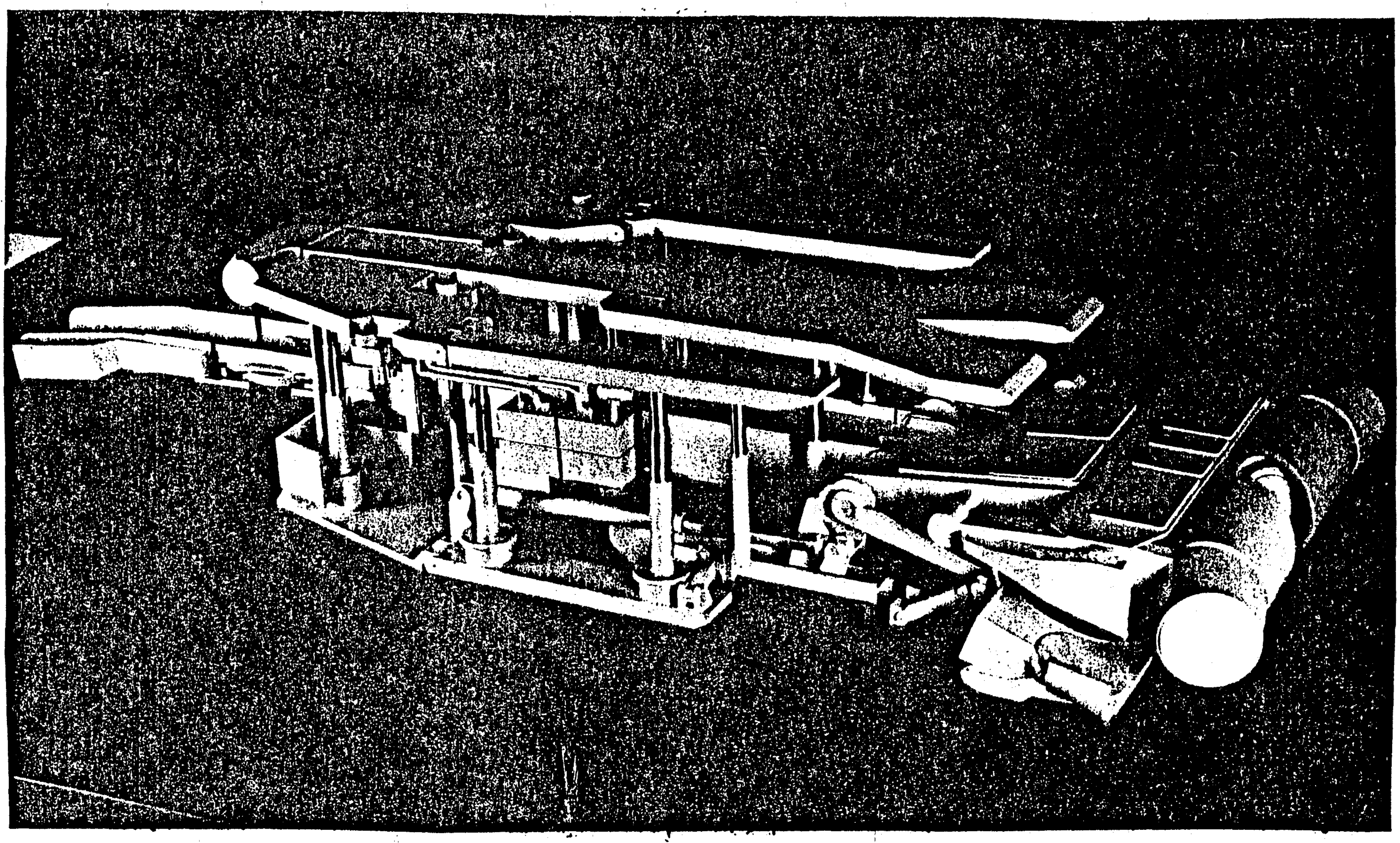

Figure 1-1. Model of the Automatic Extraction Machine (AES).

with the nature of the individual operation. These ancillary mining services include ventilation, power, moving, cleanup, rock dusting, maintenance, mine examination, monitoring, supplying fresh water, and handling drainage water.

Four stages of progressive and improved mechanization, automation, monitoring, and remote control mining section operation are compared to the present level or "Present Stage" of mechanization. These stages may be described as follows:

Stage I - The AES machine functions of cutting-loading, roof support, ventilation, and dust control are individually operator performed. Face haulage is by shuttle cars. Ancillary services are the same as present, and are substantially manually performed with limited machinery application.

Stage II - The AES machine functions of cutting, loading, roof support, ventilation, and dust control are activated by a single operator for automatic performance. Face haulage is by bridge conveyor. Ancillary services are manually performed with more equipment application.

Stage III - The AES machine, the face haulage bridge conveyors, and a limited amount of the ancillary services are system integrated for concurrent operation of their respective functions. Operators would not be required to activate individual machines during straight-ahead mining, but will have override capability if adjustments are required. The machine operator's role becomes one of technical serviceman to inspect the machine performance, provide necessary guidance information and assist in machine service or repairs when the system is inoperative. Those ancillary services not suited to system integration will be planned for service and maintenance periods. Monitoring systems are added.

Stage IV - A remote-control mode is applied to the previous operation. The two major components of the working shift in Stage IV are:

Production time-Personnel absent from the immediate face.

Service time-Personnel present in the immediate face primarily for planned or emergency service, maintenance, turning crosscuts and place changing.

The section remote control station location will be a function of monitoring capabilities, but is intended to remove all personnel from the immediate face area. The technical servicemen will observe monitoring, and when necessary, override programmed automatic operation from a remote position during the production mode of operation. A planned service and preventative maintenance period will be scheduled in the working shift. Emergency service or maintenance may require personnel in addition to the regular shift crew. Scheduling of machine turns and place changes will be indicated by continuous monitoring of applicable parameters. Although access would be limited, any personnel entering the production area during production operating periods would possess override controls and/or have constant communication capabilities with remote operators. The extent that manual-operator assistance will be required in turning crosscuts and changing places is problematic, but his presence in the machine area for visual observation and minor position adjustments is projected.

Monitoring and Control Stations

Two types of monitoring and control stations are projected.

Section Remote Console. All data relevant only to the monitoring, control and operation of section equipment will be channeled to the computerized section remote console. This environmentally protected apparatus will correlate and integrate the information received from the various monitoring stations on the section including:

1. equipment location,
2. equipment condition,
3. equipment operational audit,
4. roof condition,
5. mine environment,
6. electrical system, and
7. fresh and drainage water monitoring.

Mine Remote Console. All data pertinent to the safety and efficiency of the total mine system will be channeled to a mine remote console computer located away from the section and probably outside of the mine.

Scope and Objectives

This study investigates the levels of mechanization, automation, monitoring and remote control which may feasibly be applied to the various job functions in mining, based on health and safety, economic and humanistic considerations. Judgements are applied on the amounts of system integration and remote control which will have the greatest impact on safety and productivity.

The study attempts to review concepts that will assist the future planning of mining systems, equipment, training and research programs. It is recognized that technology break-throughs, such as hydraulic transportation, may alter the desired equipment combinations; however, the concept of additional mechanization, system integration, and monitoring remains valid.

This study investigates manpower requirements for a hypothetical mine, utilizing only automatic extraction type (AES) continuous miners in a partial extraction, room and pillar mining system. It is recognized that the most optimum utilization of an AES type machine may be developing panels for some other type of production machine, such as a shield-type long wall, or a shortwall, where accelerated development is of vital importance to the efficient operation of the total mine system.

In the expanding mine concept utilized in this study, the number of operating units (9), and the number of operating unit shifts per day (18), in the hypothetical mine are assumed to remain constant from the "present" mine through Stage IV operation. The total mine production increases with the increase in unit shift tonnage.

The premise of job mechanization, work element automation, condition monitoring, and machine system integration have been logically applied in projecting future unit shift production levels. These same ideas have been applied to predict the changes that will take place in personnel job assignments, and the impact on health and safety.

The individual job functions or work elements involved in coal production and ancillary mining services are examined in their present and proposed mode of operation. Modification or changes in worker assignment with progressive mechanization and automation are identified.

The productivity potential of the various stages from the Present Stage through Stage IV is determined utilizing existing time and motion study data plus application of manufacturers' machine performance rates for future machines, tempered with judgement.

Personnel requirements for the Present Stage through Stage IV levels of automation are developed based on the modification changes in the individual job functions and the logic of personnel changes consistent with the mine size.

The assessment of the impact of automation technology of mining health and safety for the various stages of automation is calculated from a consideration of the amount of time workers are exposed to accidents, the number of workers in a given occupation, the worker location, the introduction and modification of machines, and the utilization of monitoring systems. These factors and the various levels of personnel requirements for the respective stages are investigated for impact, based on the MESA injury statistics classification.

The analysis of the cost effectiveness of automation is examined for each progressive stage of automation compared to the Present Stage. A "profitability index" rate of return after federal income taxes (FIT) is calculated for the Present Stage through Stage IV. Initial and replacement capital, sales income, operating expenses, FIT, and the time distribution of the expenditures and income are considered.

The prediction of the psychological and organizational impacts of automated mining is made based on the experiences of automation in other selected industries. While levels of existing technology are quite different, the problems of machine movement and varying environmental considerations are somewhat similar in aviation and mining. This is in contrast to the fixed assembly-line robots of automobile plants. Therefore, the aviation industry is selected as a model for predicition of the psychological and organizational changes that will take place as mining technology advances from "seat-of-the-pants" mining to "jet-age" automation. Impacts are considered for union workers and management during the critical transition period spanning the technology advances from the present manual mode of operation to the objective automated mode of operation.

The authors would not be so presumptuous as to postulate that the development stages presented in this study are the best or only way to achieve automated mining. Considerable analysis of the various alternatives available at each stage of automation is required before such conclusions can be advanced. However, this study does establish a fairly clear potential of the desirability and feasibility of automated mining operations for workers and mine owners alike.

The human factors phase of the study investigates the extent to which automation will change the nature of the mineworker's job, vary the structure of managment, and change the interrelationship between working groups. It reviews the advantages and disadvantages of how the union worker and management may be affected. It discusses the requirements of a successful transition from manually operated continuous mining to automated remote-control continuous mining including such aspects as human relations, communications, job analysis, training and mine maintenance.

The study speaks to the labor problems of today as projected in future automated mining. It is believed that job definition (analysis), training (communication), and improvements in working environment (physical and humanistic) will be the key to improved mining operations utilizing safer and better machines. Certainly the adversary position between labor, management, and government must be overcome.

Skilled labor has been described as one of the more difficult shortages in coal mining today. It has been variously described as being effected by the "Lordstown Syndrome," after the rebellion in the auto industry over production-line boredom, to the "Farm Boy Syndrome." (79) This school of thought says the boy hoeing potatoes in the hot sun is more concerned about how long he has to stay out there than he is about getting the potatoes hoed. So it is identified for mining; the old-time hands who cared only about "rock in the box" are retiring. The young bloods who now make up the work force are a different breed, questioning, demanding, and wanting to relate in a different way. Their concern for life style, working status, and adequate training to perform a safe and meaningful job is as important as their concern for pay. However, the concepts of training and the new environment developed in automated continuous mining can turn this into an asset rather than a liability.

Various engineering analyses have been performed as part of this study. They include investigations of the production potential of the automated extraction system utilizing time study and machine performance data in a computer program; recommendations and summary of the Automated Remote Controlled Continuous Mining (ARCCM) Program Conference and the preparation of a proceedings; and detail analysis of the ARCCM program roof-bolting requirements. Results of these specific engineering requests are appended in the back of this report. They have helped the authors considerably in developing the perspective and some of the concepts embodied in the report.

The study develops cost information for both raw coal and clean coal-production levels. Research and development cost of the additional automation equipment and monitoring systems required in the respective stages is not included in the estimated purchase prices. It is presumed that research and development will have been accomplished under government sponsorships. All monies are in 1976 constant dollars and the impact of future inflation is assumed to be equal for income and expenditures.

Chapter 2
MINE DESCRIPTION

Concept

The study is a conceptual projection of mechanization and automation stages of various mining operations with an engineering analysis of the effects on health and safety, economics, and human factors in an assumed mine. The case study situation designated "Present Stage", at a hypothetical location, is typical of partial mining practices in the northern West Virginia panhandle area.

The tremendous variations in relative excavation capacity for continuous mining between "average capacity," "best-to-date," and "theoretically possible" is a documented fact. (21) Operating coal mines have "built-in" surge capacity in many of the ancillary service facilities such as haulage, electrical, and ventilation to accommodate the instantaneous peak productions that occasionally occur at the "best-to-date" and approaching "theoretically possible" levels. This leads to the premise that a mining layout can accommodate a certain number of production sections which can operate either above or below "average capacity" with only modest changes in capital expenditure levels. Therefore the true measure of the innovation or improvement value, such as automation in mining, is the extent to which it permits a mine to expand and approach its "theoretically possible" capacity. Such a procedure is adopted for this study.

A base-level mine consisting of nine operating sections is established, and designated "Present Stage." Utilizing existing time-and-motion study data plus application of manufacturers' projected machine performance rates for future machines, the section-production rates for Stage I through Stage IV levels of mechanization and automation are calculated. In this process the nine operating sections are moving from the present "average capacity" toward the "theoretically possible" capacity, and the base mine, with its built-in surge capacity, is being utilized more efficiently. In the judgement of the authors, the more correct relative measure of profitability is total mine usage rather than the alternative possibility of trying to maintain a constant annual mine tonnage. Due to variations in tons per unit shift from the Present Stage through Stage IV, it would have been difficult, if not impossible, to realistically maintain exactly the same mine output in all stages without impractical assumptions such as working fractions of shifts.

The study provides a high level of machine maintenance and service time in all the stages. The nine operating sections are only worked two out of three available shifts. In addition a spare or tenth section is provided for moving and setup. An eleventh section is provided for the rotation of all units through a comprehensive rebuilding program.

Mining is projected in the Pittsburgh Seam. The main roof is the Redstone Limestone overlying a layer of siltstone. Underneath the siltstone is a roof coal about two feet in thickness that is generally left in place as the immediate main roof to prevent the siltstone from weathering. The average mining zone consists of nine inches of draw shale beneath the roof coal, and about 5'-9" of main coal seam, for a total mining height of 6'-6". The seam has a fireclay bottom.

The initial capital investments contain modest increases from the Present Stage to Stage IV to recognize the annual increase in mine tonnages. Reserve dedications have to be increased for the respective stages because a 25-year study production life is utilized in all cases.

The major groupings of capital items are:

1. mine plant site acquisition and site preparation;
2. surface buildings and facilities including water, sewage, electrical, and mine-road system;
3. surface mobile equipment including supply handling, road maintenance, and refuse area equipment;
4. preparation plant complete with raw-coal section and raw-coal storage, cleaning plant and equipment, clean-coal storage, thickeners, and refuse disposal system;
5. development openings including a 2000-foot slope (complete with slope belt conveyor, supply hoist, underground storage bin), a 500-foot portal shaft with elevator, and a 500-foot ventilation shaft;
6. general underground equipment including conveyors, electrics, supply track, ventilation, fresh water, drainage water, communications, central monitoring, and safety equipment;
7. general auxiliary equipment including construction, man trip, and supply vehicles;
8. production section equipment including section monitoring systems;
9. miscellaneous costs including overhead during construction, on-site engineering, and mine development excess cost over break-even point.

Initial capital provided is sufficient to bring the mine up to full production. In addition, a mine extension allowance is provided to extend the mine facilities to the limits of the assigned reserves. Replacement capital is also provided.

The projected mining dimensions are:

1. Eight entries in each submain,
2. Four entries in each panel,
3. 2,500-foot panel length,
4. 60-foot entry centers,
5. 88-foot cross cut centers, and
6. 16-foot mined entry width.

The Stage I through Stage IV mining dimensions are proposed to follow the projected Present Stage mine dimensions and percentages of coal recovery.

A typical panel development cut sequence is presented in Figure 2-1. A possible alternate development cut sequence is shown in Figure 2-2. The general panel layout is indicated in Figure 2-3.

Twenty job functions are identified in the coal production process or ancilliary services. These are discussed in detail in the "Job Function Description" following this chapter.

Table 2-1 shows the present and projected equipment, including monitoring systems for the various job functions. It is recognized that some miscellaneous jobs are of such minimal labor requirements or so structured that large capital expenditures to mechanize and automate may be unjustifiable.

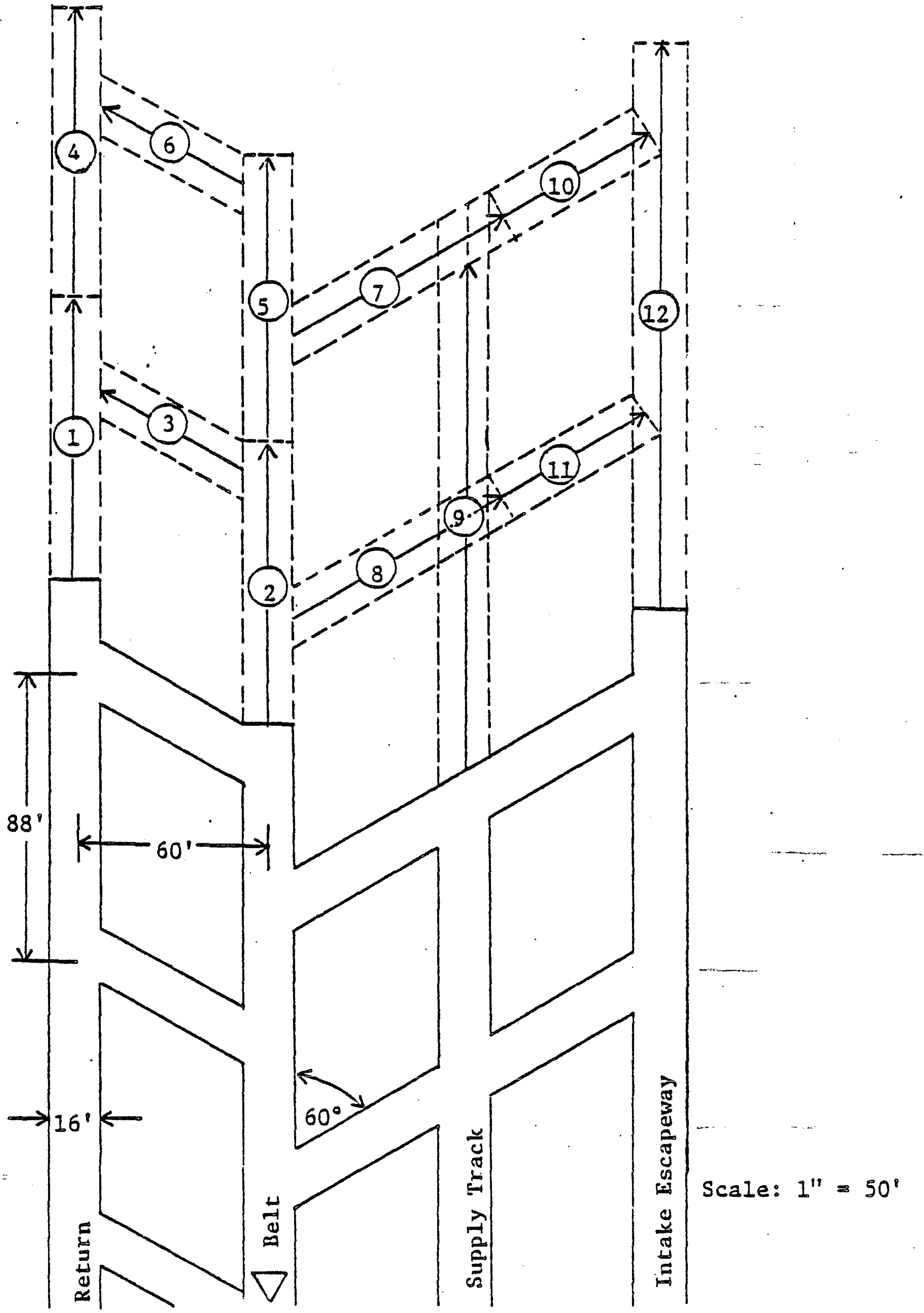

Figure 2-1. Panel Development Cut Sequence.

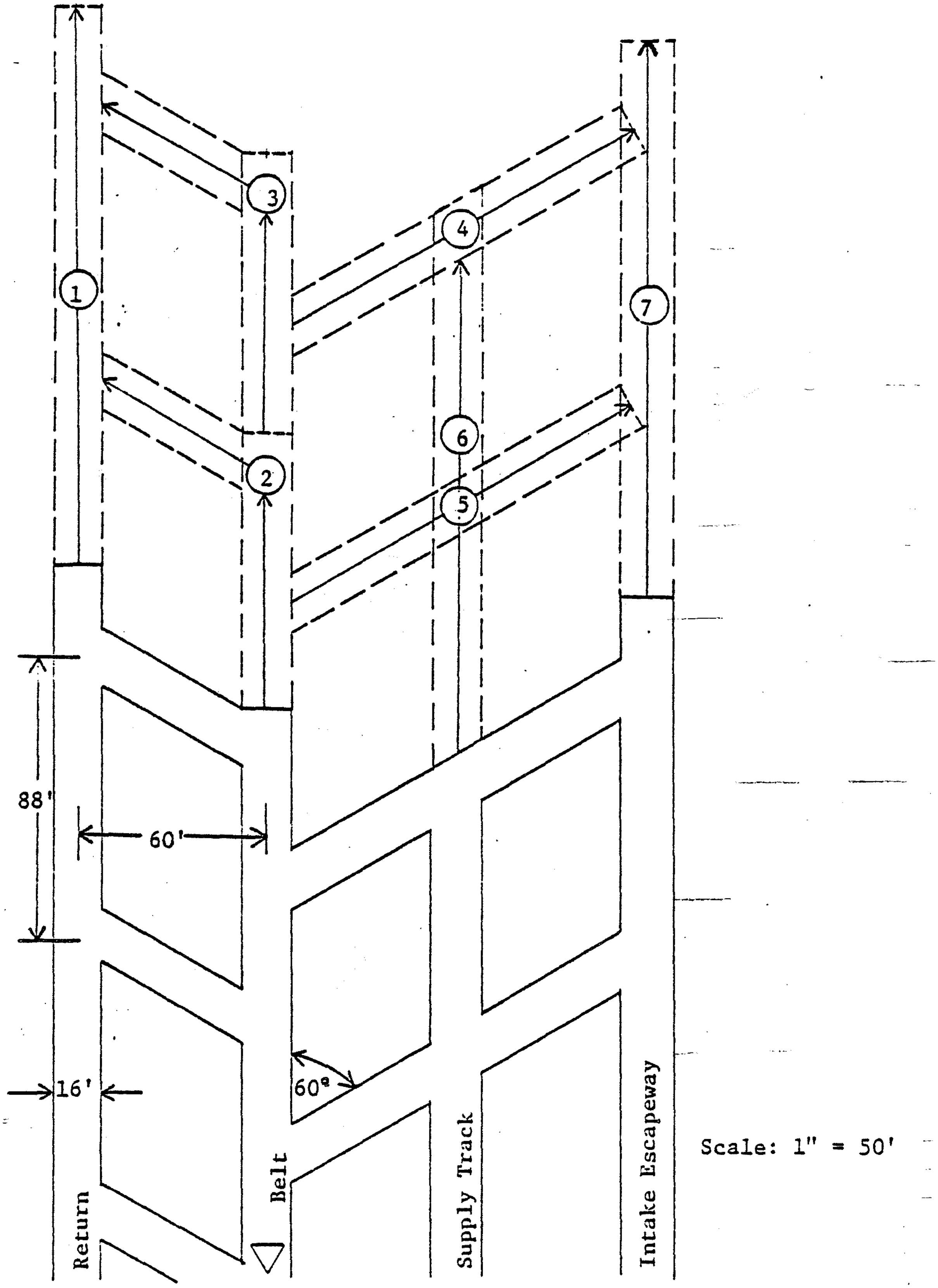

Figure 2-2. Alternate Panel Development Cut Sequence.

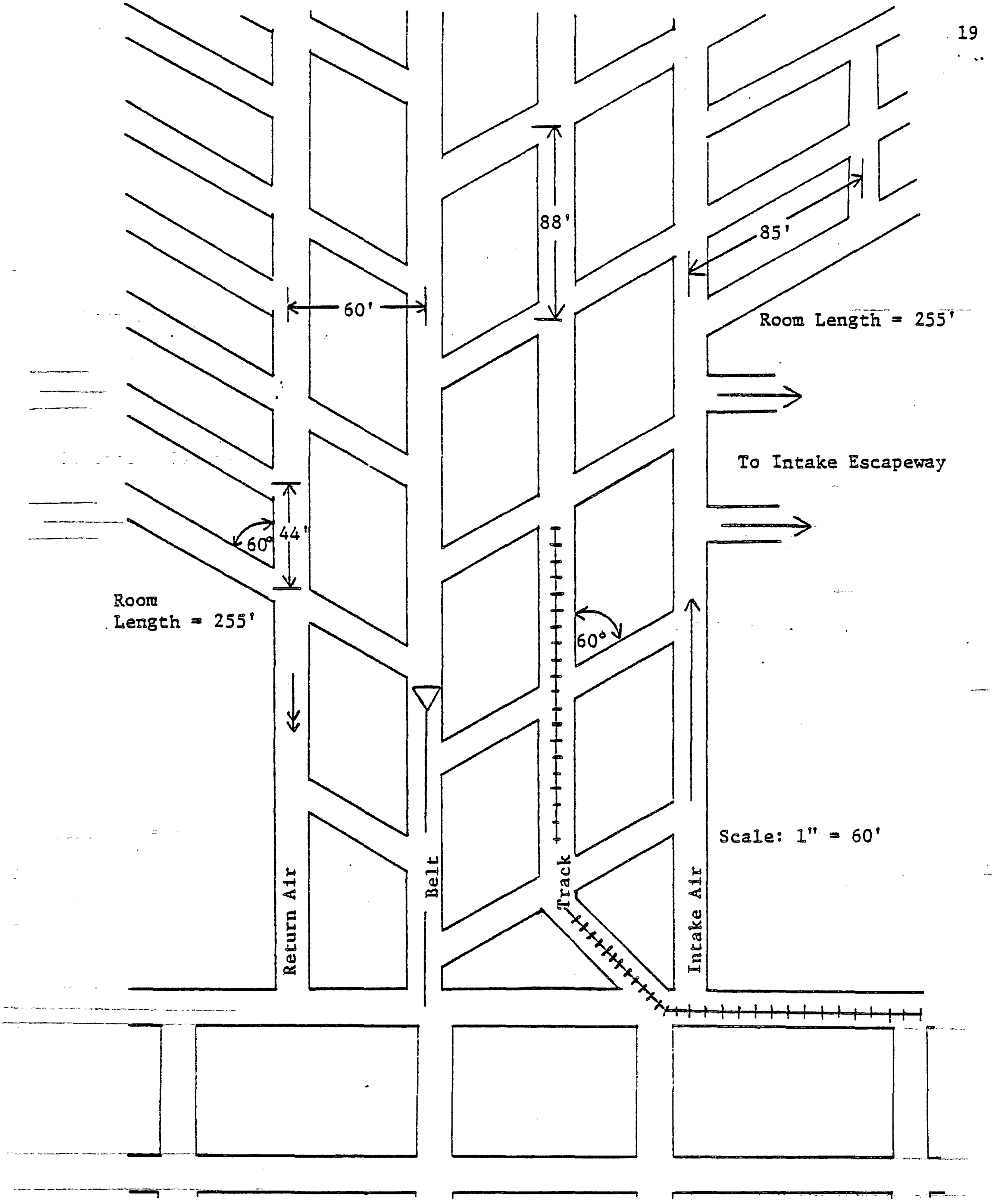

Figure 2-3. General Panel Layout.

Table 2-1. Present and Proposed Section Equipment

Item	Present	Stage I	Stage II	Stage III	Stage IV
1. Cutting and Loading	1. Continuous Miner 1. Pickup Loader	1. AES Machine	1. AES Machine	1. AES Machine 1. Face Equipment Integration System	1. AES Machine 1. Face Equipment Integration System
2. Face Haulage	2. Shuttle Cars	2. Shuttle Cars	3. Mobile Bridge Carriers 4. Mobile bridges Shuttle Cars	3. Mobile Bridge Carriers 4. Mobile bridges Shuttle Cars	3. Mobile Bridge Carriers 4. Mobile bridges Shuttle Cars
3. Section Roof Control	2. Roof Bolters on Miner. 1. "Touchup" Bolter	4. Roof Bolters on AES 1. "Touchup" Bolter	4. Roof Bolters on AES 1. "Touchup" Bolter	4. Roof Bolters on AES 1. "Touchup" Bolter 1. Roof Condition Monitoring System	4. Roof Bolters on AES 1. "Touchup" Bolter 1. Roof Condition Monitoring System
4. Section Face Ventilation Advance and Retreat	1. Face Fan	2. Fans on AES	2. Fans on AES 1. Mine Environment Monitoring System	2. Fans on AES 1. Mine Environment Monitoring System	2. Fans on AES 1. Mine Environment Monitoring System
5. Section Ventilation Outby the Face	---------	------------	1. Stopping Emplacer	1. Stopping Emplacer	1. Stopping Emplacer
6. Trailing Power Cable Handling	---------	------------	------------	---------------	---------------
7. Moving Section Power Center	1. Power Center	1. Power Center	1. Power Center	1. Power Center 1. Electrical Monitoring System	1. Power Center 1. Electrical Monitoring System

Table 2-1. Present and Proposed Section Equipment (Continued)

Item	Present	Stage I	Stage II	Stage III	Stage IV
8. Section Belt Move Up	1. Section Belt 1. Feeder-Breaker	1. Section Belt 1. Feeder-Breaker	1. Section Belt 1. Belt Moving Machine	1. Section Belt 1. Belt Moving Machine	1. Section Belt 1. Belt Moving Machine
9. Section Belt Clean up	-----------	----------	1. Vacuum System	1. Vacuum System 1. Float Dust Samples	1. Vacuum System 1. Float Dust Samples
10. Section Rock Dusting	1. Rock Dusting Machine 2. Trickle Dusters	1. Rock Dusting 2. Trickle Dusters	1. Piped Rock Dust System 2. Trickle Dusters	1. Piped Rock Dust System 2. Trickle Dusters	1. Piped Rock Dust System 2. Trickle Dusters
11. Roof Testing	-----------	----------	-------------		
12. Methane Measurement	-----------	----------	(See Mine Environment Monitoring system) Item 4	(See Mine Environment Monitoring system) Item 4	(See Mine Environment Monitoring System) Item 4
13. Mine Examiner, Fireboss or Foreman Inspection	----------	----------	------------	(See Mine Environment Monitoring System) Item 4	(See Mine Environment Monitoring System Item 4
14. Section Supply Handling	----------	1. Battery Scoop 1 Lot Rubber Rail Cars	1. Battery Scoop 1. Lot Rubber Rail Cars 1. Supply Vehicle	1. Battery Scoop 1. Lot Rubber Rail Cars 1. Supply Vehicle	1. Battery Scoop 1. Lot Rubber Rail Cars 1. Supply Vehicle
15. Fresh Water Supply and Drainage Water	----------	---------	----------	1. Water Monitoring System	1. Water Monitoring System

Table 2-1. Present and Proposed Section Equipment (Continued)

Item	Present	Stage I	Stage II	Stage III	Stage IV
16. Service Equipment	----------	----------	----------	1. Equipment Status Monitoring System	1. Equipment Status Monitoring System
17. Maintenance	----------	----------	1. Section Parts Vehicle	1. Section Parts Vehicle (See Equipment Condition Monitoring - Item 16)	1. Section Parts Vehicle (See Equipment Condition Monitoring - Item 16)
18. Monitoring Systems	----------	----------	----------	1. Section Monitoring Console 1. Mine Monitoring Console	1. Section Monitoring Console 1. Mine Monitoring Console
19. Spillage and Roadway Cleanup (Other than Belts)	----------	(See Scoop - Item 14)	(See Scoop - Item 14)	(See Scoop - Item 14)	(See Scoop - Item 14)
20. Miscellaneous	----------	----------	----------	----------	----------

Table 2-2 presents a production summary for the nine operating units. The annual mine production expands with the improvements in unit shift production due to increased mechanization and automation as the shift production increases toward the "theoretically possible."

The immediate face equipment summary for the various stages is shown in Table 2-3, and a summary of the monitoring systems is shown in Table 2-4. The personnel applied on each of the 18 unit face crews is given in Table 2-5. In Table 2-5, Stage IV, the equipment is being operated remotely by technical service-maintenance personnel with no equipment operators routinely on the section. Regular service and maintenance will be scheduled in conjunction with general mine crews. Unexpected breakdowns or operating problems will be attended by the technical service-maintenance personnel moving out of the remote control station into the face area, plus general mine specialists as required. Technical service personnel will be skilled in machine trouble shooting and will utilize skilled maintenance repairmen in special situations.

The need for service and maintenance on the section, in addition to that regularly scheduled, will be evident from feedback data provided by the monitoring systems. On the section, monitoring systems for face equipment status, roof condition, mine environment (ventilation, dust, gases, etc.), electrical condition status and condition, and water-system status and condition provide information that will be fed into the computerized supervisory control station during Stages III and IV.

Table 2-2. Production Summary

	Present	Stage I	Stage II	Stage III	Stage IV
Production per Unit Shift					
Raw tons	310	380	560	800	920
Clean tons	250	310	460	660	750
No. Unit Shifts per day	18	18	18	18	18
Mine Tons per day					
Raw tons	5,580	6,840	10,080	14,400	16,560
Clean tons	4,500	5,580	8,280	11,880	13,500
Operating Days per year	220	220	220	220	220
Total Tons per year					
Raw tons (000)	1,228	1,505	2,218	3,168	3,643
Clean tons (000)	990	1,227	1,822	2,614	2,970

Table 2-3. Face Equipment Summary

Present	Stage I	Stage II	Stage III	Stage IV
1-Continuous Miner	1-AES Machine	1-AES Machine	1-AES Machine	1-AES Machine
1-Pickup Loader	---	---	---	---
---	---	3-Mobile Bridge Carriers	3-Mobile Bridge Carriers	3-Mobile Bridge Carriers
---	---	4-Mobile Bridges	4-Mobile Bridges	4-Mobile Bridges
2-Shuttle Cars	2-Shuttle Cars	1-Shuttle Car*	1-Shuttle Car*	1-Shuttle Car*
2-Roof Bolters on miner	4-Roof Bolters on AES	4-Roof Bolters on AES	4-Roof Bolters on AES	4-Roof Bolters on AES
1-"Touch-up Bolter"	1-"Touch-up Bolter"	1-"Touch-up Bolter"	1-"Touch-up Bolter"	1-Touch-up Bolter"
1-Face Fan	2-Fans on AES	2-Fans on AES	2-Fans on AES	2-Fans on AES
			1-Face Equipment Supervisory Control & Monitoring System	1-Face Equipment Supervisory Control & Monitoring System

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* Utilized for haulage at locations inaccessible to the bridge conveyor.

Table 2-4. Monitoring Systems Summary

Present	Stage I	Stage II	Stage III	Stage IV
			1-Roof Condition	1-Roof Condition
			1-Mine Environment	1-Mine Environment
			1-Electrical	1-Electrical
			1-Water	1-Water
			1-Equipment Status	1-Equipment Status

Table 2-5. Face Crew Summary

Present	Stage I	Stage II	Stage III	Stage IV
1-Miner Oper.	1-AES Oper.(cut.)	1-AES Oper.(cut.)	1-Tech.Serv.(cut.)	1-Tech.Serv.(cut.)
1-Loader Oper.				
2-S.C.Oper.	2-S.C.Oper.	3-Mobile B.Oper.	1-Tech.Serv.(haul.)	1-Tech.Serv.(haul.)
2-Roof Bolt.Oper.	2-AES Oper.(bolt.)	2-AES Oper.(bolt.)	1-Tech.Serv.(roof)	1-Tech.Serv.(roof)
1-Vent.	1-Vent.	1-Vent.	1-Vent. Tech.	1-Vent. Tech.
1-Utility	1-Utility	1-Utility	1-Utility Tech.	1-Utility Tech.
1-Mechanic	1-Mechanic	1-Mechanic	1-Mechanic	------
-----	-----	-----	1-Tech.Serv.(monitor.)	1-Tech.Serv.(monitor.)
9 Total	8 Total	9 Total	7 Total	6 Total

The Present Stage mining section may seem far removed from the cockpit of an airplane, or even the control room of a modern preparation plant. However, as machine and environmental functions are progressively monitored it will become desirable to establish a suitable working station for this type of information and control operation. This station will become the focal point for section control and should be designed to efficiently accomplish the job. The arrangement should permit interchange of information between those persons reviewing machine functions and those monitoring environmental functions, without conflict of effort. This station will be management's field headquarters. Utilizing modern communication, all persons working in or entering the section will keep in touch with the section supervisor.

Section information will be processed at either the section station console or at the central mine station console. The volume of data being handled will require computer processing to be presented in a relevant and timely fashion. Considerable work will be required during the transition period from Present Stage - Stage IV to efficiently develop documentation and report procedures.

Chapter 3
JOB FUNCTION DESCRIPTION

Introduction

Twenty job functions involved in coal production and the advancement or retreat of ancilliary mining production services are identified and discussed in this chapter in a comparison of the Present Stage operation versus the proposed manner of operation in Stages I, II, III, and IV. The job functions described are:

1. cutting and loading,
2. face haulage,
3. section roof control,
4. section face ventilation - advance and retreat,
5. section ventilation - outby the face,
6. electrical trailing cable handling,
7. moving section power center,
8. section belt advancement,
9. section belt cleaning,
10. section rock dusting,
11. roof testing,
12. methane measurement,
13. mine examiner, fireboss or foreman inspections,
14. section supply handling,
15. fresh water supply and drainage water,
16. equipment service,
17. maintenance,
18. monitoring systems,
19. spillage and roadway cleanup (other than belts), and
20. miscellaneous.

These job functions are presently performed at varying levels of manpower ranging from almost entirely manual labor, such as building a ventilation stopping, to cutting and loading operations that are mechanized and can presently be operated by available semiremote control equipment. This section of the report presents the advancements that are proposed in the individual job functions at the various stages to achieve a totally integrated automatic and remotely operated mining production section. Several operations, such as turning crosscuts and changing places, which were considered to require manual assistance are to be performed during the scheduled service periods.

There are operations in these twenty job functions, such as mine supply handling, that could be significantly improved through research and development; however, the profitability of automating them is questionable. Again the aviation industry has many similarities in the mass movement of baggage and supplies. That industry has fewer supply handling problems than mining, but the codification and grouping of material and supplies for quick movement in supply trains and supplies packaged for easy use would be beneficial in mining.

It is beyond the scope of this study to determine the desirable balance between preventative and repair maintenance labor, and the specific levels of training necessary to achieve high-quality reliable maintenance. Nevertheless, this is a severe problem even at today's level of mechanization, and will become increasingly critical with progressive stages of automation.

It is vitally important that long-range problems of this type be fully identified and resolved. Job functions should be clearly established and qualifications and responsibilities defined so that the transition period from the Present Stage to Stage IV automation may be accomplished with minimum problems. In addition, it is important that the analysis of job functions correctly relate to the transmission and presentation of data at the section monitoring console versus the central mine console.

The progressive mine expansion from Present Stage to Stage IV affords many opportunities to improve the efficient deployment of mine management if adequate job definition and training is performed. The authors' concepts are discussed in more detail in the Psychological and Organizational Impact chapter of the report.

Job Description

1. Cutting and Loading

Present - The present operating continuous mining machine selected to compare with the proposed automatic extraction system (AES) is a full-face machine with two on-board roof bolting units that allow up to 88 feet advance before place changing. A loading machine follows the continuous miner to reduce shuttle car changeout delays and improve cleanup. However, the miner must stop every four feet to install two roof bolts. The present loader - shuttle car haulage system cycle is slower than the miner cycle causing the miner to shut down whenever a pile of coal builds up behind the mining machine.

Proposed - The proposed AES cutting and loading operation for Stages I-IV follows:

Stage I - The AES machine currently being constructed by the National Mine Service Company for a USBM research contract is the machine type proposed for Stage I. Its specifications are presented in Appendix B. Improved versions of the same type machine are planned for Stages II, III, and IV. The projected average cutting rate is four tons per minute, although the machine can mine at an 8 ton per minute rate. Four roof bolting units can be operated while the machine is cutting coal, allowing long advances that will be limited only by ventilation requirements. The AES will have an operator-activated automatic sump-shear cycle. The same mining plan as the Present Stage operation is contemplated. A loading machine is not projected to be used behind the AES machine.

Stage II - The AES machine will have automatic sump-shear and advance cycle. The cycle is operator-activated and will continue cutting straight forward until interrupted by an operator command or an intermachine control signal specifying an abnormal condition such as "stop for roof bolting catchup." Operator guidance and sump-shear cycle control is required in turning crosscuts. Tramming for place changes also requires operator guidance and control.

Stage III - The AES machine will be system integrated and automatically activated. System integration means the AES control activation will interrelate with the condition of other machines and the section monitoring systems. Manning requirements are one machine observer for straight line advance. Operator guidance and sump-shear cycle control is required in turning crosscuts and tramming. During this stage a data acquisition and logic control circuit is required for supplying data from other section systems. If the other section systems are properly positioned and functioning and the environment is safe, the AES can be activated. The AES will receive signals from other section components such as haulage, roof support, ventilation, etc., and will continue operation only if the other systems are functioning properly. Start-up and shut-down alarms will be required in addition to machine condition and face environmental monitoring systems. Cutting and loading will take place during a prescribed extended straight line advance period. The period duration (described in Chapter 4) will depend on the distance between crosscuts and the machine service requirements.

Stage IV - The AES machine will be controlled from a remote, computerized console with a possible visual display from television cameras or interactive computer graphics. Manning requirements will be one technical serviceman-extraction. As in previous stages, automated, remote-controlled operation will be during straight-line advance only. Crosscuts and tramming for place changes will require visual observation for guidance. Machine data along with all other section data will be transmitted to the section console station. The station should be located in a permanent, environmentally controlled housing probably near the mining panel entrance. When the machine is remotely operated personnel will not be routinely allowed into the operating area. As in Stage III, the periods prescribed for cutting and loading versus service and turning are outlined in Chapter 4.

2. Face Haulage.

Present - The current haulage mechanism, from the face to section belt conveyor, selected for this comparison study is the shuttle car. Two shuttle cars require two operators per section. The elemental times for the car's cycle are derived from 278 feet per minute tram rate, 1.5 minutes in loading, and 1.5 minutes in dumping. However, cable handling and maintenance delays must also be accommodated. The shuttle car operator's primary tasks are guiding and controlling the vehicle along the tram route, positioning behind the miner, advancing the shuttle car conveyor during loading, positioning the shuttle car at the belt tail piece, and controlling the dumping rate to minimize dumping time but still prevent coal spillage.

Proposed - The proposed face haulage for Stages I-IV follows:

Stage I - Shuttle car haulage service similar to the present operation is proposed.

Stage II - The long, continuous advances of the AES machine indicate mobile conveyor systems may be used with more success than the more mobile, but intermittent shuttle car. A main disadvantage to the mobile bridge carrier is the necessity of a wide space for positioning the conveyor to extend around corners. Installation of an additional mobile bridge unit will allow more flexibility at the corners; however, three bridge operators instead of two will be required. Three mobile bridge carriers and four bridges will be used in this study instead of the usual two carrier, three bridge system. The basic tasks of the mobile bridge carrier operators are activation and steering the units. In this stage of programmed machine operation, the mobile conveyor will not require the operator to manually control the machine. The operator will initiate a command to turn right or left a specified number of degrees, continue straight for a specific distance, stop or start. The machine will be programmed to carry out the action. As a result the operator will activate or signal to the machine which operating mode is appropriate and the extent of movement.

Stage III - At this point the haulage systems do not require operator activation since they are system integrated. Signals between machines and monitoring systems will dictate the operating mode, extent of movement, and speed of the haulage system. A haulage observer stationed at an appropriate location will insure proper operation, make some maintenance and service checks, and take over operation (over-ride programmed operation) if necessary. The haulage system will require operator activation and control during place changing, cleaning up, and crosscut turning. The haulage system must signal the AES that it is ready to receive coal before the AES will be allowed to cut and load.

Stage IV - The haulage system will be controlled remotely and must be able to signal its position, operating mode, and mechanical condition to a remote operator. A continuous haulage system will lend itself to remote control guidance easier than shuttle cars because interconnection of units simplifies specific location at all times. No matter what haulage device is used, it must be able to locate the discharge boom of the miner and dock under it (minimizing spillage), transport the coal to the dumping point, and locate the dumping point to discharge with a minimum of coal spillage. If this can be accomplished, roadway cleanup can be kept at a minimum. Manpower requirements are a technical serviceman-haulage.

3. Section Roof Control.

Present - The present continuous mining machine being compared to the AES has a roof drill mounted on each side of the miner. Two bolts are placed simultaneously in a plank across the entry. A separate roof bolter enters a newly mined place after the machine has changed to another place and installs center bolts in the plank. The "touch-up" or "center" bolter can also bolt breakthroughs allowing the miner to change placed immediately after completing a crosscut breakthrough. Two bolter operators work on the mining machine installing six-foot mechanical, shell-anchored bolts. Utility men usually operate the center bolter, which is only worked part-time during the shift, after each place change.

Proposed - The proposed section roof control operation for Stages I-IV follows:

Stage I - The AES will install four bolts concurrently in a row across the entry within 19 feet of the face. Two extraction machine operators-bolting on the AES machine will be required to install the four bolts across the entry during the mining cycle. A longitudinal roof and floor beam support system will provide temporary roof support to within seven feet of the face. Resin type bolts, four feet in length, are projected to be utilized without planks. A "touch-up" bolter will be required to install additional bolts in areas of bad top, dead-end completions, and to bolt crosscut breakthrough completions.

The utility men will install temporary roof support (hydraulic jacks) in dead-end and crosscut breakthrough completions before they are bolted. The roof at the end of each completed cut will be sloped inby from the roof to the floor to minimize the area of unsupported roof. Utility men will also be required to supply the AES with roof bolting materials, and unscheduled auxiliary supports will be set by utility men where necessary. In areas of extremely bad roof, the AES should have the capability of installing roof mats or planks. During place changes the bolter operators will replenish supplies and assist in cable and ventilation tubing handling.

Stage II - The roof-drilling and bolt-installation cycles will be automated so all the AES operators have to do is activate the machines and handle bolting materials. Otherwise Stage II is similar to Stage I.

Stage III - The automated bolting units will be system-integrated so they will activate automatically when a signal from the section control console indicates that the proper distance from the last row of bolts is reached. The bolting system must signal the AES through the section control console that it is finished and the machine may advance. A method of signaling when more bolting supplies are needed is also necessary. Additional auxiliary roof supports beyond the programmed pattern will be installed manually during service periods. Spot bolting of bad roof that develops behind the face will be performed by an operator-guided, automated-cycle bolter. A roof condition monitoring system will be necessary for system integration during this stage.

Stage IV - The entire AES machine including the roof bolting units is remote controlled during straight ahead advances in this stage. On-board machine operator control, by the technical serviceman-roof control, is required to turn crosscuts and change places. At the remote control station, the technical serviceman-roof control will have a data display of the roof conditions throughout the section as a result of transmissions from the roof monitoring system. Therefore, anyone entering the section can be forewarned of suspected poor roof conditions. The monitoring system is not intended to replace sight, sound, and other manual roof testing evaluations by workmen entering the area. Nevertheless, it will provide a continuous detection mechanism that can indicate dangerous roof that otherwise may have gone unnoticed by a careless or preoccupied worker. Roof control data computer analysis will be required at the section remote control console because of the more comprehensive section roof condition survey being continuously performed.

4. Section Face Ventilation.

Present - The section with which the AES will be compared utilizes an auxiliary ventilation fan and tubing. The tubing is manually added in sections to maintain it within 10 feet of the face. However, the section of tubing nearest the face has a sliding insert of smaller diameter to facilitate compliance with the 10-foot maximum allowable distance. Brattice is erected for idle places, weekends, or idle-day ventilation as needed. The auxiliary fan is pulled to a new location during each place change. The ventilation tubing is also taken down and moved to a new place when a breakthrough is completed.

Proposed - The proposed section face ventilation advance and retreat operations for Stages I-IV follows:

Stage I - Two auxiliary fans are mounted on the AES machine. The fans pull air through the inner roof support beams and exhausts into a collapsable, flexible tubing that extends to the return air system. Since shuttle cars may damage the tubing by running over, or colliding with it, mobile conveyors are more desirable from a ventilation standpoint.

The ventilation system automatically advances with the machine during straight advance. However, the tubing will have to be moved manually during place changes. The ventilation fan and tubing should have enough capacity to allow advances of at least 90 feet, so the Stage I production capacity of the AES can be realized. Brattice installation is still required for idle places, weekends, idle days, and machine downtimes. The mining plan is designed so that as few dead-end places as possible are left after place changes; however, brattice will be required to ventilate the left or return entry (see Figure 2-1) until break-throughs are completed. Also, two crosscuts turned into the supply track and right or intake entries will have to be bratticed until the supply or intake entry has advanced to the crosscut. Brattice is also required whenever power must be turned off to the machine for lengthy repairs or when the machine must be trammed out of the face area to an intersection to allow room for repairs.

Stage II - The ventilation system is similar to Stage I, except the fan capacity should be increased to permit 180 feet of advance.

Stage III - In order to system integrate the already automatic face-ventilation apparatus with the total mining section, an environmental conditions monitoring system will be required. The monitoring network should measure velocity over the miner; quantity at the face and in the last open crosscut; quantity in the section intakes and returns; methane content in the intake, at the face and in the return; and carbon monoxide in the return. The monitoring system data will be transmitted to the section control console so it can alert mine machinery when ventilation is inadequate. Transmission of data describing section environmental conditions to a general mine ventilation control is also necessary to note excesses or deficiencies in quantity so regulators can be adjusted. Also dangerous conditions noted by the monitors should be transmitted throughout the mine to alert for correction or a withdrawal of people from the mine if necessary.

Stage IV - Remote control of face ventilation is extended to straight-ahead advances only. Crosscuts and place changes will probably require some manual manipulation of the tubing behind the miner. Ventilation monitoring data will be transmitted to the section remote console and the central mine console.

5. Section Ventilation - Outby the Face.

Present - Cinder block or metal stoppings are constructed to divide intake from return air, isolate the belt entry, and provide the prescribed escapeways. Both types are constructed manually with the cinder blocks generally being favored because of less leakage and lower cost. Usually one mason can construct a stopping in a shift.

Proposed - The proposed section ventilation outby the face for Stages I-IV follows:

Stage I - The same as present.

Stage II - A prefab stopping that is easy and fast to erect (utilizing some type of vehicle to transport and erect it) should be developed during this stage. The stopping should be recoverable and have minimal leakage. The prefab stopping is needed in future stages so stoppings can be erected within the time allotted for the service periods.

Stage III - The prefab stoppings will be installed during service periods utilizing the emplacement vehicle developed in Stage II by the stopping emplacer operator.

Stage IV - The same as Stage III, except the need for new stoppings will be communicated to the section supervisor by the remote console data system, the completed emplacement of a new stopping will be transmitted to the section console data bank. Otherwise excessive open breakthroughs will stop the production operation.

6. Electrical Trailing Cable Handling

Present - The continuous miner power cable is hung from the roof on hooks which are installed by the roof bolters in the Present Stage operation. The cable is hung from the load center to the miner. Hanging the cable just behind the miner is important to keep it from being covered by the pile of coal that the pickup loader is removing. Obviously, the cable must also be hung over roadways to prevent damage by the loader and shuttle cars. The miner cable is dropped and then pulled along during a place change to be rehung in the new location. The shuttle car cables are taken up and payed out by a reel on the car and are handled during place changes only if tie-off points have to be moved. The "touch-up" or auxiliary bolting machine cable is also reeled, but it must be supported on hangers to the last open crosscut to be out of the way of the shuttle cars. The pickup loader power cable is handled much the same as the continuous miner cable.

Proposed - The proposed trailing cable handling operation for Stages I-IV follows:

Stage I - No new cable handling practices are expected during this stage, but the pickup loader will not be used, which will eliminate its power cable from the section. The AES and the "touch-up" bolter trailing power cables will be manually handled.

Stage II - The shuttle cars are replaced by the mobile bridge conveyors in this stage. Therefore, both shuttle car power cables will be eliminated. The AES cable can be carried on the mobile conveyor system frame. As a result the only trailing cable that would be manually handled is the one for the "touch-up" bolter.

Stage III - In order to integrate the trailing cables with the mining system, data describing the condition of each power cable must be transmitted to the section console. The cable condition should be monitored throughout the shift by the electrical monitoring system to predict or indicate faults and broken conductors. When such a fault is predicted or indicated the appropriate machine will be shut off and information from the section console should describe what is wrong and where the trouble is located. Some manual handling of power cables is anticipated during place changes and crosscut turning. Also, the "touch-up" bolter cable will be manually handled.

Stage IV - Power cable handling in this stage will be similar to Stage III.

7. Moving the Section Power Center.

Present - Movement of power centers is done by battery scoops or shuttle cars that pull the load center from one location to another. If the load center must be energized during the move to supply power to the pulling vehicle, the requirements of The Code of Federal Regulations, Title 30, Part 75, Paragraph 75.812 must be satisfied. The load center is moved up after the mining sequence shown in Figure 2-1 is completed. After the load center, belt tailpiece, mechanics shop, etc., are moved, the mining sequence begins again. The periodic power center moveup is required to assure adequate trailing cable length for the required face advance. Maximum trailing cable lengths permitted are specified in U.S. Bureau of Mines Schedule 2G.

Before the load center is moved, sufficient high voltage cable must be available to reach the new location. If adequate slack cable is not present an additional section of cable must be coupled into the line. The low-voltage trailing cables for the face equipment are uncoupled from the load center, and the center is pulled to the new location. The low-voltage cables are then rerouted, rehung, and new cable tie-off points are provided for the shuttle cars. The high-voltage cable is then hung from the previous load center position to the present relocated position. Therefore, it can be seen that a considerable amount of manual cable handling is necessary even though the actual power center move can be accomplished fairly easily.

Proposed - The proposed operations for moving the section power center in Stages I-IV follows:

Stage I - The battery scoop required for supply delivery and cleanup will be used for pulling the load center. The load center should be mounted on wheels for more portability.

Stage II - The number of trailing cables to be moved are reduced due to the use of the mobile bridge conveyors and carrying the miner cable on the side of the bridge conveyors. This will speed up the section advance. Otherwise the move is accomplished in the same manner as Stage I.

Stage III - A number of monitoring system components may be located at the load center or connected to it. Also, monitoring of the load center itself is necessary to determine electrical power parameters into the load center and to the equipment that may indicate reliability and safety of the electrical system. The moveup may be more complex as a result of these monitoring systems. If monitoring cables are used, they should be incorporated into, or routed next to, the power cables as much as possible.

Stage IV - Remote control implies being able to manipulate power switches at the load center from a remote position. Therefore, in addition to the monitoring components described in Stage III, a control cable may also have to be moved. The power center condition and switching positional data will be transmitted to the section console for visual review and remote operation. The section console with computerized production data can be used to predict dates for future moveups, thereby facilitating planning.

8. Section Belt Moveup.

Present - The present method of extending a belt tailpiece closer to the face requires a lot of manual materials handling. The operation can be accomplished efficiently only if enough intermediate belt materials have been supplied and deployed in the correct locations. Generally, the operation consists of pulling out an existing splice, attaching an additional segment of belt, refasten the splice, extending the belting by pulling the tailpiece and securing it in a new location, inserting troughing and return idlers, and realigning the belt. Along with the tailpiece, the telephone and first-aid supplies are advanced. Usually the tailpiece is moved at the same time as the load center. The roadway in front of the tailpiece should be cleaned by the scoop before the tail is pulled up.

Proposed - The proposed section belt moveup operation for Stages I-IV follows:

Stage I - No change from the present is anticipated.

Stage II - A belt-moving machine of the type that is currently under development by a USBM research grant could be used in this stage to advnace the tailpiece. A considerable savings in time is anticipated.

Stage III - In order to system integrate the belt haulage, the appropriate monitoring equipment and sequence control must be applied to the mobile bridge conveyor and the section belt. This data will be processed through the section console. Belt moveup should be investigated to determine the extent to which it is economically feasible to more extensively automate the operation and reduce the accidents due to lifting and handling of belt conveyor materials.

Stage IV - Data concerning belt tailpiece position and operating condition should be communicated to remote console. Belt moveup will require supervision and labor on the section and it will not be remotely controlled. The remote control console should be able to predict when the next belt move is to be made, and automatically order the supplies to be delivered to the section and indicate their desired deployment.

9. Section Belt Cleanup.

Present - One employee per section per day works along the belt, shoveling spilled coal and rock dusting the entry. Sprays are used at transfer points to reduce float dust.

Proposed - The proposed section belt cleanup operation for Stages I-IV follows:

Stage I - The same situation as the present is anticipated.

Stage II - Coal spillage and float dust reduction methods should be designed into the haulage system to minimize cleanup. Such things as vacuum systems at transfer points, better deployment of water sprays (i.e., venturi systems), better belt training, and monitoring of belt alignment can do much to decrease belt spillage. However, some manual work in cleaning up spillage will still be required.

Stage III - A float dust sampling device should be installed to indicate that a particular transfer point is generating too much dust. Also, monitoring should note when the belt is misaligned and spilling coal. A piped rock-dust system will be installed in the belt entry to reduce the time to manually handle bags of rock dust for rock dusting belt entries. Controls for monitoring and operating all these systems could be integrated into the section control console. Some manual work in cleaning up spillage will still be required.

Stage IV - The monitoring and operating systems in Stage III should transmit data to the haulage portion of the control console, so the belt status will be known. Regular and unusual manual cleanup will be accomplished during service periods. However, the previously mentioned spillage notification and prevention measures should minimize cleanup. Remote activation of the dust control spray systems from the haulage control console will be accomplished through monitoring of float dust levels in the returns.

10. Section Rock Dusting.

Present - Rock dust is usually applied either by hand from bags or "blown" on to the entry surfaces by a rock dusting machine to maintain at least 65 percent of incombustible material to within 40 feet of the face in intake areas. The rock dusting machine may be mounted either on a battery scoop, a shuttle car, or be self-propelled. In addition, the return aircourses must be regularly dusted to maintain at least 80 percent incombustible material. Normally, supply delivery of the rock dust in bulk rather than bag form is more economical and requires less manual loading and unloading. However, any place that requires hand dusting rather than machine application, such as during a working shift, normally necessitates bag dust. A trickle duster is usually operated in the section return airways to keep the incombustible content of float dust fallout from the mining operations at a safe level.

Proposed - The proposed section rock dusting operation for Stages I-IV follows:

Stage I - No major change from the present is indicated, however, on-shift dusting by hand will be reduced through the use of mechanical dusting during service shifts. Improved dust control on the AES will reduce the float dust per ton of coal mined. However, increased production will increase the amount of rock dust required to be delivered and applied during service periods.

Stage II - A piped rock-dust system should be installed during this stage to reduce rock dust delivery and application time. Piped systems have experienced clogging problems if not properly operated and maintained. Good operating maintenance experience, plus developments in face distribution is necessary for piping systems to be an efficient method of keeping pace with production improvements and allowing adequate rock dust application in the face areas during selected periods in Stages III and IV.

Stage III - The system integration concept should include assurance that rock dust is within 40 feet of the face. That is, rather than stop production for rock dusting, the AES observer should stand clear (in intake air) and rock dust should be released by an automated dust distribution system attached along the mobile bridge frame. The bulk-rock dust storage tank for the section should have a level indicator that notifies the section control console that additional dust is needed. The trickle duster should be automatically activated and also have a level indicator for informing the section console. The trickle duster and rock-dust pipe will be advanced during service periods. It may be advantageous to replace the trickle duster with a branch from the main rock dust supply line at this stage.

Stage IV - Application of rock dust from the trickle duster and mobile bridge mounted dust distribution system should be accomplished remotely in this stage. Since no one should be on the section during straight-ahead production advances, application can occur during this time. Belt entries can also be dusted during production periods. Crosscuts can be dusted immediately after they are turned, that is, just prior to the straight advance. During the service periods, samples of coal and rock dust from roof, face, and ribs should be taken at designated points for analysis. The results should be entered into the remote console data bank to evaluate the effectiveness of rock dusting and float coal dust control.

11. Roof Testing.

Present - Visual observation and a sounding bar (sight and sound techniques) are used by each miner in the working place prior to commencing activity in the area. Recently mined, unsupported areas near face are especially hazardous and require frequent checking. Too often miners neglect to check the roof, which is a reason that roof falls within 25 feet of the face are a prominent cause of fatal accidents.

Proposed - The proposed roof testing operation for Stages I-IV follows:

Stage I - The roof support system on the AES should be a safety improvement since it gives positive support to previously unsupported face-roof areas. Checking for loose rock between the supports before bolting will still be necessary. The testing of unsupported roof before providing temporary or permanent support will be significantly reduced.

Stage II - The same methods as Stage I are anticipated.

Stage III - System integration requires installation of an efficient roof monitoring system. Data from sensing devices installed to detect dangerous roof should provide a warning to workers in the area. The roof-sensing devices could possibly include color indicators, strain gauges, slope indicators, microseimics, infrared viewers, vibrating wire stress sensors, covergence indicating dial gauges, or a combination of several types. Installation with the roof-bolting operation is desirable. Indicators should be placed routinely in strategic locations plus special installations where bad top is suspected. The monitored data would be fed to the section remote console and be utilized to warn workers of a dangerous area and provide a dispatch mechanism for the "touch-up" bolter and technical serviceman-roof control. The sensors could be checked, repositioned, and calibrated during the service periods. In order to prevent delays, sensors should be designed for quick and easy installation and should be highly reliable. The roof monitoring system should note excessive pillar stress, convergence between roof and floor, loose immediate roof, prominent cracks, and other indications of potential failures. Visual inspection and roof sounding before men enter an area to work will still be necessary in addition to the monitoring system. In fact, the section supervisor should report areas of suspected bad top so sensing devices can be installed to determine additional support requirements. The monitoring system should not be expected to entirely replace man's experienced evaluation of bad top. However, it should be considered an important additional data source to aid in identifying a dangerous roof area, or perhaps providing warning when a worker fails to check the top. The system's effectiveness will depend on its ability to perform satisfactorily over the wide spectrum of roof, pillar, and floor conditions normally encountered in mining.

Stage IV - Remote sensing of roof conditions will directly result from the monitoring system installed in Stage III. A visual display of roof conditions in each section should be present at the remote console. Warning signals for dangerous areas should be communicated to services and maintenance personnel before they enter a section. In fact, since people are not working in the section continuously, a careful approach and roof-testing technique should be utilized when workmen are entering a working place. The section control console should provide notification of the need for additional sensing devices.

12. Methane Measurement

Present - A hand-held flame safety lamp and methane detector are used to check for the presence of methane gas. Federal regulations require methane checks every 20 minutes at the face. When these measurements are to be made, the continuous miner is turned off, the operator walks to the face, performs the test, and then returns to the machine. Methane checks are also required in preshift and fireboss examinations, and prior to blasting, welding, and cutting.

Proposed - The proposed methane measurement operation for Stages I-IV follows:

Stage I - It is anticipated that MESA and state approval will be given for methane sensors located near the cutter head of the AES machine in lieu of manual methane checks. Therefore, the 20-minute interva manual gas checks would be replaced by continuous monitoring, while the miner is operating. No changes are anticipated for other required methane examinations.

Stage II - The same measuring system as used in Stage I is expected to be used in this stage with the addition of return airway periodic or intermittant monitoring.

Stage III - System integration requires continuous, periodic, or selected methane monitoring in all faces and the return airways. Data from the detectors will be transmitted to the section console and warning of dangerous methane levels will be given. Methane detection will be an integral part of the total ventilation monitoring system described later in this chapter.

Stage IV - Increasing methane above the satisfactory levels will be reported to the remote control console. Directions will be given to increase the air quantity or reduce the rate of advance until safe methane levels are attained. When methane levels are high enough to be dangerous, the power into the section will be turned off remotely and only persons performing remedial ventilation operations such as installing brattice or check curtains will be allowed into the area. A log of methane content in the section return entries will indicate whether or not mining is progressing into an area of higher methane concentration. If so, more air can be diverted to the section or reductions can be made in rates of advance to maintain safe gas concentrations.

13. Mine Examiner, Fireboss, or Foreman Inspections.

Present - A number of inspections required by federal law are made by a certified fireboss or foreman:

1. daily inspection of all main fans and pressure recording chart;
2. monthly inspection of automatic closing doors in multiple fan systems;
3. preshift examination of all areas where miners are to work or travel for methane accumulation, oxygen deficiency, improper seals and doors; bad roof, face, or ribs; improper direction, velocity, or quantity or air; any other hazards or violations of federal law;
4. belt conveyor examinations after each shift has begun;
5. examinations once each production shift on the section for hazardous conditions including methane and oxygen deficiency;
6. weekly examinations for hazardous conditions in the return of each air split, on pillar falls, at seals in the main return, intake and return aircourses, idle workings and abandoned areas; and
7. weekly ventilation quantity measurements in all main intakes and returns, air splits, and at the last open crosscut in each section.

The fireboss normally walks a prescribed portion of the mine each day, so by the end of each week, the entire mine has been covered. The on-shift examinations in the sections are done by the foreman. The examiner shall place his initials and date in each area examined and report his findings to the surface before other persons enter the mine.

Proposed - The proposed inspections for Stages I-IV follows:

Stage I - The anticipated method will not change from the present.

Stage II - No changes are anticipated.

Stage III - The ventilation quality and quantity measurements prescribed in Items 3, 6, and 7 could be replaced by the mine environment (ventilation) monitoring system. However, the environment monitoring system should be checked periodically for "results" calibration against a standard base. Data from preshift and on-shift examinations should be retrievable from a memory bank by the surface computer and section control console. The machine inspector should continually be investigating for hazardous conditions or law violations. Since the machine inspector does not have an operating job to accomplish, but is only on the section to assure production and safety are being performed adequately, safety will be improved. He will have less opportunity to become involved in job accomplishment and will be more aware of what is taking place around him. In addition, the worker will have valuable data from all of the monitoring systems to enforce his personal observations.

Stage IV - Even though extensive monitoring devices will be utilized during remote operation, federal regulations require that the section be manually inspected before the service or maintenance personnel enter the area. Therefore, one member of each service crew must be a certified fireboss or foreman who travels through and examines the section before the workmen enter. Data from the various monitoring equipment will improve the quality of the preshift inspection, but monitoring cannot replace manual examination of this type. The preshift inspection report will be entered into the data bank of the computer from the section console.

If a hazardous condition warning is announced by any of the monitoring systems several alternatives are available. When equipment is in the remote operating mode, an attempt to reduce or eliminate the hazard remotely may be made. (For example, a high methane content may be diluted by introducing a larger air quantity). If a remotely initiated solution is not possible, only the workers necessary to correct the hazard shall enter the area. If the hazard could possibly affect the safety in other areas, personnel should be withdrawn from those areas or not allowed to initially enter those areas.

14. Section Supply Handling

Present - Supply materials are loaded onto both rail or rubber rail supply cars on the surface, either manually or by a front end loader or similar machine, depending on the type of supplies. The supply car is pulled into the section on a nonproducing shift if rail coal haulage is utilized. If a conveyor belt is used to haul coal from the section, a track for handling men and supplies into the section is installed parallel to the belt. The supply cars are stored in a side track in the section and materials are lifted from the cars into a shuttle car or battery scoop for transportation to the face unless the supply car has both rubber and rail wheels. A "rubber-rail" car can be pulled off the end of the track and close to the working face before the supplies are unloaded.

Proposed - The proposed section supply handling operation for Stages I-IV follows:

Stage I - The first automation stage should utilize "rubber-rail" supply cars and a battery scoop that will handle supplies without interrupting production on the section. Supplies should be palletized as much as possible.

Stage II - A section supply vehicle especially designed to load and unload supplies, reducing manual handling and accidents from lifting and being caught between objects, is anticipated for Stage II. Palletized supplies will be brought in on rubber rail cars to the section supply vehicle.

Stage III - Many functions of the section supply vehicle could be automated to give the supply man a guidance and inspection role if it is determined to be economically feasible. However, the variety of its work may not permit routine programming. A powerful machine would speed up loading and unloading since the higher production of Stages II, III, and IV will require significantly more supplies. Also, the accident frequency that would increase from handling an increased amount of supplies will actually decrease by letting a machine do the dangerous handling.

The projected ordering and delivery of supplies on a routine basis will be aided by the computerized supervisory control. When a machine or operation has exhausted supplies to a point that a reorder becomes necessary, the section console will transmit the request to the central surface computer which will print an order for the supply supervisor to fill. As a result of palletizing and improved data on amount of supplies used by each section, the surface supply supervisor will be able to normally anticipate supply requests and have the pallets packed before the order reaches him for resupplying the staging area. Thereby, production delays caused by a lack of supplies will be decreased. In addition, the section console will be able to anticipate the need for supplies well in advance of a shortage if it keeps a running inventory based on deliveries, section production, and average usage per ton.

Maintenance material needs can also be predicted by the console monitoring systems and preventative maintenance schedule. Therefore, parts can actually be delivered to the section before the special maintenance crew arrives based on the predicted needs of a particular breakdown. Troubleshooting by the maintenance crew may turn up additional requirements in special instances, but maintenance delays will be considerably reduced when the anticipated repair part delivery is sufficient for the job.

Obviously, section servicing such as rock dusting, conveyor belt moves, greasing, filling hydraulic oil tanks, etc., will be considerably faster since the necessary materials will be in the right place in this more predictable mining system. The predictability extends to the point of computer initiated orders to vendors of routine supplies, such as roof bolts and oil, greatly assisting the purchasing department function.

Stage IV - Remote control mining restricts supply delivery to the service periods. Increased production results in the problem of having to deliver a large amount of supplies in a short period of time. It is expected that several section supply vehicles may be required to handle the increased supply volume. These vehicles may have special features to facilitate handling preconstructed stoppings, and other unique supply items. Detail investigation may determine that special supply crews equipped with rubber rail supply vehicles will service various sections in a prearranged schedule of programmed downtime.

15. Fresh Water Supply and Drainage Water

Present - Fresh water is needed on the mining section to cool motors, suppress respirable and float coal dust, remove roof drilling fragments, cool bits, and fight fires. If a mine section is accumulating drainage water, permissible, portable sump pumps must be utilized to remove excess water from the working section and escapeways. Pumping accumulating drainage water from old workings may also be necessary. Obviously, drainage water and supply water must utilize different pipelines to avoid the possible sediment that would plug dust suppression sprays in the fresh water system. At present, water pipes for an advancing and retreating section are transported on extra long, rail supply cars into the section supply track. They are manually unloaded and pulled into place on the section. Manual connections are made between the pipes, valves, and other required fittings which snap or bolt together. Pipes are commonly steel or cast iron, but the use of plastic and fiberglass is increasing depending on service and type of application. From the inby pipe end (usually located near the section belt tailpiece), a flexible hose extends to the continuous miner and/or roof bolter. Normally, dust suppression sprays require cleaning and a filter requires changing on a regular basis to prevent clogging.

Federal regulations for fire protection are as follows:

1. Water lines shall be capable of delivering 50 gallons per minute at 50 pounds per square inch nozzle pressure.
2. Water lines shall be installed parallel to belt conveyors with outlets at 500-foot intervals.
3. Water lines shall be installed parallel to haulage tracks with outlets at 500-foot intervals.
4. Unless fire-resistant hydraulic systems are used, a fire-suppression system (such as a water deluge system) shall be installed on underground equipment.
5. Main and secondary conveyor belt drive must have approval deluge-type water spray systems.

Proposed - The proposed water supply and drainage operation for Stages I-IV follows:

Stage I - With the exception of improvements in dust suppression designed into the AES machine, no change from the present is anticipated.

Stage II - No change anticipated from Stage I.

Stage III - Water quality and pressure at each mining machine should be monitored. The operation of all pumps and sump water levels in the mine also should be monitored, but at the surface water control center. Dust monitoring and water monitoring systems should interface data so a high dust count in a particular area can result in more spray water being applied automatically. Interlocks to automatically turn on water when conveyor belts are started and when machines are cutting coal are necessary.

Stage IV - The water flow into a section should be regulated and controlled remotely. All pumps in the mine should be remote controlled and monitored. In the startup check sequence for section operation, proper water quantity and supply should be assured. In areas where a high dust concentration is being recorded, the water quantity and/or pressure should be increased remotely to reduce dust. A water monitoring system should be established to control the fresh water supply and the drainage water outflow.

16. Equipment Service.

Present - At present, mining machinery is lubricated, hydraulic oil tanks are filled, and worn cutting bits are changed during a service or breakdown period on a production shift or during an idle shift scheduled for service and maintenance. These jobs are performed manually. They are extremely important to maintaining production levels since many maintenance delays are a result of inadequate machine service or lubrication. Automatic lubricators have been installed on some mining equipment. Service also includes cleaning the machine, which may be accomplished by washing with a water hose attached to the dust suppression water supply, and checking various operating components.

Proposed - The proposed service equipment operation for Stages I-IV follows:

Stage I - The hydraulic oil contaminant identification testing program anticipated during Stage I (see Appendix C) will be a great help to preventative maintenance scheduling. In addition, the hydraulic oil level gauge is expected to be more prominent than those currently in use, which should help prevent operating the machine when it is out of oil. Some lubrication will be automatic. Manual bit changing and some manual lubrication is expected to continue as in the Present Stage.

Stage II - The only change from Stage I is the possible addition of an individual equipment service vehicle.

Stage III - The monitoring system should indicate servicing needs of each automated piece of equipment. As much automatically applied lubrication as is practical should be utilized. A special service period will be planned into the equipment operation cycle to reduce maintenance breakdowns and equipment wear as much as possible. Equipment monitoring systems will be able to ascertain if servicing is being accomplished too frequently, or not often enough. If a service job is mistakenly omitted, the monitoring system would be able to detect a machine malfunction that is serious enough to result in excessive machine wear and transmit data to the machine inspector so he would stop the machine until the service job is performed.

Stage IV - The equipment status monitoring system developed in Stage III would transmit information to the section remote console. Levels of hydraulic oil, lubricant, and bit usage would be maintained in the section computer data that would be useful for evaluating machine conditions and provide data for reordering supplies. Also different bit, oil, and lubricant types could be easily evaluated to optimize the lowest cost product.

17. Maintenance.

Present - Almost all of the current mine maintenance is repairing equipment breakdowns. Very little preventative maintenance is practiced. Breakdown maintenance consists of determining what has failed, ordering, and supply the correct replacements and substituting the new parts. Normally, each production crew has a mechanic who is backed up by a maintenance foreman and roving general mine mechanics. The amount of delay time resulting from a breakdown repair depends on how well-trained and experienced the section mechanic is in locating the problem plus replacing the defective part. Also, the availability of required parts can have a significant time impact. Much time can be saved if a spare inventory of often-used parts is stored in the section.

Proposed - The proposed maintenance operation for Stages I-IV follows:

Stage I - The hydraulic oil contaminant tests proposed for the AES machine should improve preventative maintenance of the hydraulic system. However, breakdown and preventative maintenance are going to take longer due to the number of items on the AES, and the lack of maintenance working room. National Mine Service personnel have attempted to design a high degree of reliability into the machine, but component change-out times will increase as a result of cramped working areas that are due to placing additional components on a larger machine operating in a narrower entry than present continuous miners.

Additional maintenance delay times will result from stopping the cutting and loading function while a component relating to ventilation or roof support is repaired. These are presently separate delay functions. The ventilation system should be relatively reliable, but problems often occur with the roof bolters and there will be four of them on this machine. These should be unitized for quick replacement.

The control of force on the sump and shear cylinders by the automatic cutting cycle is a maintenance improvement. Any controls that reduce the wear on machine components produced by a bad operator will decrease maintenance delays.

Stage II - Increased training will be required to allow efficient troubleshooting and replacement of more sophisticated components. (Maintenance training is discussed in Chapter 8). Changes in the AES design to improve reliability and maintainability will result from the Stage I operation.

Stage III - Monitoring of hydraulic oil level, bearing temperatures, machine vibration, sump and shear rate, electrical, and other parameters by the equipment-condition monitoring system will produce data to indicate or predict failures. Historical data concerning monitoring data patterns and type of failure can be useful in setting up a component-change-out type of preventative maintenance program. That is, rather than wait for a component to fail, a replacement can be made at a time prior to failure that was predicted by utilizing knowledge of prior component life and patterns of monitoring data. Therefore, an unscheduled delay that stops production can be eliminated by a scheduled change-out during a service period. Also, time required for troubleshooting and waiting for the proper part to arrive on the section can be reduced with this system.

If a component change is not made in time and a breakdown occurs, information from the monitoring system should help reduce troubleshooting time. The supply handling vehicle should assist in delivering heavy maintenance parts and reduce the time spent waiting for a repair part. Maintenance records should result in a better inventory of parts on the section - further reducing delivery time. A more comprehensive and complete section-parts vehicle should be utilized.

With the introduction of sophisticated parts such as solid state electrical devices, a component change-out system is much better than trying to train mechanics to repair parts underground. The underground environment is also restrictive to many tedious repair jobs. It is better to send the parts to the surface where the right conditions and tools are available for their evaluation and repair by experienced, qualified personnel.

Stage IV - The equipment status monitoring system data will be used much the same as in Stage III for preventative maintenance; however, more experience with the prediction system will make it more accurate. The central surface computer should automatically order the correct part in instances where the anticipated failure is clearly defined and route a work order to the maintenance crew to change out the part on a preplanned service period. A remote control order to stop the machine and send in a service crew should be initiated if the section remote console computer detects a failure that would cause a safety hazard or damage the machine if preventative steps are not taken. Alternatively, the mining rate may be slowed to prevent a failure, and production continued until the necessary parts and personnel arrive to make the repair. Certain parts that break down during the production period should not require stopping production. They can be changed out on the next available service period. This decision will be made by the foreman and machine controller based on data available at the remote control station.

18. Monitoring Systems.

Present - Monitoring systems that have been used to date are methane detectors on mining equipment, fire detectors on conveyor belts and power facilities, pressure recording gages at main fans, running hour meters on continuous miners, and operational indicators on belts and other equipment. Some closed circuit television systems are used for observation monitoring of bins, crushers, and conveyor belts. Several recent research efforts have provided viable monitors, especially for ventilation and communications.

Proposed - The proposed monitoring systems for Stages I-IV follows:

Stage I - No additional monitors to the present capabilities are anticipated.

Stage II - The same requirements as in Stage I are anticipated. However, the addition of return airway environmental monitors will be initiated and the various major monitoring systems necessary for Stages III and IV should be under development.

Stage III - In order to system integrate and automatically activate the continuous mining process, a number of major monitoring systems will be required. Some systems can be machine mounted and others will be located on the roof, rib, or floor. This may require frequent moves concurrent with the advance or retreat direction of mining. All monitors will require calibration and periodic verification of correct operation at specified intervals. Equipment to check the proper functioning of vital sensors may also be necessary. The necessary major monitoring systems in general terms are as follows: equipment status and performance (AES and haulage), roof control, mine environment (ventilation and rock dusting), electrical, and water.

Condition and performance parameters to be included in the major monitoring systems are:

A. AES Machine -

1. operating mode, performance, and condition of various machine components including extraction, roof support, and ventilation;
2. position of machine in entry;
3. interrelationship with other equipment;
4. hydraulic pressure and tank level;
5. voltage, current, and power factor of electrical components;
6. noise and vibration; and
7. temperature of motors, hydraulic oil, and bearings.

B. Haulage equipment (belt) -

1. operating mode, performance, and condition of various haulage components;
2. position of haulage equipment in entry or system;
3. quantity of material in transit;
4. status of panel conveyor;
5. hydraulic pressure and tank level;
6. voltage, current, and power factor of electrical components; and
7. panel belt alignment, speed, dust generation, and spillage.

C. Roof control -

1. operating mode, performance, and condition of primary and secondary roof support systems components;
2. supplies available for roof bolting;
3. dust collector capacity;
4. distance between present AES position and last installed row of belts;
5. torque on 25 percent of recently installed bolts,
6. torque on 10 percent of bolts inby and including the last crosscut;
7. roof sag after bolts are installed;
8. roof and floor convergence;
9. seismic events on "roof talk";
10. loose immediate roof; and
11. pillar stress.

D. Ventilation -

  1. operating mode, performance, and condition of ventilating components;
  2. air quantity and quality at all faces, return, intake, and in the belt entry;
  3. air velocity over the miner; and
  4. status of the ventilating equipment.

E. Rock dust -

  1. operating mode, performance, and condition of rock dusting components;
  2. quantity of rock dust in storage bin;
  3. quantity of rock dust in trickle duster; and
  4. amount of new advance requiring rock dust.

F. Electrical -

  1. operating mode, performance, and condition of electrical components.
  2. voltage, current, and power factor on the low-voltage side of the section power center for each piece of equipments' power conductors;
  3. voltage, current, and power factor on the high-voltage side;
  4. ground current; and
  5. position of trailing cables.

G. Water supply and drainage -

  1. operating mode, performance, and condition of water equipment components;

2. pressure and quantity of water for dust suppression and fire fighting; and
3. pump operation and sump levels.

Stage IV - Remote control requires that data from the monitoring systems be transmitted to the remote console. In addition, the positions of each machine in the section must be known at any instant more accurately than in Stage III. That is, the machine inspectors in Stage III can supply information for guidance, however, in Stage IV, these inspectors will not be present in the section. As a result, information for guiding a machine to a specific location must come from some type of machine position sensor.

19. Spillage and Roadway Clean up (other than belts).

Present - The pickup loading machine utilized behind the miner is presently used to clean shuttle car roadways and coal at the face not loaded by the continuous miner. Hand shoveling is used to clean up the shuttle car dumping points.

Proposed - The proposed spillage clean up operations (other than belts) for Stages I-IV follows:

Stage I - Even though the AES machine has an improved gathering head, its size precludes the maneuverability necessary to completely clean up entries. Therefore, a battery scoop (also utilized for supply handling and power for move ups) is necessary for initial cleanup behind the AES machine and periodic recleaning of roadways.

Stage II - No change anticipated from Stage I.

Stage III - No change anticipated from Stage II.

Stage IV - Cleanup will be accomplished with the Stage I methods except it will be confined to service periods.

20. Miscellaneous.

Present - The miscellaneous category consists of general mine construction, track installation and maintenance, trolley wire installation and maintenance, and equipment moving between panels. These operations are often intermittent, rather than a regular part of the daily section work load. They are performed by the general inside work crew rather than the section crew. The scheduling of this work is a function of the face advance, and the units of work that can be efficiently performed by a work crew.

Proposed -

Stage I - No change anticipated from the Present Stage.

Stage II - No change anticipated from the Present Stage.

Stage III - No change anticipated from the Present Stage. However, movement of monitoring systems and the supervisory control station will increase the work load.

Stage IV - No change anticipated from Stage III.

Chapter 4
PRODUCTIVITY

Introduction

The overall impact of automation technology is measured in terms of safety and profitability. Chapter 6 discusses the safety impact. This chapter projects the production which is the basis for the profitability determination in Chapter 7. The unit shift production levels for the Present Stage through Stage IV are developed in this chapter.

The typical current mining cycle operation of high production for short periods of time is challenged by an automated plan of more continuous production at a slower rate - but for longer production periods - that will be less damaging to the equipment and more manageable. Scheduled downtime or service periods is an important part of this innovative mining system. The purpose of the arrangement is to be able to produce coal at a certain rate for a specified period and then deliberately shut down the total section extraction system, with the exception of certain monitoring groups necessary to insure safe working conditions, for scheduled servicing and maintenance. Consequently, unscheduled, prolonged, breakdown maintenance, and other unexpected delays will be reduced through preventative maintenance and diagnostic machine monitoring. Nevertheless, the production period length must be adequate to produce sufficient coal to pay for the additional capital investment needed in automated, remote-controlled continuous mining.

The following production analysis of automated mining is based on existing equipment time studies in a mine similar to the hypothetical case study operation. These time studies were extrapolated to the expected performance of the AES machine by computer simulation. The results of the computer analysis and comparison are reported in Appendix A. The AES machine projected performance is based on the design data, furnished by the manufacturer, that is listed in Appendix B. The mining plan used for comparison is shown in Figure 2-1. All of the production figures developed in raw tons mined in an eight-hour shift and then converted to clean tons.

The study presumes that adequate job safety and productivity analysis has been made of the procedural steps from both an innovative and safety viewpoint to develop the extensive training programs required for machine operators, service and maintenance personnel, and mine managers. The workers must be properly trained in order to operate the equipment in a productive and safe fashion, since operation and maintenance of automated equipment will differ significantly from that currently used. Effective troubleshooting methods should be a major part of training programs for maintenance personnel so the required work can be performed in the allotted service time. Training is discussed further in Chapter 8.

The monitoring system, especially the electrical and equipment condition sensors, should provide valuable information that will reduce defect detection times. In some instances, the computer analysis of data may lead to failure prediction so spare parts and required maintenance personnel can be dispatched to the section during a service period. Therefore, a repair can be made before a production limiting breakdown occurs.

The production reported here is the expected average, not "peak" or "theoretical" level. Automation should cause the day-to-day tonnage to be more constant at a mine resulting in fewer low and high production days. Production fluctuations will still occur, especially during the transition period (discussed in Chapter 8) to automation, but they will be less pronounced and less common than in the Present Stage.

The reported figures do not contain the coal mined by the construction or section setup crew. These crews are required to mine several crosscuts away from the main or submain entries in order to establish sufficient space to set up the AES system equipment when a new panel is being started. This production is intermittent and limited when compared to the total mine tonnage.

Production Analysis

The calculated unit shift productions are listed at the bottom of Table 4-1. This table lists the times for production and delay elements in each stage, that are defined in the following discussion. The Present Stage times are a result of time and motion studies and the authors' experience. Projected times for the projected automation stages are based on the anticipated occurrences of automation technology and its effect on the Present Stage production.

1. Cutting and Loading.

Cutting and loading is the period of time that the extraction machine is cutting coal and loading it into the haulage mechanism (shuttle cars or belts) or dumping the coal on the floor for the pickup

Table 4-1. Unit Shift Production Analysis.

		Present	Stage I	Stage II	Stage III	Stage IV
1.	Cutting & Loading (min.)	70	95	140	200	230
2.	Place Change (min.)	45	25	30	45	55
3.	Shuttle Car (min.)	0	40	0	0	0
4.	Mantrip (min.)	50	50	50	50	50
5.	Lunch (min.)	30	30	30	0	0
6.	Fireboss Inspection (min.)	15	15	15	10	10
7.	Other Necessary Time (min.)	30	25	25	20	15
8.	Bolt Delay (min.)	60	30	20	10	0
9.	Prepare to Start (min.)	20	20	20	15	10
10.	Prepare to Leave (min.)	20	20	20	15	10
11.	Maintenance (min.)	75	75	75	75	75
12.	Ventilation (min.)	10	10	10	10	10
13.	Outby Haulage (min.)	20	20	20	10	0
14.	Other Delays (min.)	35	25	25	20	15
	Total Shift (min.)	480	480	480	480	480
	Raw Tons per shift	310	380	560	800	920
	Clean Tons per shift	250	310	460	660	750

loader to remove. There is no time for cleanup with the miner contained in any of the five stages' production analyses. The pickup loader accomplishes the cleanup in the Present Stage and the large extraction machines could better utilize their time in cutting coal and place changing without cleaning in the latter stages. Consequently, it is projected that a battery scoop will be utilized to clean roadways so the extraction machine will not be used in this low productivity operation in Stages I through IV.

The duration of the cutting and loading period is determined by subtracting all of the other allotted time elements (described in the following) from the total shift time of 480 minutes. The average cutting rate, four tons per minute, is then multiplied by the amount of cutting and loading time to obtain the average raw tons per unit shift in Stages I through IV. The average shift tonnage for the hypothetical case study mine is utilized in the Present Stage where the average cutting rate is calculated to be 4.4 tons per minute. The AES has the capability of cutting at a rate of eight tons per minute. If this higher rate did not increase certain delay times, it could increase tonnage above the projected figures; however, its use on a continuous basis is not anticipated in this study because roof bolting will not be able to keep up. Faster bolting is projected to modify this.

2. Place Change.

The amount of time required for the extraction machine and auxiliary apparatus (ventilation tubing, cables, water hose, etc.) to move from the end of one cut to the beginning of the next, as outlined in Figure 2-1, is the place-change time. It depends on the extraction machine tram rate of 20 to 40 feet per minute, and the additional time to move the auxiliary apparatus. The Stage I time is reduced from the Present Stage due to the elimination of moving a separate auxiliary ventilation fan, waiting for the pickup loader to remove the coal pile and clean the roadway, and moving the loader and its cable.

A place-change time of 26 minutes per move and one move per 360 raw tons resulted from the computer simulation of the Stage I operation. In Stage II, an improved face ventilation system will allow advancing for two crosscuts instead of one before place changing (see Figure 2-2). Therefore, the distance to be moved increases, but the frequency of moves decreases. Since the extra distance adds little time to the move (only tram time) because the time required for moving auxiliary apparatus is about the same, the overall effect on productivity is positive. The frequency of occurrence is projected at one move per 620 tons with the changed mining plan. Replacing shuttle car haulage with mobile conveyors will increase the place change times by 20 percent. These base figures are used to project the place change times in Stages II, III, and IV - considering the increased tonnages.

3. Shuttle Car Changeout.

The shuttle car changeout time includes the amount of time the miner is waiting for an empty shuttle car to arrive and position itself under the tail boom. No delays to the miner are incurred during the Present Stage because a pickup loader is used. However, at times the coal pile behind the miner becomes too large and a delay is incurred while the coal is loaded out. This time is included in the "outby haulage" and "other delays" categories.

The computer simulation provides the shuttle car changeout times for Stage I utilizing tram speeds, loading, and dumping times. Stages II, III, and IV utilize mobile conveyors rather than shuttle cars, so no shuttle car delays are listed.

4. Mantrip.

The mantrip time includes the travel time from the portal to the working section. It encompasses the time to walk from the mantrip car, after it has arrived at the section, to the machine at the face. Automation technology, as it is envisioned in this report, will not change mantrip times. The Present Stage time is used for all four automation stages as well. This area may lend itself to future study.

5. Lunch.

The UMWA contract specified period for lunch, 30 minutes, is taken in the Present Stage, Stage I, and Stage II. In Stages III and IV, the automatic equipment will remain operating while the crew eats at designated times. A staggered lunch period, used in some present mines, will be much easier to schedule in Stages III and IV.

6. Fireboss Inspection.

Before the men advance to the working place at the beginning of each shift, the faces must be examined for hazardous conditions (methane gas, bad roof, etc.). This examination is usually made by the foreman. The fifteen minutes required for the Present Stage will be constant for Stages I and II also. However, the monitoring system information available to the examiner in Stages III and IV will reduce the time required to 10 minutes. It is desirable that the examination in Stage IV be made prior to the service period rather than at the beginning of the shift.

7. Other Necessary Time.

Time required for miscellaneous times such as testing the roof, examining for methane, talking shop, handling material, etc., that are necessary from a production or safety viewpoint are included in this category. The Stage I duration is reduced from the Present Stage because of the continuous methane monitoring system installed on the AES machine. Stage II time remains the same as Stage I. The times for Stage III and IV are reduced because of the introduction of the supply vehicle and the ability of the automated machines to continue operating while the operator is talking shop.

8. Bolt Delay.

The amount of time that the extraction machine is delayed because roof bolting is slower than the mining rate is noted in this category. In the Present Stage, the continuous miner must stop to allow the bolter to operate from a stationary position. In Stage I, the time is reduced since the bolters are allowed to remain stationary while the AES is mining due to the hydraulic sump feature. However, the mining rate is faster than the bolting rate, so some production delays, indicated by the computer simulation, are still incurred. Improvements in the AES roof bolters should reduce the delay for Stage III and eliminate it in Stage IV.

9. Prepare to Start.

A few minutes is required at the start of each shift for the men to place their lunch buckets in the lunch area, take off their coats, receive instructions from the foreman and inspect their equipment before operating it. The Stage I and II times are the same as that for the case study mine. However, the monitoring systems and section remote supervisory console will reduce equipment inspection times and improve planning so the amount of instruction required for startup is decreased in Stages III and IV.

10. Prepare to Leave.

A few minutes are required at the end of each shift for the men to put on their coats, pick up their belongings, place their equipment in a safe position, and inform the foreman of the equipment operating condition and position. Stage I and II times are the same as the Present Stage. However, Stages III and IV times decrease due to the improved efficiency of reporting machine condition and operating condition with monitoring system data. In addition, the automatic machines should be designed to automatically return to a safe position and operating mode whenever they are stopped.

11. Maintenance.

The amount of time the extraction machine is stopped due to repairs or servicing of any mining system element is classified as a maintenance delay. The lack of predictability of the result of the introduction of automation technology has led the authors to maintain a constant time for maintenance throughout the automation progression.

On one hand, automation may increase maintenance times because of the number of components and the interrelating condition of many elements. That is, there are more components on the extraction machine that can fail, which increases the possibility of a delay. In addition, the mining section functions more as an interrelated system than a collection of separate machines. Therefore, if one element fails, production is stopped - which is not always the case in the Present Stage.

On the other hand, the predictability of breakdowns should improve, better information will be available for comparison of different parts, and breakdown maintenance will decrease as preventative maintenance increases. All of which should reduce maintenance time. Present breakdown maintenance is inefficient from the standpoint of not having the correct parts, tools, and personnel at the job site when the repair is to be initiated. That is, the mechanic has to get his tools, find the problem, order the necessary parts, and make the repair. At times he must call for assistance either in locating the defect or making the repair. <u>IF</u> a computerized monitoring system can provide enough data to predict or diagnose failures, the correct parts, tools, and personnel can be in the section during the service period to make the repair.

Nevertheless, the actual times required for maintenance are difficult to predict and depend on equipment design, spare parts inventory, and trained personnel. The authors project that the advantages will equal the disadvantages and maintenance delay time will remain about the same, but it will be more scheduled and predictable. This is an area of mining offering tremendous opportunity for improvement through additional research and development.

12. Ventilation.

The amount of time that the extraction machine is delayed while face ventilation (tubing and fan) or other air coursing structures are emplaced comprises this category. The average per shift time for placing ventilation in dead-end places and in faces for weekend or other idle days is also included - if this work delays the extraction process. Otherwise the main time element is advancing the face ventilation. The Present Stage mining system utilizes an extensible section of tubing that the roof bolter operator can slide up to within 10 feet of the face during mining. Sections of tubing can be added when the machine is stopped for bolting. Consequently, very little time is lost for ventilation. Even though the AES has a much improved face ventilation system, the time for ventilating faces for idle days will remain about the same as the Present Stage so no decrease in this category is anticipated for the progressive automation stages. As was noted previously, the improved AES ventilation system will decrease place change time.

13. Outby Haulage.

Delays caused by the section or main conveyor belt when it stops are included in outby haulage delays. Problems with controllers, slippage switches, fire alarms, and other protective devices may shut down the belt. Also, maintenance problems such as bad splices and transfer point "plugup" will stop the belts. The Stage I and II delays remain the same as the Present Stage. However, the introduction of monitoring systems and scheduled maintenance periods will reduce the delays in Stage III and reduce them to a low enough level that they will be included in the "Other Delays" category of Stage IV.

14. Other Delays.

Miscellaneous unscheduled delays such as roof falls, excessive water in the faces, stopping the machines to reduce methane concentrations, installing additional roof supports, applying rock dust, etc., are classified as other delays. These delays remain constant for the Present Stage, Stage I, and Stage II. They will be reduced in Stages III and IV because the monitoring systems and computerized supervisory control will make them more predictable, detectable, and easier to avoid.

Chapter 5
PERSONNEL REQUIREMENTS

Introduction

This chapter of the report presents the logic of personnel changes from the Present Stage through Stages I, II, III, and IV for each of the projected job functions or mine operations. The personnel requirements for Stage I and Stage II, in many instances, are similar in structure to the present classification with appropriate adjustments for work loads. In Stage III the section is system-integrated with substantial machine and control interrelationship. At this point, the machine operator and helper role should be significantly upgraded through job definition and training to encompass more technical work such as inspection and monitoring. In Stage IV it is intended to remove all personnel from the immediate face area during scheduled production periods. Personnel will re-enter the face area for emergency breakdown and routine service times.

The shift time will be subdivided (as outlined in Chapter 4) into scheduled production and service times. Maintenance and ancillary service functions will require a high degree of preplanning to be performed quickly and efficiently on schedule. Consequently, a larger percentage of the mine personnel will be involved in supervisory, maintenance, inspection, and training jobs compared to present operations. Computerization, procedure manuals, and operational check lists will become standard practice in the later stages to assist in efficient planning of all work.

The mine expansion will require more people in the general service and supervision area. Training personnel will assume an increasingly important role in the company organization. The extensive use of communications, monitoring, and computer will require a greater number of skilled electronics and computer technicians and engineers. The substantial amount of engineering preplanning, production data analysis, and more sophisticated mining systems resulting from automated mining and system monitoring will require substantially more engineers of all types.

The transition period from the Present Stage to Stage IV will require extensive efforts on the part of management and union personnel to absorb in an efficient manner the technology being developed in research and development programs. It is important that nonproductive paperwork jobs not develop in the maze of data processing.

Following the model of the aviation industry, well-documented instruction procedures similar to "flight training" should be established for the various job functions. This will be necessary both for engineering preplanning and personnel training. The engineering preplanning will utilize computer analysis of monitoring system output data. The impact of increased personnel training changing worker roles and the introduction of computers will be discussed in more detail in the Psychological and Organizational Impact chapter of this report.

In a number of job classifications the manpower requirements are considered to be directly related to production tonnages and are prorated accordingly. Significant improvements may be made in the future in some labor intensive activities, such as general mine supply delivery, that have been considered directly related to production, but a separate study is needed to justify the economics of such advancement, so such changes are not included here.

In addition, more rapid panel extraction may permit larger panels to be mined, thereby reducing the amount of deadwork per ton for established panel services. However, more research is required in the modifications which can take place in total mine layout, so panel dimensions remain constant throughout this study.

Personnel Requirements

Development of personnel requirements for the individual mine operations is the subject of the remainder of this chapter. Tables 5-1 and 5-2 list the required labor and management personnel, respectively.

1. Cutting and Loading.

Present Stage - One continuous miner operator and one loading machine operator or continuous miner operator helper are required per producing section. One million clean tons per year requires 18 machine shifts producing at 250 clean tons per shift on a 220-day-per-year basis. Therefore, the total manning is 18 continuous miner operators and 18 helpers.

Stage I - One extraction machine (AES) operator is required per producing section. The total manning is 18 extraction machine operators.

Stage II - Manning is the same as in Stage I.

Stage III - The extraction machine operator job title changes to technical service-extraction. One technical serviceman-extraction is required per producing section for a total manning of 18. The operating

Table 5-1. Labor Manning

Present Stage Manshifts per Day	
Section Crew	
Miner Operator	18
Loader Operator	18
Shuttle Car Operator	36
Roof Bolter	36
Brattice Man	18
Utility Man	18
Mechanic	18
Subtotal	162
General Inside	
Supply Motorman	12
Beltman	22
Trackman	8
Wireman	4
Mason	5
Pumper-Pipeman	3
Mechanic	15
Rock Duster	2
Equipment Mover	4
Conveyor Mover	9
Fireboss	4
Oiler-greaser	9
Electrician	6
Utility Man	21
Subtotal	124
Outside	
Lampman	3
Scoop Operator	2
Mechanic	18
Hoistman	3
Supply Crew	4
Subtotal	30
Total Mine Labor	316
Total Management from Table 5-2	59
Cleaning Plant Employees	25
TOTAL	400
Clean tons/man shift	11.3

Stage I Manshifts per Day	
Section Crew	
Extraction Machine Operator-cutting	18
Shuttle Car Operator	36
Extraction Machine Operator-bolting	36
Ventilation Man	18
Supply/Utility Man	18
Mechanic	18
Subtotal	144
General Inside	
Supply Motorman	15
Beltman	22
Trackman	10
Wireman	5
Mason	7
Pumper-Pipeman	4
Mechanic	19
Rock Duster	3
Equipment Mover	5
Conveyor Mover	11
Fireboss	4
Oiler-greaser	9
Electrician	8
Utility Man	28
Subtotal	150
Outside	
Lampman	3
Scoop Operator	2
Mechanic	18
Hoistman	3
Supply Crew	6
Subtotal	32
Total Mine Labor	326
Total Management from Table 5-2	74
Cleaning Plant Employees	30
TOTAL	430
Clean tons/man shift	13.0

Table 5-1. Labor Manning (Continued)

Stage II Manshifts per Day	
Section Crew	
Extraction Machine Operator-cutting	18
Mobile Bridge Operator	54
Extraction Machine Operator-bolting	36
Ventilation Man	18
Supply Vehicle Operator	18
Mechanic	18
Subtotal	162
General Inside	
Supply Motorman	22
Beltman	22
Trackman	15
Wireman	8
Mason	10
Pumper-Pipeman	6
Mechanic	28
Rock Duster	5
Equipment Mover	8
Conveyor Mover	11
Fireboss	4
Oiler-greaser	9
Electrician	12
Utility Crew	35
Subtotal	195
Outside	
Lampman	3
Scoop Operator	3
Mechanic	20
Hoistman	3
Supply Crew	9
Subtotal	38
Total Mine Labor	395
Total Management from Table 5-2	101
Cleaning Plant Employees	35
TOTAL	531
Clean tons/man shift	15.6

Stage III Manshifts per Day	
Section Crew	
Technical Serviceman-Extraction	18
Technical Serviceman-Haulage	18
Technical Serviceman-Roof Control	18
Ventilation Technician	18
Supply Vehicle Operator	18
Mechanic	18
Electrician	18
Monitoring Systems Technician	18
Subtotal	144
General Inside	
Supply Motorman	31
Beltman	22
Trackman	22
Wireman	12
Stopping Emplacer Operator	15
Pumper-Pipeman	9
Mechanic	40
Rock Duster	8
Equipment Mover	12
Conveyor Mover	12
Fireboss	4
Oiler-greaser	9
Electrician	18
Utility Crew	49
Subtotal	263
Outside	
Lampman	3
Scoop Operator	3
Mechanic	22
Hoistman	3
Supply Crew	12
Subtotal	43
Total Mine Labor	450
Total Management from Table 5-2	117
Cleaning Plant Employees	40
TOTAL	607
Clean tons/man shift	19.6

Table 5-1. Labor Manning (Continued)

Stage IV Manshifts per Day

Section Crew	
Technical Serviceman-Extraction	18
Technical Serviceman-Haulage	18
Technical Serviceman-Roof Control	18
Ventilation Technician	18
Supply Vehicle Operator	18
Monitoring Systems Technician	18
Subtotal	108
General Inside	
Supply Motorman	36
Beltman	22
Trackman	26
Wireman	14
Stopping Emplacer Operator	17
Pumper-Pipeman	11
Mechanic	45
Rock Duster	9
Equipment Mover	14
Conveyor Mover	14
Fireboss	4
Oiler-greaser	9
Electrician	21
Utility Crew	49
Subtotal	291
Outside	
Lampman	3
Scoop Operator	3
Mechanic	24
Hoistman	3
Supply Crew	15
Subtotal	48
Total Mine Labor	447
Total Management from Table 5-2	126
Cleaning Plant Employees	45
TOTAL	618
Clean tons/man shift	21.8

Table 5-2. Management Personnel

Position	Present	Stage I	Stage II	Stage III	Stage IV
Superintendent	1	1	1	1	1
General Mine Foreman	1	1	1	1	1
Asst. General Mine Foreman	3	3	4	5	6
Section Foreman/Supervisor	18	18	18	18	18
Construction Foreman/Supervisor	3	4	6	6	6
Haulage Foreman	1	2	3	3	3
Supply Foreman	1	2	3	3	3
Maintenance Superintendent	1	1	1	1	1
Asst. Maintenance Superintendent	1	2	3	3	3
General Maintenance Foreman	1	1	1	1	1
Shop Foreman	3	3	3	3	3
Maintenance Foreman	6	9	12	12	12
Chief Mine Engineer	1	1	1	1	1
Draftsman	1	2	3	4	5
Survey Crew	2	2	3	4	4
Safety Director	1	1	1	1	1
Safety Inspector	1	2	3	3	3
Training Instructor	1	2	4	6	8
Dust and Noise Technician	1	1	1	1	1
Officer Personnel Manager	1	1	1	1	1
Time and Bookkeeper	1	1	2	2	2
Purchasing Agent	1	1	1	1	1
Warehouseman	3	3	4	5	6
Industrial Engineer	1	2	4	6	6
Electrical Engineer	1	2	4	6	8
Asst. Mine Superintendent	0	1	1	1	1
Mine Engineer	0	1	2	3	4
Design Engineer	0	0	1	1	1
Mechanical Engineer	0	0	1	1	1
Ventilation Engineer	0	0	1	1	1
Supplies Engineer	0	0	1	1	1
Haulage Engineer	0	0	1	1	1
Computer Scientist	0	0	0	1	1
Computer Technician	0	0	0	3	3
Additional Salary	3	4	5	6	7
TOTAL SALARY	59	74	101	117	126

philosophy of scheduling a maintenance and service period for a portion of the shift in Stages III and IV require that the employee be trained in trouble shooting and machine repair. However, extensive repairs will be performed by maintenance specialists. He does routine maintenance and services the machine during the scheduled down time period and inspects its operation during the production period. He is also required to operate the machine when turning crosscuts and changing entries.

Stage IV - One technical serviceman-extraction stationed at the remote section console is required per producing section. The serviceman-extraction will travel into the section to maintain, service, and place change the machine and turn crosscuts during the scheduled service periods. He will remain at the remote section console station to interpret monitoring feedback data and make limited remote adjustments during the straight ahead mining advances.

2. Face Haulage.

Present Stage - Two shuttle car operators are required per producing section. The total manning is 36 shuttle car operators.

Stage I - Manning is the same as the Present Stage.

Stage II - It is anticipated that a mobile bridge conveyor system will outperform shuttle cars in this stage. The low production rate (4 tons/min), long straight ahead advances that reduce place changes, 60° crosscuts, need for a mechanical means to advance ventilation and miner cable and hose, and a method to remotely sense the continuous miner position in preparation for Stage IV are factors that point to the usefulness of a conveyor behind the extraction machine.

This is in addition to eliminating the cable and positional problems associated with shuttle cars. A problem with mobile conveyor installation is the need for three short bridges to negotiate the corners of a 16-foot-wide entry. Therefore, three bridge operators will replace two shuttle car operators in each section for a total manning of 54 mobile bridge operators.

Stage III - One technical serviceman-haulage near the belt tailpiece or near the area of turns being negotiated by the bridge is required to monitor the equipment operation and provide guidance in each producing section for a total manning of 18.

Stage IV - One technical serviceman-haulage is required per producing section at the remote console station. Service and repairs to the haulage system will be accomplished by this employee during the scheduled periods. During production periods he will monitor the status of the haulage system and communicate necessary data to the extraction machine controller.

3. Section Roof Control.

Present Stage - Two roof bolters place bolts on either side of the miner as it advances. In addition, two men center bolt entries and crosscuts previously mined; however, these two men are utility men that are listed in the chapter section on ventilation and supply handling. The total manning requirement is 36 roof bolters.

Stage I - Two extraction machine operators-bolting will place four bolts across the entry in front of the cutting and loading extraction machine operator. Total manning is 36 extraction machine operators-bolting.

Stage II - Manning is the same as Stage I.

Stage III - One technical serviceman-roof control is required to oversee the bolt installation process and assure adequate supplies.

Stage IV - One technical serviceman-roof control at each section remote console is required. He will monitor the roof bolting process and the output data from the roof control monitoring system. He will communicate necessary information to the extraction machine controller. He will service the roof bolters and assist in supplying the bolting units.

4. Section Face Ventilation.

Present Stage - One brattice man per section is required; however, the roof bolters at the continuous miner advance the tubing to within 10 feet of the face during miner advance, leaving the bratticeman, who is assisted by the utilityman, to place brattice in entries not being mined. The bratticing job does not require all of his time, so the brattice and utility men operate the center bolter when required. They also handle supplies and install auxiliary supports such as timber when necessary. Total present manning is 18 utility and 18 brattice men.

Stage I - Manning is the same as the Present Stage.

Stage II - Utilizing the cut sequence in Figure 2-1 reduces the number of brattice installations so the ventilation man can assist the supply vehicle operator. The total manning requirements is 18 ventilation men.

Stage III - One ventilation technician is required per section. The ventilation technician will set up ventilation facilities during service periods and place changes. When coal is being produced he will review data from the monitoring systems, move up, install, and calibrate new sensors. The total manning requirement is 18 ventilation technicians.

Stage IV - A remote console ventilation technician is required per producing section. He will observe environmental monitoring system feedback information and communicate the necessary data to the extraction machine controller. During service periods he will set up ventilation and assist in servicing the monitoring system. The total manning requirement is 18 ventilation technicians.

5. Section Ventilation - Outby the Face.

Present Stage - Three stoppings are required for each 88 feet of advance in the four entry systems shown in Figure 2-1. At 27 raw tons per foot of advance, one stopping will be constructed for each 790 tons on development. The Present Stage tonnage mined on development is 38 percent of the total. Therefore, three stoppings per day are required. If a mason constructs a stopping in a shift, three masons are required for building stoppings. If each panel is 3000 feet long, and at least five overcasts are required per panel, or one overcast per 43,000 tons. Assuming two masons can construct an overcast in a week, and maintenance of old stoppings and overcasts require one mason, the total mason crew is five men ($\frac{\text{4500 tons per day}}{\text{43,000 tons per overcast}} \times \frac{\text{10 man shifts}}{\text{overcast}} +$ 1 + 3 masons).

Stage I - Due to increased production, $\frac{380}{310} \times 5 = 7$ masons will be required.

Stage II - An improved stopping emplacement machanism will be developed to mechanize and speed up stopping construction, As a result one stopping emplacer operator will be able to install two stoppings per shift. Therefore, $1/2 \times 4 \times \frac{560}{310} = 4$ men are required in addition to $3 \times \frac{560}{310} = 6$ workers for overcast construction and maintenance for a total of 10 employees.

Stage III - Production increases $\frac{800}{560} \times 10 = 15$ stopping emplacer operators and men to construct overcasts and maintain ventilation structures.

Stage IV - Additional production requires $15 \times \frac{920}{800} = 17$ stopping emplacer operators and men to construct overcasts and maintain ventilation structures.

6. Trailing Power Cable Handling.

See Electricians (Item 17) and mobile bridge conveyor system introduction in Stage II (Item 2).

7. Moving Section Power Center.

See Electricians (Item 17), they will work with the conveyor movers (Item 8) to accomplish this task.

8. Section Conveyor Belt Advancement.

Present Stage - Extension or retraction of two crosscuts or 180 feet of belt can be accomplished by a six-man crew in one shift. In addition, four man shifts are required to prepare for the belt move. An average of 155 feet of conveyor must be moved per day at the present retreat and advance rates. Therefore, a nine-man conveyor move crew is required.

Stage I - Increased tonnage will expand the crew size to $\frac{380}{310} \times 9 = 11$ conveyor movers.

Stage II - It is expected that the belt-moving apparatus introduced at this stage will allow the present belt crew size to keep up with the increased production. Therefore, 11 conveyor movers are needed.

Stage III - In order to keep up with production at this stage, two crews of six employees each for a total of 12 will be necessary.

Stage IV - Due to increased production and frequency of moves, the crew size will be increased to seven for a total of 14 conveyor movers.

9. Conveyor Belt Cleaning.

Present Stage - One man on each producing shift plus four men on the general mine belts are required to maintain conveyor belts within legal requirements. The total manning is 22 beltmen.

Stage I - The same manning requirements as the Present Stage are anticipated.

Stage II - The manning will not change during this stage.

Stage III - The same manning requirements apply.

Stage IV - The section conveyors will be cleaned only during service periods which means that a portion of the general mine belts can be cleaned by the section beltmen during production periods. The manning can remain at 22 beltmen.

10. Rock Dusting (Section and Mine).

Present Stage - Rock dust is spread by hand from bags in each section by the utility man. A bantam-type duster is used periodically. Rock dust on main haulage entries and supply tracks is done by a rail mounted duster. Two men are required to rock dust main entries.

Stage I - It is anticipated that rock dust will be applied by mechanical blowers during service shifts rather than by hand during the production shift. Therefore, the oiler-greaser on each section maintenance shift will rock dust the section after the equipment has been serviced. The general mine rock dust crew expands to $\frac{310}{250} \times 2 = 3$.

Stage II - Increased production results in a requirement of $\frac{460}{310} \times 3 = 5$ general mine rock dusters.

Stage III - Production changes increase the general mine rock dust crew to $\frac{660}{460} \times 5 = 8$.

Stage IV - Additional production increases manning to a total of $\frac{750}{660} \times 8 = 9$ rock dusters.

11. Roof Testing.

Stage I and Stage II operations will remain the same as the Present Stage. That is, the section workers, foremen, and firebosses check the roof in each working place by "sounding." Stages III and IV will include the roof-control monitoring system which will not replace manual sounding except during Stage IV production periods, but will provide more quantitative data. The roof-control technician will operate the monitoring system.

12. Methane Measurement.

Stage I and Stage II operations will remain the same as the Present Stage. That is, the section workers, foremen, and firebosses check methane levels with methanometers and flame safety lamps manually at 20-minute intervals and prior to working in a place. Stages III and IV will include the environmental monitoring system which will not replace manual testing except during Stage IV production periods. The ventilation technician will operate the environmental monitoring system.

13. Mine Examiner, Fireboss, or Foreman Inspections.

Present Stage - A total of four firebosses will be necessary to make the required mine examinations.

Stage I - No change from the Present Stage manning is anticipated.

Stage II - No change from the Present Stage manning is anticipated.

Stage III - No change from the Present Stage manning is anticipated.

Stage IV - No change from the Present Stage manning is anticipated.

14. Supply Handling.

Section Supply Handling

Present Stage - The utility man, with the help of the shuttle-car operators, handles supplies for the section. Manning requirements for these positions are already listed.

Stage I - The manning requirements do not change, but a battery scoop is introduced to help with cleanup and supply handling. The amount of assistance from the shuttle car operators should decrease. There are 18 supply/utility men already listed.

Stage II - A vehicle to handle supplies is introduced in Stage II. The increased production results in increased supply handling so an operator is designated at this stage. One operator per production section is required for a total manning of 18 supply vehicle operators.

Stage III - As in Stage II, 18 supply vehicle operators will be required. The supplies should be unloaded at the panel submain intersection during the production period or some other designated location to allow a prompt delivery to the section during the service period. Since supplies will be primarily for maintenance, roof control and ventilation it is anticipated that men from these areas will assist the supply vehicle operator.

Stage IV - The same procedure as Stage III will be used except no supplies will be delivered to the section during production periods. Computerized supply ordering should allow supply handling to be confined to service periods due to improved scheduling.

General Mine Supply Delivery

Present Stage - It is assumed that groups of sections are generally located in close proximity to each other in the mine so that three sections can be serviced by each supply crew (a supply motorman and a helper). Assuming that production is at a level that supplies need to be delivered only once each working day, six supply motormen are required. In addition, three more crews, or six supply motormen will be required to deliver to general mine construction projects such as overcasts, conveyor-belt extensions, track-laying jobs, and outlying sections. The total manning is 12 supply motormen. This is a requirement of one motorman per 465 raw tons per day.

Stage I - Due to increased production, the supply motorman ratio calculated above means approximately 15 supply motormen and helpers are required.

Stage II - Maintaining the same ratio of one motorman to 465 tons, the required number of supply motormen and helpers increases to 22 in this stage.

Stage III - A similar increase will raise the required number to 31 in this stage.

Stage IV - Another production and supply-usage increase raises the total to 36 supply motormen and helpers.

15. Fresh Water Supply and Drainage.

Present Stage - One man per day is required to travel to all pumps in the mine, and to service, maintain, and operate them. In addition, one foot of pipe must be installed per 27 raw tons mined on development and one foot removed per 45 tons on retreat. Therefore, 125 feet of pipe must be moved daily. This task can be accomplished by two men, resulting in a total manning of three pumper-pipemen.

Stage I - Production increase results in $1 + (2 \times \frac{380}{310}) = 4$ pipemen.

Stage II - Additional production requires $1 + (3 \times \frac{560}{380}) = 6$ employees.

Stage III - Increased tonnage results in a total manning of $1 + (5 \times \frac{800}{560}) = 9$.

Stage IV - Another production change increases pumper-pipemen to $1 + (8 \times \frac{920}{800}) = 11$.

16. Equipment Service.

Present Stage - An oiler-greaser lubricates machines on the service shift daily in each section. Their duties will include filling hydraulic oil tanks and changing the bits on the continuous miner, and rock dusting the section. Nine oiler-greasers are required.

Stage I - No change from the Present Stage is anticipated.

Stage II - Even though some automatic lubrication will be available on the automatic equipment some lubrication and oiling will still be required as a result, the manning requirement will remain constant.

Stage III - The same requirements as Stage II are expected, except oiling and greasing can be done in the service periods.

Stage IV - The same requirements as Stage III are expected.

17. Maintenance

Present Stage - Currently one mechanic per section is required for a total manning of 18 mechanics.

Stage I - Manning is the same as the Present Stage.

Stage II - Due to the increasing complexity of equipment an electrician and a mechanic are required in each producing section.

Stage III - Manning is the same as Stage II.

Stage IV - Due to the removal of personnel from the section and the clear division of production and service-maintenance times, the positions of machine operator and mechanic are consolidated. Additional maintenance and electrical personnel will be available from a central pool. Operation of equipment does not require a full-time person at this stage due to its automatic control nature.

General Mine Maintenance

Present Stage - It is anticipated that nine section shifts per day be utilized for maintaining equipment in addition to the 18 production shifts. Two mechanics for each of the nine maintenance section shifts will be required. In addition, six roving mechanics and three mechanics for general mine construction jobs will be required each day for a total of 15 mechanics.

Stage I - Increased production results in a requirement of $\frac{380}{310} \times 15 = 19$ mechanics.

Stage II - The mechanic force will be increased to $\frac{560}{380} \times 19 = 28$ people.

Stage III - Production changes increase the maintenance force to $\frac{800}{560} \times 28 = 40$.

Stage IV - Additional production increases manning to a total of $\frac{920}{800} \times 40 = 45$.

General Mine Electrician

Present Stage - Two electricians per shift or six per day are needed in the present mine.

Stage I - Increased tonnage in addition to increased electrical complexity of machines indicates a need for eight electricians.

Stage II - Due to increased tonnage and manual operations becoming mechanized with electric controls in addition to increased electrical complexity in automated equipment, the number of electricians is expanded to 12.

Stage III - It is estimated that the number of electricians will increase from the previous requirement due to the introduction of monitoring systems and system integration control requirements. Total manning is projected at 18.

Stage IV - Electrical maintenance requirements for sophisticated remote control equipment will increase the electrician force to 21.

18. Monitoring Systems.

See electricians and maintenance (Item 17) and Stage III and IV section workers (Items 1, 2, 3, and 4).

19. Spillage and Roadway Cleanup (other than belts).

See utility men in section Supply Handling (Item 14) and mobile bridge operators in Stages II, III, and IV (Item 2).

20. Miscellaneous.

General Mine Construction

General - The following major jobs must be accomplished to establish a new production section. (Some items do not apply to the Present or Stages I and II.)

1. Drill, shoot, and load out six overcasts.
2. Develop for a distance of four crosscuts from the submain and install stoppings.
3. Install conveyor belt head, drive, tailpiece and belt.
4. Install supply track and trolley wire.
5. Install water supply pipe.
6. Install load center and cables.
7. Move in equipment and monitoring systems.
8. Construct supervisory control station.

Present Stage - At a production rate of 100 tons per shift, 1.5 months are required to drive four crosscuts working three shifts per day. Another .5 month is necessary to install conveyor, track, and establish ventilation for a total of two months time to set up a new section. Using the present production rate, a 3000 foot panel can be mined out in 1.6 years:

$$\frac{3000 \text{ feet} \times 72 \text{ tons/foot}}{310 \text{ tons/shift} \times 2 \text{ shifts/day} \times 220 \text{ days/year}}$$

Since there are nine sections, a new panel has to be set up every 2.1 months. Therefore, one development crew of about seven men working three shifts per day can keep ahead of basic requirements. Obviously, they will have to use mining equipment that is more flexible than the AES for initial panel development, so this equipment must be moved from one development area to the next. This requires a set of mining equipment just for development and construction work. The total manning is 21 utility men.

Stage I - Increased production requires a panel to be set up every 1.7 months; therefore, seven man development crews are required in two areas for two shifts per day which will result in a setup time of 1.5 months and a manning of 28 utility men.

Stage II - The setup requirement is one section every 1.2 months. Therefore, two areas, one at three shifts per day and one at two shifts per day and 35 utility men are necessary.

Stage III - At this production level, a new section is required every 0.8 months, so three development areas with two at three shifts per day and one at one shift per day and 49 utility men are required.

Stage IV - At the final tonnage level, a section is required every 0.7 months, which can be accomplished at the same manning as in Stage III.

Track Installation and Maintenance

Present Stage - Using the mining projection in Figure 2-1, an advance of one foot per 27 raw tons and a retreat of 45 raw tons per foot are calculated. Therefore, daily track moves of 155 feet must be made. It will be assumed that supply track will be placed in each section and advanced or retreated every two crosscuts. A four-man track crew is considered capable of installing or removing two crosscuts, or 180 feet of track per shift, excluding maintenance on old track; four men per day are required. Four additional men are required for maintenance and switch installation. Therefore, a total manning of eight track men is indicated.

Stage I - Due to tonnage increase, the number of trackmen required is $\frac{380}{310} \times 8 = 10$.

Stage II - Additional tonnage increase brings the total to $\frac{560}{380} \times 10 = 15$.

Stage III - Another rise in tonnage results in a requirement of $\frac{800}{560} \times 15 = 22$ trackmen.

Stage IV - At the final tonnage, $\frac{920}{800} \times 22 = 26$ trackmen are required.

Trolley Wire Installation and Maintenance

Present Stage - Two wiremen are required for the daily track move previously discussed. In addition, two more wiremen will be needed for trolley wire maintenance. Therefore, a total of four wiremen will be required.

Stage I - Due to tonnage increases, the total number of wiremen required is $\frac{380}{310} \times 4 = 5$.

Stage II - Additional tonnage brings the total to $\frac{560}{380} \times 5 = 8$.

Stage III - Another rise in tonnage results in a requirement of $\frac{800}{560} \times 8 = 12$ wiremen.

Stage IV - At the final tonnage, $\frac{920}{800} \times 12 = 14$ wiremen are required.

Equipment Moving (between panels)

Present Stage - Moving equipment from one mined-out panel to another and to and from the surface for overhaul or replacement requires four men.

Stage I - Due to increased production and more frequent moves, the number of equipment movers is increased to five.

Stage II - Additional components in a section such as the piped rock-dust system and supply handling vehicle in addition to more complex and frequent moves will expand the moving crew to eight men.

Stage III - Relocating and monitoring systems will be a major effort in addition to the more often and complex moves which will change manning requirements to 12 people.

Stage IV - There will be much more complexity involved in moving a supervisory control station in addition to increased move frequency; therefore 14 people are projected.

21. Management.

Table 5-2 lists requirements for management personnel. Mine supervisors, particularly front-line people such as foremen, are increased in number due to increased production. Technical people, such as engineers and computer personnel, are added as automation progresses to the higher levels of technical support required. The maintenance department in particular requires mechanical, electrical, and design engineers as automation progresses to provide information on rebuilding, improving, and evaluating automated, remote controlled equipment and monitoring systems. The purchasing and warehousing functions will receive considerable support from the computer staff.

Discussion

Several generalities may be reported as a result of the preceeding analysis. These statements provide some of the basis for the discussion of psychological and organizational impact of automation in Chapter 10. Tables 5-3, -4, -5, and -6 summarize the following discussion.

The portion of section or face workers to the total mine employment decreases significantly from 56.6 percent to 27 percent. (See Table 5-3). It is also significant that most of the employees from the working

Table 5-3. Percent of Underground Work Force by Occupation

	Present	Stage I	Stage II	Stage III	Stage I
Section Crew					
Extraction Machine Operator	6.3	6.1	5.0	4.4	0
Loading Machine Operator	6.3	0	0	0	0
Haulage Machine Operator	12.6	12.2	15.1	4.4	0
Roof Bolter Operator	12.6	12.2	10.1	4.4	0
Ventilation Personnel	6.3	6.1	5.0	4.4	4.5
Supply/Utility Personnel	6.3	6.1	5.0	4.4	4.5
Maintenance Personnel	6.3	6.1	5.0	13.3	18.0
Section Crew	56.6	49.0	45.4	35.4	27.1
General Inside					
Supply Motorman	4.2	5.1	6.2	7.6	9.0
Beltman	7.7	7.5	6.2	5.4	5.5
Trackman	2.8	3.4	4.2	5.4	6.5
Wireman	1.4	1.7	2.2	2.9	3.5
Mason	1.7	2.4	2.8	3.7	4.3
Pumper-Pipeman	2.5	1.4	1.7	2.2	2.8
Mechanic	5.2	6.5	7.8	9.8	11.3
Rock Duster	0.7	1.1	1.4	2.0	2.3
Equipment Mover	1.4	1.7	2.2	3.0	3.5
Conveyor Mover	3.1	3.7	3.1	3.0	3.5
Fireboss	1.4	1.4	1.1	1.0	1.0
Oiler-greaser	3.1	3.1	2.5	2.2	2.3
Electrician	2.1	2.8	3.4	4.4	5.3
Utility Man	7.4	9.5	9.8	12.0	12.3
General Inside	43.4	51.0	54.6	64.6	72.9

Table 5-4. Manshift Summary for Selected Personnel Groups

Personnel Group	Present	Stage I	Stage II	Stage III	Stage IV
Maintenance					
Labor	61	68	86	146	176
Supervisors	13	18	26	32	34
Total Maintenance	74	86	112	178	210
Management					
Maintenance	13	18	26	32	34
Engineering	5	8	16	25	27
Operating	29	32	37	38	39
Other	12	16	22	22	26
Total Supervisors	59	74	101	117	126
Section Crew	162	144	162	144	108
General Inside Crew	124	150	195	263	291
General Outside Crew	30	32	38	43	48
All Personnel	400	430	531	607	618

Table 5-5. Raw Tons per Manshift Summary for Selected Personnel Groups

Personnel Group	Present	Stage I	Stage II	Stage III	Stage IV
Maintenance					
Labor	91	101	117	99	94
Supervisors	429	380	388	450	487
Total Maintenance	75	80	90	81	79
Management					
Maintenance	429	380	388	450	487
Engineering	1116	855	630	576	613
Operating	192	214	272	379	424
Other	465	428	458	654	636
Total Supervisors	95	92	100	123	131
Section Crew	34	48	62	100	153
General Inside Crew	45	46	52	55	57
General Outside Crew	186	214	265	334	345
All Personnel	14	16	19	24	27

Table 5-6. Percent of Total Work Force Summary for Important Personnel Groups

Personnel Group	Present	Stage I	Stage II	Stage III	Stage IV
Maintenance					
Labor	15	16	16	24	28
Supervisors	3	4	5	5	6
Total Maintenance	18	20	21	29	34
Management					
Maintenance	3	4	5	5	6
Engineering	1	2	3	4	4
Operating	7	7	7	6	6
Other	4	4	4	4	4
Total Supervisors	15	17	19	19	20
Section Crew	41	33	31	24	17
General Inside Crew	31	35	37	43	47
General Outside Crew	8	7	7	7	8
All Personnel	100	100	100	100	100

section will be transferred to general mine work as the percentage of those employees increases from 43.4 to 72.9 percent of the total force. However, general mine workers will rotate into the sections to do specialized work during maintenance and service periods.

Table 5-4 indicates that the number of manshifts of maintenance personnel increases almost threefold from 74 to 210 per day. This increase holds for union employees and supervisors. An additional large increase is obvious in engineering - fivefold - from five to 27 manshifts per day. The overall increase for all employees is only 1.5 times.

The large increases in these groups is not solely due to production, but more a result of the introduction of automation and remote control technology as is evidenced by the raw tons per manshift summary for selected personnel groups in Table 5-5. Normally as production increases in current underground coal mines, tons per shift for maintenance employees rises. However, the tons per shift changes only from 75 to 79. It is almost constant. This is the result of the introduction of automation technology. Engineering personnel productivity is even more pronounced since a decrease in tons per manshift from 1116 to 613 is recorded. As expected, the productivity of the section crew increases greatly (from 34 to 153 tons per manshift).

Table 5-6 summarizes the percent of total work force for selected personnel groups. The rise in maintenance and engineering personnel percentages is evident as well as the section crew decrease and general mine increase.

Chapter 6
HEALTH AND SAFETY

Introduction

This report section investigates the extent to which automation and remote control will change the health and safety of mine workers. Automation introduces technological advances to the underground coal mine operation that should greatly increase safety; however, as in all innovations, care must be taken to eliminate the introduction of new hazards. In addition, the change in personnel requirements from one stage to another (reported in the previous section) will also affect the overall mine safety record. That is, automation technology changes both accident causes and personnel disposition which produce a combined effect on health and safety. A variety of work factors will change including:

1. the amount of time workers are exposed to accidents, that is, when they are outside of canopy protection or in the face area;
2. the number of workers in a given occupation;
3. worker location, whether it is a more or less hazardous area;
4. introduction of new machines;
5. combinations of several functions into one machine;
6. introduction of monitoring systems; and
7. job functions or work performed by individual employees.

Obviously, variations in these work factors or job parameters affect the health and safety of miners. How much and in what manner is investigated in this report section. For example, the exposure time to possible hazards (in minutes per shift and percent change from the present) is estimated for each occupation in the various stages of automation.

The well-accepted USBM injury statistics tabulation that relates occupation at time of injury with general work location and principal injury cause is used as the basic format for this analysis. The various mine worker occupations are investigated for hazards that could cause injury from the several categories listed in the table. The categories are roof falls, face or rib falls, bumps or bursts, other falling objects, slips or falls of persons, handling materials, hand tools, stepping or kneeling on sharp or loose objects, striking or bumping againt objects, haulage, explosions, explosives, electricity, machinery, suffocation, mine fires, pneumoconiosis, and all other causes. An example of this tabulation format is shown in Table 6-1, which reports the number of 1970 injuries.

Analysis Technique

Automation and remote control technology will change the working environment and job functions of miners. Consequently, the possibility of injury from the aforementioned accident causes will change. Deciding what automation and remote control innovations affect injury causes for different occupations and how much the accident frequencies (number of lost time, disabling, and fatal injuries per million man hours worked) will change is a complicated investigation because of the many interacting variables. In order to logically present the possible effects of automation technology on present accident causes, fault tree diagrams

Table 6-1. Number of 1970 Injuries.*

Occupation at time of injury and general work location	Underground (including shaft and slope)																		
	Falls of roof	Falls of face or rib	Pressure bumps or bursts	Other falling materials or objects	Slips or falls of persons	Handling materials	Handtools	Stepping or kneeling on sharp or loose objects	Striking or bumping against objects	Haulage	Explosions (gas or dust)	Explosives	Electricity	Machinery	Suffocation	Mine fires	All other	Pneumoconiosis	All injuries
Underground mines:																			
Underground (including shaft and slope):																			
At or near face:																			
Coal drillers (machine and hand) ---	19	7	-	4	8	27	4	2	1	14	-	4	7	43	-	-	4	-	144
Continuous miner operators ---------	174	29	4	10	32	88	18	11	1	38	4	1	10	146	-	-	7	1	574
Cutting-machine operators ----------	53	21	-	1	9	65	15	4	2	32	-	7	6	120	-	2	3	2	342
Hand loaders (to car or conveyor) --	7	1	-	2	1	15	1	1	-	3	-	-	-	2	-	-	-	-	33
Hand or pick miners ----------------	3	-	-	2	4	4	2	-	1	3	-	1	-	3	-	-	-	-	23
Loading machine operators ----------	128	60	-	31	13	73	19	7	2	33	2	7	13	149	1	1	3	1	543
Longwall crew ----------------------	36	3	2	-	3	21	3	-	-	12	-	-	1	38	-	-	2	-	121
Roof bolters -----------------------	400	54	3	18	48	133	36	21	4	72	-	2	16	448	-	2	13	-	1,270
Shot firers ------------------------	30	22	-	2	12	44	6	5	1	18	-	24	2	22	-	-	4	1	193
Timbermen and jacksetters ----------	71	16	1	4	20	157	22	15	3	43	-	-	3	34	1	1	1	1	393
Haulage activities:																			
Belt and boom operators and crews --	26	4	-	12	31	132	35	9	5	71	1	1	9	44	-	1	10	-	391
Brakemen ---------------------------	1	-	-	-	-	10	-	-	-	37	-	-	-	-	-	1	1	-	50
Car droppers and dumpers, and cagemen ---------------------------	1	-	-	-	2	11	1	-	-	18	-	-	-	4	-	-	2	-	39
Motormen ---------------------------	16	3	-	2	15	65	2	4	1	217	-	2	30	12	-	1	4	-	374
Shuttle car operators --------------	92	32	2	16	32	177	24	12	3	395	1	6	39	45	-	4	8	-	888
Trackmen, bonders and wiremen ------	5	2	-	-	11	86	17	3	-	24	-	-	5	5	-	-	1	-	159
Tractor and truck operators --------	2	-	-	-	4	5	1	1	-	2	-	-	-	2	-	-	-	-	17
General:																			
Electricians -----------------------	10	6	-	3	17	77	26	4	1	47	-	-	25	9	-	1	14	-	240
Laborers and move crews ------------	81	31	-	13	59	277	50	10	9	174	-	6	24	100	-	1	16	1	852
Machinists -------------------------	-	1	-	1	-	2	3	1	-	-	-	-	3	4	-	-	1	-	16
Mechanics, oilers and greasers -----	26	9	-	12	34	177	54	13	5	93	-	1	48	48	-	3	16	-	539
Pumpmen ----------------------------	1	2	-	2	1	7	1	2	-	5	-	-	4	3	-	-	2	-	30
Rock dusters -----------------------	4	2	-	2	6	24	3	1	-	26	-	-	3	3	-	-	1	-	75
Supplymen --------------------------	7	2	-	2	8	84	6	4	1	67	-	-	1	7	-	1	3	-	193
Ventilation men --------------------	16	5	-	2	10	45	10	3	-	17	-	-	2	8	-	-	5	-	123
Supervisory and technical:																			
Superintendent, mine foremen, and assistants ------------------------	23	7	-	5	23	45	6	8	2	43	1	2	6	15	1	-	1	-	188
Working foremen, crew leaders, and fire bosses ----------------------	43	12	-	3	23	69	8	13	7	65	-	6	17	38	-	3	9	-	316
All other supervisory and technical	2	-	-	-	-	8	2	-	-	6	1	-	1	-	1	-	-	-	21
Other, not elsewhere classified ------	4	1	-	2	4	27	5	3	-	12	-	-	1	10	-	-	2	-	71
In major disaster 2/ ----------------	-	-	-	-	-	-	-	-	-	-	38	-	-	-	-	-	-	-	38
Not stated --------------------------	109	29	-	12	26	164	35	18	10	132	-	2	15	124	-	1	8	2	687
Total ------------------------------	1,390	361	12	163	456	2,119	415	175	59	1,719	48	72	291	1,486	4	23	141	9	8,943

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* Extracted from Injury Experience in Coal Mining, 1970, U.S.B.M. Information Circular 8613 by F. T. Moyer and M. B. McNair.

of the numerous events leading to each major accident type were constructed. They comprise Appendix D. The fault tree analysis technique can also be used to recommend technology innovations that will improve safety in the various automation stages. The diagrams are discussed in more detail later in this section.

A quantitative estimate of percent change in accident frequencies from the Present Stage to Stages I, II, III, and IV is made to approximate the amount of impact automation will have on health and safety. The percentages are developed for each occupation and injury cause using the format of Table-1. An example using the latest figures available from the USBM in this format (1970) is utilized to project the impact of automation innovations on mine worker accident frequency. The result, summarized in Table 6-18, is that health and safety will improve significantly.

Fault Tree Analysis

The fault tree diagrams in Appendix D have a dual purpose. First, they are used to show the interactions of various events that could lead to an injury causing accident. In this regard, the diagrams are a useful tool for estimating accident frequency change caused by a proposed automation technique that varies the possibility of occurrence of one of the events. Second, fault trees reveal the underlying causes of injuries, so recommendations can be developed for automation innovations to reduce the possibility of occurrence of a certain event.

The fault tree is an orderly path of events that could produce a fault or undesired outcome such as an accident that injures a mine worker. Its construction begins with the undesired outcome at the top. The combination of events that could produce that result are then added to the tree. Next, each of these events is analyzed for its underlying causes. When the desired detail has been obtained or information is lacking, the lower limit of the diagram has been reached.

Events are combined along the path at junctions called "gates." Depending on the relationship between the events, an "or" gate () or an "and" gate () is used. For example, if both events A and B must occur to produce the outcome an "and" gate is required. However, if either the A or B event will produce the results, an "or" gate is used.

If numerical values for the possibility of occurrence of the events are known, they can be combined by the laws of Boolean algebra to produce the possibility of the fault occurrence. The algebraic equations are formed by multiplying probabilities at "and" gates and adding them at "or" gates. Unfortunately, the probability of a human action, such as testing the roof, occurring is impossible to quantify. The numerical calculations for the probability of an accidental injury are severely restricted since they are commonly a result of improper mine worker actions.

The fault tree diagrams will be used in the following discussion to show how automation and remote control will affect accident causes.

<u>Falls of Roof, Face, or Rib</u>. The fault tree diagram in Figure D-1 shows that a worker can be exposed to a roof fall in several ways. He may not be aware of dangerous roof as a result of failing to test it,

testing improperly, or receiving no warning signs during the test. A roof condition monitoring system that measures such items as roof and floor convergence, degree of bending in the roof beam, microseismic emissions, and pillar stress would be an extremely important addition to an integrated automatic or remote controlled mining system. The monitoring system would provide warning to the worker without requiring him to test the roof or listen for "roof talk." In addition to the obvious safety advantage, the monitoring system would reduce production delays caused by cleaning up roof falls and repairing equipment damaged by falls.

A monitoring system is extremely important in the Stage IV remote controlled system. Men entering the section during the service period would not be aware of changes in roof conditions that occurred during the production period unless sensors were present to allow remote monitoring of roof conditions. Therefore, when bad roof is detected, a roof support team could enter the section to stabilize the roof before the service crew began work.

Pillar and entry design would be improved as a result of the data available from the monitoring system. Therefore, actual ground control measurement data, which is usually not available at present, could be used in evaluating experimental pillar sizes. Obviously, correct pillar and entry dimensions will minimize roof falls, thus improving safety and production.

Automation and remote control will decrease the time workers are exposed to roof falls. Machinery operators will be in a relatively safe cab or canopy during the Stage I, II, and III production periods. However, they will be out of the cabs during service periods. As a result, reducing the length of service periods and maximizing production time will improve safety as well as production. The entire section crew will be located in the remote console station during Stage IV production periods. Therefore, the station should be of adequate structural strength and located in a safe area to eliminate roof-fall injuries when the miners are working in the station.

In addition to showing the relationship of worker exposure to roof falls, Figure D-1 diagrams events necessary for a roof-fall occurrence. Some of the occurrences are due to lack of or improper temporary support installation. Men are exposed to unsupported roof while installing temporary support. This has been the cause of a number of injuries. Therefore, one of the biggest safety advantages of the AES is the temporary roof-support units. As the machine advances, temporary roof support is automatically set within eight feet of the face. As a result, men are not exposed to unsupported roof while setting supports and the roof is well supported by properly installed beams. In addition, there is very little time lapse between roof exposure and temporary support. Minimizing the length of time that unsupported top must stand is of paramount importance because roof failure is time dependent. Unsupported roof is also minimized by tapering the roof profile at the "dead end" cuts when the AES is to withdraw the charge places.

The AES machine also improves immediate support. Roof bolters on the present mining machine at the proposed AES trial site install only two bolts across the entry on either side of the continuous miner.

Center bolts are installed after the miner has moved to another entry. The AES will install four bolts across the entry, 16 feet back from the face as it advances. Consequently, the support installed immediately after mining in Stage I is a great improvement over the Present Stage.

Slips or Falls of Persons. Figure D-2 shows that a situation for a person to slip or fall must exist and the person must be in a position to slip or fall for the accident to take place. Automation will not cause a person to be more cautious or improve housekeeping, but it will reduce the exposure time to such accidents. Besides reducing exposure time, the amount of manual labor in supply handling (where many slips and falls occur) will be reduced when the supply handling vehicle is introduced in Stage II.

Handling Material. The greatest reduction of materials handling injuries, diagrammed in Figure D-3, by automation will result from the introduction of a supply handling vehicle and reduction in exposure time. The amount of supplies required will increase due to improved production and the greater mechanical and electrical complexity of automated equipment.

Hand Tools. Reduction in the hand-tool injuries diagrammed in Figure D-4 will result from a decrease in exposure time by workers using hand tools. Increased mechanization in the areas of supply handling and conveyor-belt installation will reduce the number of situations where possibility of hand-tool injury exists.

Haulage. Conveyor belts are used from the sections to the portal for transporting coal in the present and all four stages of automation.

Therefore, little change in haulage accidents will occur out by the section. On the other hand, face-haulage equipment changes from shuttle cars to a mobile-bridge conveyor, which will significantly reduce haulage accidents. As the shuttle cars are replaced in Stage II, the number of accidents from collisions will decrease dramatically; however, the increased injury possibility of being caught in the conveyor will be introduced. Consequently, the mobile conveyor should be well guarded, especially in the operator cab areas.

Men, supplies, and equipment will be transported by rail haulage from the portal to the panels. Improved scheduling of supply delivery, better dispatch control of rail traffic, and improved track conditions, should reduce accidents in Stages III and IV.

Electricity and Machinery. Automation will increase the number of electrically powered machines that mine workers will contact. Therefore, the possibility of an accident occurrence will be greater. However, Stage IV remote control operation should greatly reduce the amount of contact with operating machinery except for mechanics and electricians. The increased number of repairs will require a larger maintenance staff, so the possibility of injury to a single employee will not change considerably.

Accident Frequency Change

Exact accident frequencies are impossible to predict due to the human factors of memory lapse or being careless or unaware of danger. Consequently, changes are predicted by using quantifiable parameters such as exposure time while assuming that these unpredictable worker actions will have the same effect on all automation stages.

The predicted accident frequencies result from variation in job activities where an accident might occur. The previously discussed fault-tree diagrams show how job activities are related to the probability of an accident occurrence. Changes in the detailed events that cause accidents are determined comparing the Present Stage job activities with Stage I, II, III, and IV. An approximation of percentage variations in accident frequencies is the result.

Accident frequency percentages developed here may be applied to both fatal and nonfatal accidents. The number of injuries per million man hours (accident frequency) can be calculated for any stage by multiplying the percentages shown in Tables 6-9, -10, -11, and -12 by the current accident frequency for a particular occupation. An example calculation with the 1970 data given in Table 6-13 is used to arrive at the frequencies listed in Tables 6-14, -15, -16, and -17. (Current statistics are not available to project personnel.)

Job titles will change as noted in the previous report section, "Personnel Requirements." In order to facilitate tabulation in this section, tables are constructed using a category of work responsibility such as "Extraction Personnel." The reader should infer that the job titles change through stages when examining the tables. For example, in Table 6-2, "Extraction Personnel" are actually "Technical Servicemen" in Stages III and IV. Additionally, Stage IV technical servicemen duties are more similar to a mechanic than a machine operator, consequently, this job function will be considered in the mechanic class when computing variations in injury probability.

Table 6-2. Exposure Time in Minutes per Shift. (Based on a total shift of 480 minutes)

	Extraction Machine Personnel*		Haulage Personnel*	Ventilation Personnel	Supply Personnel	Mechanic, Electrician, & Monitoring Personnel
	Cutting	Bolting				
Present	210	210	225	385	385	385
Stage I	195	195	220	385	385	385
Stage II	195	195	225	385	200	385
Stage III	165	165	210	390	110	390
Stage IV	135	135	135	135	70	135

* In Stage IV the technical servicemen's duties are more similar to a mechanic than a machine operator; therefore, these jobs will be considered in the maintenance category when computing accident frequency variations.

Table 6-3. Percent of Present Stage Exposure Time.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	93	93	79	35
Haulage Personnel	86	88	82	35
Roof Support Personnel	93	93	79	35
Ventilation Personnel	100	100	101	35
Supply/Utility Personnel	100	52	29	18
Mechanic, Electrician, and Monitoring Personnel	100	100	101	35

Exposure Time. It is assumed that all equipment cabs and canopies are strong enough to protect the operator from roof, rib, or face falls. Therefore, the operator is exposed to roof falls only when he is out of the cab. For example, the continuous miner operator is not exposed to roof falls during the times listed in Table 4-1 for mantrip, lunch, fireboss inspection, cutting and loading, place changing, shuttle car changeout, and bolt delay. Similar analysis applied to all face employees results in the exposure times summarized in Table 6-2. The percent of present exposure time is presented in Table 6-3. The calculated exposure times apply to many accident causes since the cab protects the operator from accidents other than roof falls. Consequently, increased operating time improves safety since the operator is protected during production periods.

The reduction in "face or rib falls" accident probability is due only to reduction in exposure time (see Table 6-3). Other accident causes that depend only on exposure time are "bumps or bursts," "other falling objects," "slips or falls of persons," "stepping and kneeling on sharp or loose objects," and "striking or bumping against objects."

The supply vehicle will have a cab or canopy to protect the supply man during Stages II, III, and IV. It is estimated that the supply man will spend 50 percent of the Stage II shift in the supply vehicle. The percentage increases directly with the amount of production improvement in Stages III and IV.

Other Factors. Other factors that will affect safety, but are more difficult to quantify are:

1. The roof is supported immediately after mining by the AES roof support beams in Stages I, II, III, and IV rather

than the two bolts that are presently installed on each side of the comparison miner. The presently installed bolts are 16 feet back from the face while the AES beams are within eight feet of the face.

2. The miner operator has fewer tasks to perform as more automation is introduced. Therefore, he should be less involved in his job tasks and more aware of what is happening around him.
3. Improved face lighting will facilitate hazard recognition.
4. Improved supply handling systems will reduce the amount of manual supply handling, and therefore, decrease injuries.
5. Reducing the number of place changes with long straight advances decreases time spent placing temporary roof supports which lowers worker exposure to unsupported roof.
6. Ventilating the face through the hollow AES roof beams eliminates the hazardous job of advancing brattice or tubing under unbolted roof.
7. Monitoring systems provide more reliable and more frequent advanced warning of potential hazards.
8. Training must improve for automation and remote control to be effective. Improved training should reduce accidents.
9. Operator fatigue should decrease as increased mechanization, automation, and remote control reduce physical labor requirements.

Roof Fall Injuries. Two improvements reduce the roof fall hazard. First, the roof ahead of the bolters on the present continuous miner stands for about 30 minutes or longer before it is bolted. However, the AES roof support beams provide support within two minutes after mining. Second, four bolts are installed as the AES advances rather than the two presently emplaced, thereby reducing the spacing between bolts by 50 percent.

According to the fault-tree diagram in Appendix D, the basic criteria necessary for injury from roof falls are:

1. fall of supported roof, or
2. fall of unsupported roof, and
3. a man is exposed to the fall.

The two roof-fall hazard-reduction factors previously discussed decrease the probability of injury by minimizing criteria 1 and 2.

Since roof-strata strain is time dependent, the roof may sag slowly after mining. It can be pulled up when roof bolts are tightened or torqued. The sag and/or subsequent straightening of the roof beam may fracture the strata; therefore, the optimum situation is to support the roof before it sags. Other factors that contribute to unstable supported roof are insufficient support, entries or intersections cut too wide, and superimposed stress from adjacent mined-out areas. It is estimated that the present case probability of a criteria 1 (supported roof fall) occurrence is reduced 33 percent from the use of immediate roof support.

The AES roof support canopy and bolting pattern decreases the unsupported roof area to four, 16 feet by 16 feet, dead-end areas at the end of each mining pass. The unsupported areas will be bolted by the "touch-up" bolter after the AES moves to another entry. As a result, unsupported roof may exist for about one hour per shift while the present mining system always has a 16 foot by 16 foot unsupported area at the face. If the men are on the section for six hours, the Stage I roof is unsupported for 1/6 of the present time. Consequently, the probability of the present case criteria 2 (unsupported roof fall) occurring is reduced by 83 percent (5/6).

The estimated variation in probability of roof-fall injuries can now be calculated for each section worker. The "either-or" relationship between criteria 1 and 2 implies addition of probabilities. More roof-fall injuries result from unsupported roof, so a weighing factor of .6 will be assigned to it, and a .4 factor to probability of a supported roof fall. Therefore, criteria 1 and 2 probabilities are reduced by 63 percent (.4 x 33 percent + .6 x 83 percent).

The "and" relationship between criteria 3 and the first two criteria implies multiplication. The percent of present exposure rate for each face employee from Table 6-3 is multiplied by 37 percent (100 - 63) to obtain the estimated reduction in probability of injury from roof falls for Stages I and II. The results are reported in Table 6-4.

The roof-conditions monitoring system will decrease accident probability in Stages III and IV. The sensors will point out areas of stress buildup and unstable roof, and a well-defined warning will result. The monitoring hazard indication will be much more reliable and quantitative than the present methods of sounding the roof or listening for "roof talk." Also, the worker will not be exposed to a bad roof during testing. If the monitoring system indicates a need for additional support, a roof bolting or timber crew could repair the area before the fall occurs or the area could be barricaded.

Table 6-4. Percent of Present Stage Roof Fall Injury Frequency.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	34	34	24	10
Haulage Personnel	32	33	23	10
Roof Support Personnel	34	34	24	10
Ventilation Personnel	37	37	29	10
Supply/Utility Personnel	37	19	15	5
Mechanic, Electrician, and Monitoring Personnel	37	37	29	10

Table 6-5. Percent of Present Stage Material Handling Injury Frequency.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	93	70	40	16
Haulage Personnel	86	66	41	18
Roof Support Personnel	93	70	40	18
Ventilation Personnel	100	75	51	18
Supply/Utility Personnel	100	39	15	9
Mechanic, Electrician, and Monitoring Personnel	100	75	51	18

Consideration of these factors resulted in an estimation of 25 percent reduction in accident probability for the Stage III and IV monitoring system.

Handling Materials Injuries. Injuries from handling materials are affected by increased supply usage due to increased production, exposure time of workers, and introduction of the supply handling vehicle in Stage II. The supply handling vehicle will reduce physical contact between the operator and materials being handled. The operator will remain in a cab and move materials with a semiremote controlled boom on the machine. Therefore, the possibilities for injury from material handling such as improper lifting, being caught between or pinched, being struck by or striking against materials being moved, will be minimized. A 25-percent reduction in accident frequency is estimated in Stage II, and a 50-percent reduction will occur in Stage III due to anticipated improvements in the machine.

The section supplies are mostly for roof bolting, ventilation, and maintenance. As production increases, the amount of supplies used per ton remains nearly the same, and since the number of supply personnel was increased to reflect production changes, the amount of supplies handled per man remains essentially constant through the four stages. Therefore, any increase in the frequency of materials-handling injuries will result from an increased amount of employees handling supplies.

The percent change calculation in probability of materials-handling injury is a multiplication of changes in exposure time and supply vehicle use. For example, percent change in probability for the Stage II continuous miner operator is (.93 x .75 x 100) = 70. Table 6-5 relates the percent change in material handling injury frequency.

Hand Tool Injuries. Exposure time will affect the probability of hand-tool injury frequency for all employees. In addition, the increased amount of maintenance work due to increased number of machines will affect mechanics hand-tool accident probability. The number of machines to be repaired increased by 1.00, 1.09, 1.45, and 1.45 for Stages I through IV. The percent change in injury probability for mechanics is computed by a multiplication of changes in exposure time and machinery. Table 6-6 contains the results of the computations.

Haulage. Operating with mobile bridge carriers rather than shuttle cars in Stages II, III, and IV will significantly reduce haulage accidents. The percent changes shown in Table 6-7 should be applied to mobile-bridge operator and not shuttle-car operator accident frequencies in Stages II - IV. Other than elimination of shuttle cars, the change in haulage accident frequency rate is anticipated to be a direct result of change in exposure time for section personnel. Remote control of switches, improved track and trolley conditions, and better dispatch control of rail traffic will reduce haulage injuries to general mine personnel by 25 percent in Stage III and 50 percent in Stage IV.

Electricity and Machinery. Two factors will affect the number of injuries from electricity and machinery - exposure time and the number of machines on the section. Table 2-1 shows that the present and proposed mobile section equipment (not including monitoring systems) increases by factors of 1.00, 1.09, 1.27, and 1.27 for Stages I, II, III, and IV, respectively. However, maintenance personnel must work

Table 6-6. Percent of Present Stage Hand Tool Injury Frequency.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	93	93	79	35
Haulage Personnel	86	88	82	35
Roof Support Personnel	93	93	79	35
Ventilation Personnel	100	100	101	35
Supply/Utility Personnel	100	52	29	18
Mechanic, Electrician, and Monitoring Personnel	100	109	146	51

Table 6-7. Percent of Present Stage Haulage Injury Frequency.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	93	93	79	35
Haulage Personnel	86	88*	82*	35
Roof Support Personnel	93	93	79	35
Ventilation Personnel	100	100	101	35
Supply/Utility Personnel	100	50	28	18
Mechanics, Electrician, and Monitoring Personnel	100	100	101	35

* Percentages should be applied to mobile belt operator accident frequency, not to shuttle car operator frequency.

on all systems, mobile or not, so a 1.45 factor is used in Stages III and IV for these occupations. Multiplying change in amount of equipment with the exposure factors from Table 6-2 results in the percentages of electricity and machinery injury probability listed in Table 6-8.

<u>Explosions, Explosives, Suffocation, Mine Fires, Pneumoconiosis, and All Other Injuries</u>. The frequency rate for explosions, explosives, suffocation, mine fires, pneumoconiosis, and all other injuries is not projected to change substantially from the present except that the Stage III and IV monitoring systems will reduce explosions and mine fires by an estimated 25 percent. However, the AES machine may reduce respirable and float dust.

<u>General Inside</u>. Previous calculations were for section personnel. The following assumptions allow extension to general mine personnel.

1. The roof-fall injury frequencies of general inside employees working in the sections will be 67 percent of the Present Stage except the Stage III monitoring system will decrease the percent from 67 to 34.
2. Handling materials calculations for the supply/utility man will apply to the supply motorman.
3. Except where otherwise noted, the injury frequency for beltman, trackman, wireman, equipment mover, or rock duster will not change.
4. The mechanic and electrician injury probabilities will be the same as the section mechanic.
5. Mason and conveyor mover injuries will remain the same until Stage II where new machinery will decrease their exposure to

Table 6-8. Percent of Present Stage Electricity and Machinery Injury Frequency.

	Stage I	Stage II	Stage III	Stage IV
Extraction Personnel	93	101	100	44
Haulage Personnel	86	96	104	44
Roof Support Personnel	93	101	100	44
Ventilation Personnel	100	109	128	44
Supply/Utility Personnel	100	57	37	23
Mechanic, Electrician, and Monitoring Personnel	100	109	146	49

accidents from handling materials and hand tools by 75 percent. Improvements in the Stage III machinery will reduce accident potential by 50 percent. All other injury frequencies for the two occupations will remain the same as the Present Stage.

Hypothetical Application to the Automated Case Study Mine

General. The previously developed percent change in accident frequencies can be utilized to estimate safety improvement in Stages I through IV of an automated mine. In order to simplify the calculations and present the percentages in an organized tabulation, Tables 6-9, -10, -11. and -12 are included. They contain the percent change for each stage according to the well-accepted USBM format (Table 6-1) discussed at the beginning of this report section. These percentages are applied to the accident frequencies of the present mine to approximate new frequencies for each stage of automation.

Since the latest USBM statistics available in the detail required for this analysis are six years old (1970), they are used only as an example of what the present mine values would be. However, the percent change in accident frequencies from the present to each of the automation stages will be used to approximate the overall effect of the introduction of automation technology on health and safety. If more up-to-date figures are available at a particular mine, the influence of automation could be estimated by applying the percentages from Tables 6-9, -10, -11, and -12 along with the change in personnel requirements.

Table 6-9. Stage I Percent of Present Injury Frequency.

Occupation at Time of Injury	Principal Injury Cause	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis
Section Crew																			
Extraction Machine Operator (Cutting)		34	93	93	93	93	93	93	93	93	93	100	100	93	93	100	100	100	100
Shuttle Car Operator		32	86	86	86	86	86	86	86	86	86	100	100	86	86	100	100	100	100
Extraction Machine Operator (Bolting)		34	93	93	93	93	93	93	93	93	93	100	100	93	93	100	100	100	100
Ventilation Man		37	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Supply/Utility Man		37	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mechanic		37	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
General Inside																			
Supply Motorman		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Beltman		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Trackman		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Wireman		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mason		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Pumper-Pipeman		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mechanics		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Rock Duster		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Equipment Mover		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Conveyor Mover		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Fireboss and Supervisors		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Oiler-Greaser		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Electrician		67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Utility Man		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 6-10. Stage II Percent of Present Injury Frequency,

	Principal Injury Cause																	
Occupation at Time of Injury	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis
Section Crew																		
Extraction Machine Operator (Cutting)	34	93	93	93	93	70	93	93	93	93	100	100	101	101	100	100	100	100
Mobile Belt Operators	33	88	88	88	88	66	88	88	88	88	100	100	96	96	100	100	100	100
Extraction Machine Operator (Bolting)	34	93	93	93	93	70	93	93	93	93	100	100	101	101	100	100	100	100
Ventilation Man	37	100	100	100	100	75	100	100	100	100	100	100	109	109	100	100	100	100
Supply/Utility Man	19	52	52	52	52	39	52	52	52	52	100	100	57	57	100	100	100	100
Mechanic	37	100	100	100	100	75	109	100	100	100	100	100	109	109	100	100	100	100
General Inside																		
Supply Motorman	67	100	100	100	100	75	100	100	100	100	100	100	100	100	100	100	100	100
Beltman	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Trackman	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Wireman	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mason	67	100	100	100	100	75	75	100	100	100	100	100	100	100	100	100	100	100
Pumper-Pipeman	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mechanics	67	100	100	100	100	75	109	100	100	100	100	100	109	109	100	100	100	100
Rock Duster	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Equipment Mover	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Conveyor Mover	67	100	100	100	100	75	75	100	100	100	100	100	100	100	100	100	100	100
Fireboss and Supervisors	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Oiler-Greaser	67	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Electrician	67	100	100	100	100	75	109	100	100	100	100	100	109	109	100	100	100	100
Utility Man	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 6-11. Stage III Percent of Present Injury Frequency.

Occupation at Time of Injury	Principal Injury Cause: Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis
Section Crew																		
Technical Serviceman - Extraction	24	79	79	79	79	40	79	79	79	79	75	100	100	100	100	75	100	100
Technical Serviceman - Haulage	23	82	82	82	82	41	82	82	82	82	75	100	104	104	100	75	100	100
Technical Serviceman - Roof Control	24	79	79	79	79	40	79	79	79	79	75	100	100	100	100	75	100	100
Ventilation Technician	29	101	101	101	101	51	101	101	101	101	75	100	128	128	100	75	100	100
Supply Technician	15	29	29	29	29	15	29	29	29	29	75	100	37	37	100	75	100	100
Mechanic	29	101	101	101	101	51	146	101	101	101	75	100	146	146	100	75	100	100
Electrician	29	101	101	101	101	51	146	101	101	101	75	100	146	146	100	75	100	100
Monitoring Systems Technician	29	101	101	101	101	51	146	101	101	101	75	100	146	146	100	75	100	100
General Inside																		
Supply Motorman	34	100	100	100	100	51	100	100	100	100	75	100	100	100	100	75	100	100
Beltman	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Trackman	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Wireman	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Mason	34	100	100	100	100	50	50	100	100	100	75	100	100	100	100	75	100	100
Pumper - Pipeman	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Mechanics	34	100	100	100	100	51	146	100	100	100	75	100	146	146	100	75	100	100
Rock Duster	100	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Equipment Mover	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Conveyor Mover	34	100	100	100	100	50	50	100	100	100	75	100	100	100	100	75	100	100
Fireboss	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Oiler-Greaser	34	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100
Electrician	34	100	100	100	100	51	146	100	100	100	75	100	146	146	100	75	100	100
Utility Man	100	100	100	100	100	100	100	100	100	100	75	100	100	100	100	75	100	100

Table 6-12. Stage IV Percent of Present Injury Frequency.

Occupation at Time of Injury	Principal Injury Cause Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis
Section Crew																		
Technical Serviceman - Extraction	10	35	35	35	35	18	35	35	35	35	75	100	44	44	100	75	100	100
Technical Serviceman - Haulage	10	35	35	35	35	18	35	35	35	35	75	100	44	44	100	75	100	100
Technical Serviceman - Roof Support	10	35	35	35	35	18	35	35	35	35	75	100	44	44	100	75	100	100
Ventilation Technician	10	35	35	35	35	18	35	35	35	35	75	100	44	44	100	75	100	100
Supplies Technician	5	18	18	18	18	9	18	18	18	18	75	100	23	23	100	75	100	100
Monitoring Systems Technician	10	35	35	35	35	18	51	35	35	35	75	100	49	49	100	75	100	100
General Inside																		
Supply Motorman	34	100	100	100	100	9	100	100	100	50	75	100	100	100	100	75	100	100
Beltman	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Trackman	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Wireman	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Mason	100	100	100	100	100	50	50	100	100	50	75	100	100	100	100	75	100	100
Pumper-Pipeman	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Mechanics	100	100	100	100	100	18	51	100	100	50	75	100	49	49	100	75	100	100
Rock Duster	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Equipment Mover	34	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Conveyor Mover	100	100	100	100	100	50	50	100	100	50	75	100	100	100	100	75	100	100
Fireboss	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Oiler-Greaser	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100
Electrician	34	100	100	100	100	18	51	100	100	50	75	100	49	49	100	75	100	100
Utility Man	100	100	100	100	100	100	100	100	100	50	75	100	100	100	100	75	100	100

Method. The number of injuries in 1970 (Table 6-1) for each occupation and injury cause was divided by the total number of man-hours worked and multiplied by one million to arrive at the accident frequencies for the Present Stage listed in Table 6-14. Two factors were applied to the Table 6-13 frequencies to calculate the values in Table 6-14, -15, -16, and -17 for Stages I, II, III, and IV, respectively. First the individual frequencies were multiplied by the percent change from the Present Stage in the number of workers in the particular occupation. The change in number of workers by occupation for each stage is given in Table 5-3.

For example, the frequency of injuries for the extraction machine operator from roof falls in Stage I is calculated as follows. The present injury frequency from Table 6-13 (1.071) is multiplied by the percent change from Table 6-9 (34 percent) to obtain the accident frequency (.363) providing the portion of extraction machine operator hours worked remains the same as the present. It does not, so the percent change in the portion of total hours worked by extraction machine operators (6.1 ÷ 6.3 x 100 = 97%) is multiplied by the previous result (.363) to obtain the Stage I frequency (.351).

Result. The frequencies per million man-hours and per million tons are summarized in Table 6-18. The calculated percent of injury frequency from the Present Stage shows a dramatic reduction in injuries, especially in injuries per million tons (since tons/man hour increases during the four progressive stages of automation). Even though out-of-date frequencies were used in the present case, the authors

Table 6-13. 1970 Injury Frequencies.

	Principal Injury Cause																			
Occupation at Time of Injury	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis	All Injuries
At or Near Face:																			
Continuous Miner Operators	1.071	.179	.025	.062	.197	.542	.111	.068	.006	.234	.025	.006	.062	.899	-	-	.043	.006	3.534
Loading Machine Operators	.788	.369	-	.191	.080	.450	.117	.043	.012	.203	.012	.043	.080	.917	.006	.006	.018	.006	3.341
Roof Bolters	2.463	.333	.018	.111	.296	.819	.222	.129	.024	.443	-	.012	.099	2.759	-	.012	.080	-	7.820
Timberman and Jacksetters	.437	.099	.006	.024	.123	.967	.135	.092	.018	.265	-	-	.018	.209	.006	.006	.006	.006	2.417
Haulage Activities:																			
Belt and Boom Operators and Crews	.160	.024	-	.074	.191	.813	.216	.055	.030	.437	.006	.006	.055	.271	-	.006	.062	-	2.406
Motormen	.098	.018	-	.012	.092	.400	.012	.024	.006	1.336	-	.012	.185	.074	-	.006	.024	-	2.299
Shuttle Car Operators	.567	.197	.012	.098	.197	1.090	.148	.014	.018	2.432	.006	.036	.240	.277	-	.024	.048	-	5.464
Trackmen, Bonders, and Wiremen	.030	.012	-	-	.067	.530	.105	.018	-	.148	-	-	.030	.030	-	-	.006	-	.976
General:																			
Electricians	.061	.036	-	.018	.105	.474	.160	.024	.006	.289	-	-	.154	.055	-	.006	.086	-	1.474
Laborers and Move Crews	.499	.191	-	.080	.363	1.706	.308	.061	.055	1.071	-	.036	.148	.616	-	.006	.098	.006	5.244
Mechanics, Oilers, and Greasers	.160	.055	-	.073	.209	1.090	.333	.080	.030	.573	-	.006	.296	.296	-	.018	.098	-	3.317
Pumpmen	.006	.012	-	.012	.006	.042	.006	.012	-	.030	-	-	.024	.018	-	-	.012	-	.180
Rock Dusters	.024	.012	-	.012	.036	.148	.018	.006	-	.160	-	-	.018	.018	-	-	.006	-	.458
Supply Men	.042	.012	-	.012	.049	.517	.036	.024	.006	.413	-	-	.006	.042	-	.006	.018	-	1.188
Ventilation Men	.098	.030	-	.012	.061	.277	.061	.018	-	.104	-	-	.012	.049	-	-	.030	-	.752
Working Foremen and Firebosses	.265	.074	-	.018	.142	.425	.049	.080	.042	.400	-	.036	.105	.234	-	.018	.055	-	1.943
Total	6.769	1.653	.061	.809	2.214	10.290	2.037	.808	.253	8.538	.049	.193	1.532	6.764	.012	.114	.690	.024	42.810

Table 6-14. Revised 1970 Injury Frequencies From Stage I Automation.

	Principal Injury Cause																	
Occupation at Time of Injury	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis	All Injuries
At or Near Face:																			
Continuous Miner Operators	.353	.161	.023	.056	.177	.488	.100	.061	.005	.211	.024	.006	.056	.810	-	-	.042	.006	2.579
Loading Machine Operators		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Roof Bolters	.811	.300	.016	.100	.267	.738	.200	.116	.022	.399	-	.012	.089	2.484	-	.012	.077	-	5.643
Timbermen and Jack Setters	.157	.096	.006	.023	.119	.936	.131	.089	.017	.257	-	-	.017	.202	.006	.006	.006	.006	2.074
Haulage Activities:																			
Belt and Boom Operators and Crews	.104	.023	-	.072	.186	.792	.210	.054	.029	.426	.006	.006	.054	.264	-	.006	.060	-	2.292
Motormen	.080	.022	-	.015	.112	.392	.015	.029	.007	1.622	-	.015	.225	.090	-	.007	.029	-	2.660
Shuttle Car Operators	.176	.164	.010	.082	.164	.907	.123	.062	.015	2.025	.006	.035	.200	.231	-	.023	.046	-	4.269
Trackmen, Bonders, and Wiremen	.024	.015	-	-	.081	.644	.128	.022	-	.180	-	-	.036	.036	-	-	.007	-	1.173
General:																			
Electricians	.054	.048	-	.024	.140	.632	.265	.032	.008	.385	-	-	.205	.073	-	.008	.115	-	1.989
Laborers and Move Crews	.547	.239	-	.100	.454	2.136	.386	.076	.069	1.341	-	.049	.185	.771	-	.008	.123	.008	6.488
Mechanics, Oilers, and Greasers	.093	.059	-	.079	.225	1.125	.426	.086	.032	.616	-	.006	.318	.318	-	.019	.105	-	3.507
Pumpmen	.002	.007	-	.007	.003	.024	.003	.007	-	.017	-	-	.013	.010	-	-	.007	-	.100
Rock Dusters	.038	.019	-	.019	.057	.233	.028	.009	-	.251	-	-	.028	.028	-	-	.009	-	.719
Supply Men	.015	.012	-	.012	.047	.501	.035	.203	.006	.400	-	-	.006	.041	-	.006	.017	-	1.121
Ventilation Men	.093	.042	-	.017	.086	.391	.086	.025	-	.147	-	-	.017	.069	-	-	.042	-	1.015
Working Foremen and Firebosses	.178	.074	-	.018	.142	.425	.049	.080	.042	.400	-	.036	.105	.234	-	.018	.055	-	1.856
Total	2.725	1.281	.055	.624	2.620	10.364	2.185	.771	.252	8.677	.036	.161	1.554	5.661	.006	.113	.749	.020	37.485

Table 6-15. Revised 1970 Injury Frequencies From Stage II Automation.

	Principal Injury Cause																		
Occupation at Time of Injury	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis	All Injuries
At or Near Face:																			
Continuous Miner Operators	.289	.132	.018	.046	.145	.301	.082	.050	.004	.173	.020	.005	.050	.721	--	--	.034	.005	2.075
Loading Machine Operators	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0
Roof Bolters	.621	.248	.013	.083	.221	.460	.165	.096	.018	.330	--	.010	.080	2.212	--	.010	.064	--	4.681
Timbermen and Jack Setters	.128	.079	.005	.019	.098	.576	.107	.073	.014	.210	--	--	.016	.181	.005	.005	.005	.005	1.526
Haulage Activities																			
Belt and Boom Operators and Crews	.188	.061	--	.185	.478	1.645	.541	.138	.083	1.094	.017	.017	.147	.724	--	.017	.172	--	5.507
Motormen	.097	.027	--	.018	.136	.231	.009	.035	.009	1.972	--	.018	.273	.109	--	.009	.035	--	3.978
Shuttle Car Operators	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0
Trackman, Bonders, and Wiremen	.031	.018	--	--	.102	.808	.160	.027	--	.226	--	--	.046	.046	--	--	.009	--	1.473
General																			
Electricians	.066	.058	--	.029	.170	.576	.283	.039	.010	.468	--	--	.249	.089	--	.010	.139	--	2.186
Laborers and Move Crews	.590	.242	--	.102	.461	1.943	.351	.077	.070	1.359	--	.046	.188	.782	--	.008	.124	.008	6.351
Mechanics, Oilers, and Greasers	.096	.058	--	.076	.219	.831	.352	.084	.031	.600	--	.006	.318	.318	--	.019	.103	--	3.111
Pumpmen	.003	.008	--	.008	.004	.029	.004	.008	--	.020	--	--	.016	.012	--	--	.008	--	.120
Rock Dusters	.048	.024	--	.024	.072	.296	.036	.012	--	.320	--	--	.036	.036	--	--	.012	--	.916
Supply Men	.006	.005	--	.005	.020	.160	.015	.010	.002	.170	--	--	.003	.019	--	.005	.014	--	.434
Ventilation Men (Masons)	.108	.049	--	.020	.100	.228	.050	.030	--	.171	--	--	.020	.081	--	--	.049	--	.906
Working Foremen and Firebosses	.140	.058	--	.014	.112	.334	.039	.063	.033	.314	--	.028	.083	.184	--	.014	.043	--	1.459
Total	2.461	1.067	.036	.629	2.338	8.418	2.194	.742	.274	7.427	.037	.130	1.525	5.514	.005	.097	.811	.018	33.723

Table 6-16. Revised 1970 Injury Frequencies From Stage III Automation.

Occupation at Time of Injury	Principal Injury Cause																		
	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis	All Injuries
At or Near Face																			
Continuous Miner Operators	.180	.099	.014	.034	.109	.152	.061	.038	.003	.129	.013	.004	.043	.488	--	--	.030	.004	1.401
Loading Machine Operators	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Roof Bolters	.206	.092	.005	.031	.082	.114	.061	.036	.007	.122	--	.004	.035	.963	--	.003	.028	--	1.789
Timbermen and Jack Setters	.089	.069	.004	.017	.086	.344	.095	.064	.013	.185	--	--	.016	.188	.004	.003	.004	.004	1.185
Haulage Activities																			
Belt and Boom Operators and Crews	.059	.028	--	.087	.223	.760	.253	.064	.035	.511	.006	.008	.071	.351	--	.006	.079	--	2.541
Motormen	.060	.033	--	.022	.166	.139	.022	.043	.011	1.814	--	.022	.293	.117	--	.008	.043	--	2.793
Shuttle Car Operators	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Trackmen, Bonders, and Wiremen	.020	.024	--	--	.132	1.047	.208	.036	--	.219	--	--	.059	.059	--	--	.012	--	1.816
General																			
Electricians	.043	.075	--	.035	.220	.567	.490	.050	.013	.455	--	--	.471	.168	--	.009	.180	--	2.719
Laborers and Move Crews	.583	.289	--	.121	.549	2.357	.426	.092	.083	1.215	--	.054	.224	.932	--	.007	.148	.009	7.089
Mechanics, Oilers, and Greasers	.079	.080	--	.106	.302	.765	.579	.116	.043	.621	--	.009	.587	.587	--	.020	.142	--	4.036
Pumpmen	.002	.011	--	.011	.005	.037	.005	.011	--	.020	--	--	.021	.016	--	--	.011	--	.150
Rock Dusters	.069	.034	--	.034	.103	.423	.051	.017	--	.343	--	--	.051	.051	--	--	.017	--	1.193
Supply Men	.004	.002	--	.002	.010	.069	.007	.005	.001	.063	--	--	.002	.011	--	.003	.013	--	.192
Ventilation Men (Masons)	.073	.065	--	.026	.133	.302	.066	.039	--	.170	--	--	.026	.107	--	--	.065	--	1.072
Working Foremen and Firebosses	.064	.053	--	.013	.101	.304	.035	.057	.030	.215	--	.026	.075	.167	--	.013	.039	--	1.192
Total	1.531	.954	.023	.542	2.221	7.320	2.359	.668	.239	6.082	.019	.127	1.974	4.205	.004	.072	.811	.017	29.168

Table 6-17. Revised 1970 Injury Frequencies From Stage IV Automation.

	Principal Injury Cause																		
Occupation at Time of Injury	Roof Falls	Face or Rib Falls	Bumps or Bursts	Other Falling Objects	Slips or Falls of Persons	Handling Materials	Hand Tools	Stepping or Kneeling on Sharp or Loose Objects	Striking or Bumping Against Objects	Haulage	Explosions	Explosives	Electricity	Machinery	Suffocation	Mine Fires	All Others	Pneumoconiosis	All Injuries
At or Near Face																			
Continuous Miner Operator	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Loading Machine Operator	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Roof Bolters	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Timbermen and Jack Setters	.031	.025	.002	.006	.031	.124	.034	.023	.005	.066	--	--	.006	.066	.004	.003	.004	.004	.434
Haulage Activities																			
Belt and Boom Operators and Crews	.119	.018	--	.055	.142	.604	.161	.041	.022	.325	.003	.004	.041	.201	--	.003	.046	--	1.785
Motormen	.071	.039	--	.026	.197	.077	.026	.051	.013	1.432	--	.026	.396	.159	--	.010	.051	--	2.574
Shuttle Car Operators	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Trackmen, Bonders, and Wiremen	.071	.029	--	--	.160	1.262	.250	.043	--	.176	--	--	.071	.071	--	--	.014	--	2.147
General																			
Electricians	.052	.091	--	.045	.265	.215	.206	.061	.015	.365	--	--	.190	.068	--	.011	.217	--	1.801
Laborers and Move Crews	.713	.310	--	.130	.589	2.518	.455	.099	.089	.869	--	.058	.240	.999	--	.066	.159	.010	7.244
Mechanics, Oilers, and Greasers	.346	.119	--	.158	.451	.636	.406	.173	.065	.619	--	.013	.349	.349	--	.029	.212	--	3.925
Pumpmen	.007	.013	--	.013	.007	.047	.007	.013	--	.017	--	--	.027	.020	--	--	.013	--	.164
Rock Dusters	.079	.039	--	.039	.118	.486	.059	.020	--	.263	--	--	.059	.059	--	--	.020	--	1.241
Supply Men	.002	.002	--	.002	.006	.033	.005	.003	.001	.027	--	--	.001	.007	--	.003	.013	--	.105
Ventilation Men (Masons)	.248	.076	--	.030	.154	.350	.077	.046	--	.132	--	--	.030	.124	--	--	.076	--	1.343
Working Foremen and Firebosses	.189	.053	--	.013	.101	.304	.035	.057	.030	.143	--	.026	.075	.167	--	.013	.039	--	1.245
Total	1.928	.814	.002	.517	2.221	6.654	1.721	.630	.240	4.434	.003	.127	1.435	2.290	.004	.078	.864	.014	24.028

believe these results to be good approximations of the overall effect of automation and remote-control technology on underground coal mine health and safety.

Table 6-19 shows the change in accident frequency by occupation for each stage. Several jobs were eliminated and their frequency is reported as zero. It is interesting to note the rank from the most hazardous (rank 1) to the least hazardous that is reported in parenthesis next to the frequencies.

The jobs that could be automated and remote controlled show a considerable drop in accident frequency. Jobs that could not be automated and occupations comprising a larger portion of the work force, had an increase in frequency. Safety emphasis from management and training programs should concentrate on these occupations. Research to define automation possibilities for the work performed by trackmen, haulers, wiremen, electricians, laborers and move crews, mechanics, oilers, greasers, rock dusters, and ventilation personnel is recommended.

Table 6-20 reveals that the rank of injury causes from the worst (rank 1) to the least, remains about the same through all four stages for most cases. In general, injury frequencies decline in most cases, however, some declines, such as roof falls, are more pronounced than others.

Table 6-18. Accident Frequency Summary for Example

	Frequency		Percent of Present Frequency	
	per 1,000,000 man hrs.	per 1,000,000 tons	per 1,000,000 man hrs.	per 1,000,000 tons
Present	42.8	30.4	100	100
Stage I	37.5	23.0	87	76
Stage II	33.7	17.3	79	57
Stage III	29.2	11.8	68	39
Stage IV	24.0	8.8	56	29

Table 6-19. Accident Frequency According to Occupation (Figures in Parentheses are Ranks).

OCCUPATION	PRESENT	STAGE 1	STAGE 2	STAGE 3	STAGE 4
Continuous Miner Operator	3.534 (4)	2.579 (6)	2.075 (7)	1.401 (8)	0 (-)
Loading Machine Operator	3.341 (5)	0 (-)	0 (-)	0 (-)	0 (-)
Roof Bolters	7.820 (1)	5.643 (2)	4.681 (3)	1.789 (7)	0 (-)
Timbermen and Jacksetters	2.417 (7)	2.074 (8)	1.526 (8)	1.185 (11)	.434 (10)
Belt and Boom Operators and Crews	2.406 (8)	2.292 (7)	5.507 (2)	2.541 (5)	1.785 (6)
Motormen	2.299 (9)	2.660 (5)	2.978 (5)	2.793 (3)	2.574 (3)
Shuttle Car Operators	5.464 (2)	4.269 (3)	0 (-)	0 (-)	0 (-)
Trackmen, Bonders, Wiremen	.976 (13)	1.173 (11)	1.473 (9)	1.816 (6)	2.147 (4)
Electricians	1.474 (11)	1.989 (9)	2.186 (6)	2.719 (4)	1.801 (5)
Laborers and Move Crews	5.244 (3)	6.488 (1)	6.351 (1)	7.089 (1)	7.244 (1)
Mechanics, Oilers, Greasers	3.317 (6)	3.507 (4)	3.111 (4)	4.036 (2)	3.925 (2)
Pumpmen	.180 (16)	.100 (14)	.120 (14)	.150 (14)	.184 (11)
Rock Dusters	.458 (15)	.719 (13)	.916 (11)	1.193 (9)	1.241 (9)
Supplymen	1.188 (12)	1.241 (12)	.434 (13)	.192 (13)	.105 (12)
Ventilation	.752 (14)	1.015 (11)	.906 (12)	1.072 (12)	1.343 (7)

Table 6-20. Accident Frequency According to Principal Injury Cause (Figures in Parentheses are Rank).

PRINCIPAL INJURY CAUSE	PRESENT	STAGE 1	STAGE 2	STAGE 3	STAGE 4
Falls of Roof	6.769 (3)	2.725 (4)	2.461 (4)	1.531 (7)	1.928 (5)
Falls of Face or Rib	1.653 (7)	1.281 (8)	1.067 (8)	.954 (8)	.814 (9)
Bumps or Bursts	.061 (15)	.055 (15)	.036 (16)	.023 (15)	.002 (18)
Other Falling Objects	.809 (9)	.624 (11)	.629 (11)	.542 (11)	.517 (11)
Slips or Falls of Persons	2.214 (5)	2.620 (5)	2.338 (5)	2.221 (5)	2.221 (4)
Handling Materials	10.290 (1)	10.364 (1)	8.418 (1)	7.320 (1)	6.654 (1)
Handtools	2.037 (6)	2.185 (6)	2.194 (6)	2.359 (4)	1.721 (6)
Stepping or Kneeling on Sharp or Loose Object	.808 (10)	.771 (10)	.742 (10)	.668 (10)	.630 (10)
Striking or Bumping Against Objects	.253 (12)	.252 (12)	.274 (12)	.239 (12)	.240 (14)
Haulage	8.538 (2)	8.677 (2)	7.427 (2)	6.082 (2)	4.434 (2)
Explosions	.049 (16)	.036 (16)	.037 (15)	.019 (16)	.003 (17)
Explosives	.193 (13)	.161 (13)	.130 (13)	.127 (13)	.127 (12)
Electricity	1.532 (8)	1.554 (7)	1.525 (7)	1.974 (6)	1.485 (7)
Machinery	6.764 (4)	5.661 (3)	5.514 (3)	4.205 (3)	2.290 (3)
Suffocation	.012 (18)	.006 (18)	.005 (18)	.004 (18)	.004 (16)
Mine Fires	.114 (14)	.113 (14)	.097 (14)	.072 (14	.078 (13)
All others	.690 (11)	.749 (9)	.811 (9)	.811 (9)	.864 (8)
Pneumoconiosis	.024 (17)	.020 (17)	.018 (17)	.017 (17)	.014 (15)

Chapter 7
ECONOMIC ANALYSIS

Introduction

The profitability of the investment in automation and remote-control equipment is evaluated in this chapter. Obviously, it must be economically attractive if the mining industry is to ever employ automation to a great extent. The increased level of capital investment must produce higher tons per man shift so a desirable risk rate of return on capital investment will be realized. The previously calculated production (Chapter 4), labor manning or productivity (Chapter 5), and health and safety impact (Chapter 6) must be combined with estimates of required capital investment and operating costs to evaluate the profitability of future automation and remote control in underground coal mines. All capital and operating cost figures used in this investigation are in 1976 dollars.

The profitability of the Present Stage through Stage IV automation will be examined for the case study mine considered in this report. Even though the return on investment figures developed will apply only to the specific case study, the method of calculation may be applied to all mines. That is, changes in seam height or other basic parameters will affect the final answer, but will not change the method used. Additionally, the return on investment percentages should be considered relative. They have significance in this report only as a means of comparing the profitability of the various progressive automation and remote-control stages.

A risk rate of return on all initial capital requirements is computed in this study. That is, no borrowing of capital or interest charges during the construction period is utilized. This leveraging of equity capital, while common in industry, is highly dependent on the financial resources of the individual investor. In addition, when a portion of the initial capital is borrowed, the investor usually desires a much higher than 15 percent risk rate of return on the equity, or unborrowed portion of capital, commensurate with the proportion of borrowed/unborrowed funds.

The rate of return calculation begins with a listing of the necessary initial capital expenditure items including an estimation of the capital dollar purchase price for the Present Stage equipment. Subsequent stages require capital for additional equipment and monitoring systems necessary in each of the progressive automation stages. Research and development cost of the additional automation equipment and monitoring systems required in the respective stages is not included in the estimated purchase prices. Next, the labor costs are calculated and added to the operating and maintenance supply costs, other cash costs, cleaning plant costs, and miscellaneous costs to determine the total operating costs per ton for the respective stages. Replacement-of-capital-equipment monies are also included and depreciation is calculated. A Present Stage selling price is determined using an iteration method since taxes must be computed for each trial that will give a 15 percent return in investment after federal income tax (FIT). The Present Stage selling price is held constant in all four automation stages and the resultant rate of return is used to compare their relative profitability.

Analysis Technique

The "profitability-index" (PI) is the method chosen to calculate the rate of return for each automation stage because it is a simple well-documented approach that accounts for the time value of money. (59) The term profitability index means an interest rate or rate of return calculated in the following prescribed fashion. To begin, a tabulation of anticipated income, operating expenses, capital investment, and expected federal income taxes is developed which recognizes the sequence of occurrence of each item. Several steps are necessary to complete this table. First, the annual production is entered in the table and then multiplied by the selling price per ton to give a year-by-year listing of anticipated income. Second, initial and replacement expenditures are scheduled year-by-year. Third, annual depreciation and federal income tax are determined since the rate of return is to be calculated on an after-tax basis. Fourth, operating costs are listed for each year, and when added to the income taxes (the fifth step), equal the total annual expense. In the final calculation, the total annual expense is subtracted from the annual income to obtain the annual cash flow.

After all the statistics have been entered in the calculations table, the present worth of all investments and cash flows at several trial interest rates is determined. It is assumed that all expenditures and incomes occur continuously during the year. Therefore, the discount factors used to obtain present value are those for midpoint of the year application. The rate of return on total invested capital is the interest rate at which the present worth of all expenditures (designated

"A"), and the present worth of all cash flow income (designated "B") are equal. In other words, the ratio A/B is equal to one or unity at that point. Next, graphs of the PI versus A/B ratio are made - using the ratio calculated at each of the trial interest rates - to graphically determine the interest rate where the A/B ratio equals unity. The present worth factors used and a detailed description of the profitability index can be found in Reul's article in the Harvard Business Review. (59)

These calculations are made for each of the automation stages in this chapter. The following documents how the initial and replacement capital, mine operating costs, depreciation, and income tax figures were developed in addition to summarizing the PI evaluation.

Capital

Both the initial and replacement capital investment requirements are listed in Table 7-1 for the Present Stage through Stage IV automation. The replacement capital is estimated to be 85 percent of the total initial investment. The general categories of capital expenditure included are:

1. mine plant site acquisition and preparation,
2. surface buildings and facilities,
3. surface mobile equipment,
4. preparation plant,
5. shafts and slopes,
6. general underground,
7. general auxiliary,

Table 7-1. Initial Equipment, Facilities, and Capital Investment.

	Present 1,227,620 Raw Tons		Stage I 1,504,800 Raw Tons		Stage II 2,217,600 Raw Tons		Stage III 3,168,000 Raw Tons		Stage IV 3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
I. Mine Plant Site Acquisition and Preparation		1,100		1,200		1,300		1,400		1,500
II. Surface Building & Facilities										
Administration		250		300		400		450		500
Bathhouse, lamphouse and equipment		600		700		800		900		1,000
Supply and shop		500		700		900		1,300		1,500
Bulk storage and sheds		150		175		200		225		250
Bulk oil storage		30		35		40		45		50
Fresh water system										
Pump station and lines		100		110		120		130		140
Elevated storage tank		100		110		120		130		140
Fire protection lines		100		110		120		130		140
Potable water										
Plant and pumps		30		33		36		39		42
Wells		10		10		10		10		10
Pipelines		20		22		24		26		28
Head tank		20		22		24		26		28
Sewage system										
Plant		120		140		160		180		200
Pipeline		20		22		24		26		28
Mine water treatment		150		225		300		375		450
Rock dust system		40		45		50		55		60
Mine roads, yard and fencing		300		330		360		390		420
Surface electrical substation and distribution system		400		500		600		700		800
Ventilation - twin fans		250		275		300		325		350
Total		3,190		3,864		4,588		5,462		6,136

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
III. Surface Mobile Equipment										
Front end loader	1	45	1	45	1	45	1	45	1	45
Forklift	1	33	1	33	1	33	2	66	2	66
3/4-ton pickups-4WD	2	12	2	12	3	18	3	18	4	24
Dump truck	1	15	1	15	1	15	1	15	1	15
Flatbed truck	1	7	1	7	1	7	1	7	1	7
Utility tool truck	1	15	1	15	1	15	1	15	1	15
Portable welder	1	9	1	9	1	9	1	9	1	9
Portable pumps	1	3	1	3	2	6	3	9	4	12
Mobile crane	1	90	1	90	1	90	1	90	1	90
Backhoe-mower-tractor	1	25	1	25	1	25	1	25	1	25
Diesel locomotive (10 ton)	1	55	1	55	1	55	1	55	1	55
Scraper-refuse	1	300	2	600	2	600	3	900	4	1,200
Dozer-refuse	1	150	1	150	1	150	1	150	1	150
Compactor-refuse	1	140	1	140	1	140	1	140	1	140
Liquid spreader	1	6	1	6	1	6	1	6	1	6
Lowboy trailer	1	6	1	6	1	6	1	6	1	6
Automobiles	3	15	3	15	4	20	4	20	5	25
Total		926		1,226		1,240		1,576		1,890
IV. Preparation Plant (complete with raw coal section and storage, plant and equipment, clean coal storage, thickeners and refuse disposal system)										
Present - 400 tons/hr rating		14,000								
Stage I - 500 tons/hr rating				17,000						
Stage II - 660 tons/hr rating						21,000				
Stage III - 1,000 tons/hr rating								29,000		
Stage IV - 1,200 tons/hr rating										32,000

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
V. Shafts and Slopes										
Belt Conveyor and supply slope with conveyor, supply hoist and underground storage bin	2M'	4,000	2M'	4,200	2M'	4,400	2M'	4,600	2M'	4,800
Portal shaft, 500 ft deep, with curtain wall and elevator	500'	1,350		1,375		1,400		1,425		1,450
Ventilation shaft, 500 ft deep	500'	1,000		1,100		1,200		1,300		1,400
Total		6,350		6,675		7,000		7,325		7,650
VI. Underground - General										
42" Conveyor - Mainline										
Belting	52M'	832	56M'	896	32M'	512	32M'	512	32M'	512
Structure	26M'	624	28M'	672	16M'	384	16M'	384	16M'	384
Terminals	6	480	6	480	4	320	4	320	4	320
Starter-transformers	6	198	6	198	4	132	4	132	4	132
48" Conveyor - Mainline										
Belting					36M'	756	52M'	1,092	60M'	1,260
Structure					18M'	450	26M'	650	30M'	750
Terminals					4	580	6	870	7	1,015
Starter-transformers					4	168	6	252	7	294
AC Electrics										
Switchhouse	17	289	17	289	17	289	17	289	17	289
Isolation switchhouse	3	24	3	24	3	24	3	24	3	24
Power centers	2	84	2	84	2	84	2	84	2	84
Cables, couplers, etc.		670		670		670		670		670
DC Electrics										
Rectifiers	4	112	4	112	5	140	5	140	6	168
Circuit breakers	20	120	20	120	20	120	20	120	20	120
Trolley, bonding	57M'	342	59M'	354	65M'	390	73M'	438	77M'	462
Track										
Rail, ties and ballast	57M'	1,026	59M'	1,062	65M'	1,170	73M'	1,314	77M'	1,386
Switches	60	45	66	50	72	54	78	59	84	63
Ventilation		100		120		140		160		180

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
VI. Underground - General (Continued)										
Fresh water system										
6" pipe	10M'	55	12M'	66	18M'	99	26M'	143	30M'	165
4" pipe	16M'	48	16M'	48	16M'	48	16M'	48	16M'	48
3-1/2" pipe	28M'	42	28M'	42	28M'	42	28M'	42	28M'	42
Drainage system										
Piping		145		156		189		233		255
Pumps and stations		100		120		140		160		180
Communication and Monitoring-General										
Phones	40	64	44	70	48	77	52	83	56	90
Cable	54M'	54	56M'	56	62M'	62	70M'	70	74M'	74
Airsplit monitoring	30	60	30	60	30	60	30	60	30	60
Circuit breaker and fan control	30	9	30	9	30	9	30	9	30	9
Conveyor monitoring		54		56		62		70		74
Central mine monitor console	1	100	1	100	1	125	1	200	1	300
Safety equipment										
All service mask	30	3	35	4	40	4	45	5	50	5
Breathing apparatus	30	39	35	46	40	52	45	59	50	65
Self rescuers	450	18	500	20	600	24	650	26	700	28
Stretcher sets	15	5	15	5	15	5	15	5	15	5
Safety lamps	150	8	165	8	200	10	210	11	230	12
Methanemeters	150	60	165	66	200	80	210	84	230	92
Dust samplers	45	14	50	15	60	18	65	20	70	21
Noise exposimeters	15	6	17	7	20	8	22	9	25	10
Anemometer	110	22	125	25	150	30	160	32	175	35
Conveyor fire protection		54		56		62		70		74
Cap lamps and racks	450	18	500	20	600	24	650	26	700	28
Total		5,924		6,186		7,613		8,975		9,785

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
VII. General Auxiliary Equipment										
Rock miner	1	300	1	300	2	600	2	600	2	600
Loading machine	1	100	1	100	2	200	2	200	2	200
Cutting machine	1	150	1	150	2	300	2	300	2	300
Shuttle car	1	70	1	70	2	140	2	140	2	140
Roof bolter	1	70	1	70	2	140	2	140	2	140
Scoop tractor	1	46	1	46	2	92	2	92	2	92
Tractor batteries	1	9	1	9	2	18	2	18	2	18
Belt winders	1	15	1	15	2	30	2	30	2	30
Cat winches	1	30	1	30	2	60	2	60	2	60
Locomotives	3	240	3	240	3	240	4	320	5	400
Rail cars	1	4	1	4	2	8	2	8	3	12
Ballast cars	1	10	1	10	2	20	2	20	3	30
Pod rock duster	1	30	1	30	2	60	2	60	3	90
Duster slave car	1	15	1	15	2	30	2	30	3	45
Track tamper	1	50	1	50	1	50	1	50	1	50
Compressors	1	30	1	30	2	60	2	60	3	90
Equipment carriers	1	7	1	7	2	14	2	14	3	21
Portal busses	15	300	15	300	15	300	15	300	15	300
Jitneys	15	225	15	225	15	225	15	225	15	225
Fire fighting equipment	1	15	1	15	2	30	2	30	3	45
Rock cars	15	90	20	120	25	150	30	180	35	210
Hoists	1	10	1	10	2	20	2	20	3	30
Portable welders	15	15	15	15	15	15	15	15	15	15
Miscellaneous tools and equipment		20		24		36		50		60
Total		1,851		1,885		2,838		2,962		3,203

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
VIII. Production Section Equipment										
Continuous miner	11	3,300								
Pickup loader	11	1,100								
AES machine - Stage 1 type			11	5,500						
Stage 2 type					11	6,600				
Stage 3 type							11	7,700		
Stage 4 type									11	8,800
Shuttle cars	22	1,540	22	1,540	11	770	11	770	11	770
Mobile bridge carriers and bridges					11	3,300	11	3,300	11	3,300
"Touchup" bolter	11	275	11	275	11	275	11	275	11	275
Belt feeder	11	385	11	385						
Stopping emplacer					11	550	11	550	11	550
Power centers	11	462	11	462	11	462	11	462	11	462
Section belt conveyor										
Belting, 55,000'	11	550	11	550	11	550	11	550	11	550
Structure, 27,500'	11	399	11	399	11	399	11	399	11	399
Terminals	11	440	11	440	11	440	11	440	11	440
Starter-transformers	11	220	11	220	11	220	11	220	11	220
Belt moving machine					11	550	11	550	11	550
Dust vacuum system					11	1,100	11	1,320	11	1,540
Rock duster	11	66	11	66						
Trickle dusters with ventilation fan	11	198	11	198	11	198	11	198	11	198
Piped rock dust system					11	1,100	11	1,100	11	1,100
Scoop tractor and charger	11	506	11	506	11	506	11	506	11	506
Tractor batteries	11	99	11	99	11	99	11	99	11	99
Supply cars- Rubber rail			165	660	220	880	275	1,100	330	1,320
Supply vehicle					11	550	11	825	11	1,100
Section monitoring systems										
Face equipment status							11	2,200	11	2,750
Roof conditions							11	1,100	11	1,650
Mine environment							11	1,100	11	1,650
Electrical system							11	1,100	11	1,650
Water system							11	550	11	825
Section monitoring console							11	1,650	11	2,750
Total		9,540		11,300		18,549		28,064		33,454

Table 7-1. Initial Equipment, Facilities, and Capital Investment (Continued).

	Present		Stage I		Stage II		Stage III		Stage IV	
	1,227,620 Raw Tons		1,504,800 Raw Tons		2,217,600 Raw Tons		3,168,000 Raw Tons		3,643,200 Raw Tons	
	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)	Amount	$(000)
IX. Miscellaneous										
Overhead during construction		150		200		300		400		450
Engineering		100		125		200		250		300
Mine development-excess cost		1,000		1,200		1,800		2,600		3,000
Total		1,250		1,525		2,300		3,250		3,750
Grand Total Initial Capital		44,131		50,861		66,428		88,014		99,368

8. production sections, and
9. miscellaneous

The authors have relied on a combination of sources including manufacturers' information and their own past experience in the assemblage. The research and development status of the monitoring systems for roof condition, electrical, water, and equipment status is insufficiently advanced to permit accurate knowledge of the production models' commercial cost. Therefore, best judgement estimates based on relative complexities compared to presently available environmental monitoring and communications systems have been utilized. It is presumed that research and development will have been accomplished under government or private sponsorship and that monitoring systems will be produced by several companies in competitive models.

The changes in equipment sophistication and quantity from stage to stage were projected on the basis of information from the job function descriptions (Chapter 3) and the calculated production. Purchase prices used resulted from the size and level of sophistication projected.

As stated earlier, the cost of developing the automated equipment and technology is not included as a portion of the commercial model. It is assumed that this is covered by research funds.

The total initial expenditure for capital equipment and facilities is listed in Table 7-1. The funds will be expended over the first six years of the project. In order to identify the incremental capital expenditures by year which is required for computing the PI, Table 7-2 was constructed. Each of the nine categories is listed with anticipated annual expenditure amounts in the Present Stage case. The abbreviations P-3, P-2, and P-1 represent the three years of development, respectively, before production (P) begins. Percentage distribution of the initial capital over the development years is also listed. These percentages were used to develop the corresponding annual expenditure amounts for Stages I through IV. The same general percentage for all five stages (Present Stage through Stage IV) assures that any differences in the PI is a result of changes caused by introduction of automation technology and not a contrasting time outlay of capital expenditure. In addition, all calculations are based on total initial capital requirements without financing so that borrowing or capital leveraging distortions are not involved.

The increase in back up mine services such as additional plant areas, surface buildings, surface mobile equipment, preparation facilities, and other items are apparent from a comparison of the various stages.

A useful figure for comparison of initial capital investment for the Present Stage through Stage IV automation is cost per annual clean ton. Table 7-3 presents this comparison. Even though the capital expenditures increases significantly through progressive automation stages, the increased production is large enough to cause a decrease in the ratio of investment to annual clean tons. When this fact is coupled with the Chapter 5 information that tons per manshift increases, the basic reasons for improved profitability are evident.

Table 7-2. Present Initial Capital Expenditure by Year (in thousand dollars)

Category	Total	Year P-3		Year P-2		Year P-1		Year 1		Year 2		Year 3	
		Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
1. Plant Site	1,100	1,100	100										
2. Surface Facilities	3,190			1,595	50	1,595	50						
3. Surface Mobile Equip.	926	100	11	300	32	526	57						
4. Preparation Plant	14,000	500	4	4,667	33	4,666	33	4,167	30				
5. Shafts and Slopes	6,350			3,175	50	3,175	50						
6. General Underground	5,924							2,000	34	3,500	59	424	7
7. General Auxiliary Equip.	1,851							900	49	900	49	51	2
8. Production Sections	9,540							3,500	37	5,200	55	840	8
9. Miscellaneous	1,250	50	4	50	4	50	4	500	40	500	40	100	8
Total	44,131	1,750	4	9,787	22	10,012	23	11,067	25	10,100	23	1,415	3

Table 7-3. Initial Investment per Annual Clean Ton.

Stage	Initial Investment/Ton	Initial Annual Investment(M)
Present	$44.58	$44,131
Stage I	$41.42	$50,861
Stage II	$36.46	$66,428
Stage III	$33.67	$88,014
Stage IV	$33.46	$99,368

The potential for varying annual mine production rates is based on the premise that a mining layout can accommodate a certain number of production sections which can operate at either above or below average productivities with only modest changes in levels of capital expenditures. Automation affords the opportunity to significantly increase annual mine production from a fixed number of working sections.

Operating Costs

The operating costs per raw tons listed in Table 7-4 are divided into three basic categories of labor, other cash costs, and cleaning plant. The costs were developed by calculations from previous data where possible and by utilizing the authors' experience when data were not available. The figures are for full production. During the first three development years, partial production is recorded on the basis of two operating units during the first year, five during the second and seven during the third year. Operating costs are incurred partially during this period. Percentages of 35, 60, and 80 are the portions of annual operating expenditures projected for the first three production years, respectively.

Labor. The cost of labor and management at the mine and cleaning plant is derived from the personnel requirements outlined in Chapter 5. The August 1976 UMWA wage rates were applied to the labor manning lists to produce Tables 7-5, -6, -7, -8, and -9. In some instances, higher wages are applicable to highly skilled workers in later automation stages. Additional discussion of this subject is contained in the Psychological and Organizational Impact Chapter. The cost per day is le 7-4. Operating Costs.

	Present (1,227,620 Raw Tons)		Stage I (1,504,800 Raw Tons)		Stage II (2,217,600 Raw Tons)		Stage III (3,168,000 Raw Tons)		Stage IV (3,643,200 Raw Tons)	
COAL COST	Thousands of Dollars/Year	Dollars/ Raw Ton	Thousands of Dollars/Year	Dollars/ Raw Ton	Thousands of Dollars/Year	Dollars/ Raw Ton	Thousands of Dollars/Year	Dollars/ Raw Ton	Thousands of Dollars/Year	Dollars/ Raw Ton
or										
ourly Labor	3,967	3.23	4,147	2.76	4,749	2.14	5,764	1.82	5,737	1.57
alaried Employees	1,248	1.02	1,570	1.04	2,100	0.95	2,374	0.75	2,536	0.70
ocial Security	346	0.28	372	0.25	460	0.21	526	0.17	535	0.15
alaried Benefits	312	0.25	393	0.26	525	0.24	594	0.19	634	0.17
oliday & Vacation Pay	433	0.35	452	0.30	518	0.23	629	0.20	626	0.17
ther UMWA Benefits	204	0.17	213	0.14	248	0.11	295	0.09	295	0.08
ealth & Welfare Fund	1,686	1.37	1,903	1.26	2,566	1.16	3,344	1.06	3,507	0.96
bsenteeism	96	0.08	100	0.07	115	0.05	134	0.04	136	0.04
vertime	397	0.32	415	0.28	475	0.21	576	0.18	574	0.16
orkmen Insurance & C.O.L.A.	1,390	1.13	1,502	1.00	1,797	0.81	2,120	0.67	2,147	0.60
on productive Training	98	0.08	102	0.07	123	0.06	140	0.04	140	0.04
dle Day Work	96	0.08	99	0.07	114	0.05	137	0.04	136	0.04
ubtotal Labor	10,273	8.37	11,268	7.49	13,791	6.22	16,633	5.26	17,003	4.68
er Cash Costs										
perating Supplies	1,780	1.45	2,137	1.42	3,082	1.39	4,308	1.36	4,918	1.35
aintenance Supplies	2,148	1.75	2,543	1.69	4,191	1.89	6,399	2.02	7,469	2.05
ower (Mine & Plant)	615	0.50	752	0.50	1,109	0.50	1,584	0.50	1,822	0.50
ine Extension	246	0.20	801	0.20	444	0.20	634	0.20	729	0.20
dministrative	491	0.40	602	0.40	881	0.40	1,267	0.40	1,457	0.40
egal Penalties	25	0.02	30	0.02	44	0.02	63	0.02	73	0.02
roperty Taxes	368	0.30	451	0.30	665	0.30	950	0.30	1,093	0.30
nsurance	123	0.10	123	0.08	123	0.06	123	0.04	123	0.03
ssociation Dues	37	0.03	45	0.03	67	0.03	95	0.03	109	0.03
oyalty & Sales Fee	1,247	1.02	1,535	1.02	2,262	1.02	3,231	1.02	3,716	1.02
iscellaneous	123	0.10	150	0.10	222	0.10	317	0.10	364	0.10
ubtotal Other Cash Costs	7,202	5.87	8,670	5.76	13,096	5.91	18,972	5.99	21,873	6.00
aning Plant										
perating Supplies	245	0.20	286	0.19	399	0.18	539	0.17	583	0.16
aintenance Supplies	491	0.40	572	0.38	798	0.36	1,109	0.35	1,239	0.34
al Excluding Depreciation	18,192	14.84	20,796	13.82	28,084	12.66	37,252	11.76	40,679	11.17
reciation	3,465	2.82	3,991	2.65	5,211	2.35	6,875	2.17	7,811	2.14
al	21,657	17.66	24,787	16.47	33,295	15.01	44,127	13.93	48,490	13.31
EAN COAL COST										
efore Depreciation		18.41		16.95		14.79		14.25		13.70
fter Depreciation		21.90		20.20		18.29		16.91		16.34

Table 7-5. Present Labor Cost

Occupation	Daily Employment	Rate	Cost Per Day
Section Crew			
Miner Operator	18	$57.20	$ 1029.60
Loader Operator	18	54.06	973.08
Shuttle Car Operator	36	51.20	1843.20
Roof Bolter	36	57.20	2059.20
Brattice Man	18	48.91	880.38
Utility Man	18	48.91	880.38
Mechanic	18	57.20	1029.60
Subtotal	162		$ 8695.44
General Inside			
Supply Motorman	12	49.48	593.76
Beltman	22	48.91	1076.02
Trackman	8	48.91	391.28
Wireman	4	48.91	195.64
Mason	5	51.20	256.00
Pumper-Pipeman	3	48.91	146.73
Mechanics	15	57.20	858.00
Rock Duster	2	49.48	98.96
Equipment Mover	4	48.91	195.64
Conveyor Mover	9	48.91	440.19
Fireboss	4	57.20	228.80
Oiler-Greaser	9	48.91	440.19
Electrician	6	57.20	343.20
Utility Man	21	48.91	1027.11
Subtotal	124		$ 6291.52
Outside			
Lampman	3	49.76	149.28
Scoop Operator	2	49.76	99.52
Mechanic	18	51.48	926.64
Hoistman	3	57.48	172.44
Supply Crew	4	47.20	188.80
Subtotal	30		$ 1536.68
Shift Differential-Mine			261.58
Total Mine Labor Cost	316		16785.22
Cost per Raw Ton		3.01	
Cleaning Plant Employees	25	49.05	
Shift Differential-Cleaning Plant			18.58
Total Labor Cost	341		$18030.05
Cost per Clean Ton		4.01	
Average Daily Wage		$52.41	

Table 7-6. Stage I Labor Cost

Occupation	Daily Employment	Rate	Cost Per Day
Section Crew			
Extraction Machine Oper.(cut.)	18	$57.20	$ 1029.60
Shuttle Car Operator	36	51.20	1843.20
Extraction Machine Oper.(bolt.)	36	57.20	2059.20
Ventilation Man	18	48.91	880.38
Supply/Utility Man	18	48.91	880.38
Mechanic	18	57.20	1029.60
Subtotal	144		$ 7722.36
General Inside			
Supply Motorman	15	49.48	742.20
Beltman	22	48.91	1076.02
Trackman	10	48.91	489.10
Wireman	5	48.91	244.55
Mason	7	51.20	358.40
Pumper-Pipeman	4	48.91	195.64
Mechanics	19	57.20	1144.00
Rock Duster	3	49.48	148.44
Equipment Mover	5	48.91	244.55
Conveyor Mover	11	48.91	538.01
Fireboss	4	57.20	288.80
Oiler-Greaser	9	48.91	440.19
Electrician	8	57.20	457.60
Utility Man	28	48.91	1369.48
Subtotal	150		$ 7736.98
Outside			
Lampman	3	49.76	149.28
Scoop Operator	2	49.76	99.52
Mechanic	18	51.48	926.64
Hoistman	3	57.48	172.44
Supply Crew	6	47.20	283.20
Subtotal	32		$ 1631.08
Shift Differential-Mine			267.32
Total Mine Labor Cost	326		$17357.74
Cost per Raw Ton		2.54	
Cleaning Plant Employees	30	49.05	1471.50
Shift Differential-Cleaning Plant			22.29
Total Labor Cost	356		$18851.53
Cost per Clean Ton		3.38	
Average Daily Wage		$52.95	

Table 7-7. Stage II Labor Cost

Occupation	Daily Employment	Rate	Cost Per Day
Section Crew			
Extraction Machine Oper. (cut.)	18	$57.20	$ 1029.60
Mobile Bridge Operator	54	51.20	2764.80
Extraction Machine Oper. (bolt.)	36	57.20	2059.20
Ventilation Man	18	48.91	880.38
Supply Vehicle Operator	18	51.20	921.60
Mechanic	18	57.20	1029.60
Subtotal	162		$ 8685.18
General Inside			
Supply Motormen	22	49.48	1088.56
Beltmen	22	48.91	1076.02
Trackman	15	48.91	733.65
Wireman	8	48.91	391.28
Mason	10	51.20	512.00
Pumper-Pipeman	6	48.91	293.46
Mechanics	28	57.20	1601.60
Rock Duster	5	49.48	247.40
Equipment Mover	8	48.91	391.28
Conveyor Mover	11	48.91	538.01
Fireboss	4	57.20	228.80
Oiler-greaser	9	48.91	440.19
Electrician	12	57.20	686.40
Utility Crew	35	48.91	1711.85
Subtotal	195		$ 9940.50
Outside			
Lampman	3	49.76	149.28
Scoop Operator	3	49.76	149.28
Mechanic	20	51.48	1029.60
Hoistman	3	57.48	172.44
Supply Crew	9	47.20	424.80
Subtotal	38		$ 1925.40
Shift Differential-Mine			323.90
Total Mine Labor Cost	395		$20874.98
Cost per Raw Ton		1.97	
Cleaning Plant Employees	35	49.05	1716.75
Shift Differential-Cleaning Plant			26.01
Total Labor Cost	430		$22617.74
Cost per Clean Ton		2.73	
Average Daily Wage		$52.60	

Table 7-8. Stage III Labor Cost

Occupation	Daily Employment	Rate	Cost Per Day
Section Crew			
Tech. Serviceman-Extraction	18	$57.20	$ 1029.60
Tech. Serviceman-Haulage	18	57.20	1029.60
Ventilation Technician	18	57.20	1029.60
Roof Control Tech. Serviceman	18	57.20	1029.60
Supply Technician	18	57.20	1029.60
Mechanic	18	57.20	1029.60
Electrician	18	57.20	1029.60
Monitoring Systems Technician	18	57.20	1029.60
Subtotal	144		$ 8236.80
General Inside			
Supply Motormen	31	49.48	1533.88
Beltman	22	48.91	1076.02
Trackman	22	48.91	1076.02
Wireman	12	48.91	586.92
Mason	15	51.20	768.00
Pumper-Pipeman	9	48.91	440.19
Mechanics	40	57.20	2288.00
Rock Duster	8	49.48	395.84
Equipment Mover	12	48.91	586.92
Conveyor Mover	12	48.91	586.92
Fireboss	4	57.20	228.80
Oiler-greaser	9	48.91	440.19
Electrician	18	57.20	1029.60
Utility Crew	49	48.91	2396.59
Subtotal	263		$13433.89
Outside			
Lampman	3	49.76	149.28
Scoop Operator	3	49.76	149.28
Mechanic	22	51.48	1132.56
Hoistman	3	57.48	172.44
Supply Crew	12	47.20	566.40
Subtotal	43		$ 2169.96
Shift Differential-Mine			369.00
Total Mine Labor Cost	450		$24209.65
Cost per Raw Ton		1.68	
Cleaning Plant Employees	40	49.05	1962.00
Shift Differential-Cleaning Plant			29.73
Total Labor Cost	490		$26201.38
Cost per Clean Ton		2.21	
Average Daily Wage		$53.47	

Table 7-9. Stage IV Labor Cost

Occupation	Daily Employment	Rate	Cost Per Day
Section Crew			
Tech. Serviceman-Extraction	18	$57.20	$ 1029.60
Tech. Serviceman-Haulage	18	57.20	1029.60
Ventilation Technician	18	57.20	1029.60
Roof Control Technician	18	57.20	1029.60
Supplies Technician	18	57.20	1029.60
Monitoring Systems Technician	18	57.20	1029.60
Subtotal	108		$ 6177.60
General Inside			
Supply Motormen	36	49.48	1781.28
Beltman	22	48.91	1076.02
Trackman	26	48.91	1271.66
Wireman	14	48.91	684.74
Mason	17	51.20	870.40
Pumper-Pipeman	11	48.91	538.01
Mechanics	45	57.20	2574.00
Rock Duster	9	49.48	445.32
Equipment Mover	14	48.91	684.74
Conveyor Mover	14	48.91	684.74
Fireboss	4	57.20	228.80
Oiler-greaser	9	48.91	440.19
Electrician	21	57.20	1201.20
Utility Crew	49	48.91	2396.59
Subtotal	291		$14877.69
Outside			
Lampman	3	49.76	149.28
Scoop Operator	3	49.76	149.28
Mechanic	24	51.48	1235.52
Hoistman	3	57.48	172.44
Supply Crew	15	47.20	708.00
Subtotal	48		$ 2414.52
Shift Differential-Mine			366.54
Total Mine Labor Cost	447		$23836.35
Cost per Raw Ton		1.44	
Cleaning Plant Employees	45	49.05	2207.25
Shift Differential-Cleaning Plant			33.44
Total Labor Cost	492		$26077.04
Cost per Clean Ton		1.93	
Average Daily Wage		$53.00	

multiplied by 220 operating days per year to obtain the annual cost listed in Table 7-4. The annual cost of supervision is detailed in Table 7-10 where estimated annual salaries are listed according to the supervision requirements determined in Chapter 5.

Labor and supervisory benefits and other costs such as absenteeism, overtime, training, and idle day work are based on the information presented in Table 7-11.

The daily cost of each worker is summarized in Table 7-12. The total cost per man day increases 11 percent from the Present Stage through Stage IV, which is primarily due to a larger payment per man to the UMWA Health and Welfare Fund. The increased expenditure results primarily from the tonnage based portion of the welfare payment.

Other Cash Costs. The other cash category includes mine operating supplies, mine maintenance supplies, mine and plant power, mine extension, administration, legal penalties, property taxes, insurance, association dues, miscellaneous costs, and royalty and selling fee. Cleaning plant costs, depreciation, federal income tax, and return on investment (income) are discussed in later report sections. The expenditures are primarily based on the author's experience of costs in current mining operations. The previously outlined production rates, job functions, and equipment lists are the basis for projecting these costs through the automation stages. Many "other cash costs" while judgmental in their specific amounts for the Present Stage would be considered more absolute in their relative position from Present Stage through Stage IV.

Table 7-10. Supervision Annual Cost (in thousand dollars)

Position	Present	Stage I	Stage II	Stage III	Stage IV
Superintendent	$ 35	$ 35	$ 35	$ 35	$ 35
General Mine Foreman	28	28	28	28	28
Assistant General Mine Foreman	72	72	96	120	144
Section Foreman/Supervisor	396	396	396	396	396
Construction Foreman/Supervisor	66	88	132	132	132
Haulage Foreman	22	44	66	66	66
Supply Foreman	22	44	66	66	66
Maintenance Superintendent	30	30	30	30	30
Asst. Maintenance Superintendent	28	56	84	84	84
General Maintenance Foreman	26	26	26	26	26
Shop Foreman	72	72	72	72	72
Maintenance Foreman	132	198	264	264	264
Chief Mine Engineer	25	25	25	25	25
Draftsman	12	24	36	48	60
Survey Crew	24	24	36	48	48
Safety Director	24	24	24	24	24
Safety Inspector	22	44	66	66	66
Training Instructor	16	32	64	96	128
Dust and Noise Technician	12	12	12	12	12
Office Personnel Manager	18	18	18	18	18
Time and Bookkeeper	12	12	24	24	24
Purchasing Agent	18	18	18	18	18
Warehouseman	36	36	48	60	72
Industrial Engineer	20	40	80	120	120
Electrical Engineer	20	40	80	120	160
Mechanical Engineer	-	-	20	20	20
Mine Engineer	-	22	44	66	88
Design Engineer	-	-	20	20	20
Asst. Mine Superintendent	-	30	30	30	30
Computer Scientist	-	-	-	18	18
Computer Technician	-	-	-	42	42
Ventilation Engineer	-	-	20	20	20
Supplies Engineer	-	-	20	20	20
Haulage Engineer	-	-	20	20	20
Additional Salary (includes cleaning plant)	60	80	100	120	140
Total Salary	$1248	$1570	$2100	$2374	$2536

Table 7-11. Basis of Labor and Supervisory Benefits and Other Costs

1. Social Security: 5.85% of the first $14,800 annually or $865.80 per employee
2. Salaried Benefits: 25% of annual salary
3. Holiday and Vacation Pay: 24 days (10 holidays, 14 vacation) per employee at average rate annually
4. Other UMWA Benefits:
    a. safety equipment and protective clothing allowance @ $75 per employee annually
    b. bereavement, jury, and military duty @ 3 days per employee annually
    c. sickness and accident benefit insurance @ $100 per employee annually
    d. sickness pay @ 5 days per employee at average rate annually
5. Health and Welfare Fund: $.78 per clean ton and $1.40 per hour worked
6. Absenteeism: 10% additional employment including payment of benefits
7. Overtime: 10% of the hourly labor cost
8.
    a. black lung insurance and workmen's compensation insurance: 19.24 per $100 of payroll
    b. cost of living adjustment (COLA): $3.68 per day per employee
    c. unemployment insurance: 0.8% of the first $4,200 annually or $33.60 per employee
9. Nonproductive Training: estimated cost based on the authors' experience
10. Idle Day Work: 20% of the labor force will work 21 days annually at the average rate

Table 7-12. Average Daily Cost of Union Employees.

Category	Present	Stage I	Stage II	Stage III	Stage IV
Number Employed	344	356	430	490	492
Wages	$ 52.41	$ 52.95	$ 52.60	$ 53.47	$ 53.00
Social Security	3.94	3.94	3.94	3.94	3.94
Holiday & Vacation Pay	5.72	5.78	5.74	5.83	5.78
Other Benefits	2.70	2.72	2.71	2.74	2.72
Health & Welfare Fund	22.78	24.30	27.12	31.02	32.40
Unemp, COLA, Blacklung & Wkm. Comp.	18.37	19.17	19.00	19.67	19.84
Subtotal	$105.42	$108.86	$111.11	$116.67	$117.68
Overtime	5.24	5.30	5.26	5.35	5.30
Training	1.30	1.30	1.30	1.30	1.30
Idle Day Work	1.27	1.27	1.27	1.27	1.27
Absenteeism	1.26	1.26	1.26	1.26	1.26
Total	$114.49	$117.99	$120.20	$125.85	$126.81

Table 7-13 lists both operating and maintenance supplies costs. Due to increased production volume the annual dollars available for operating and maintenance supplies increases significantly from the Present Stage through Stage IV, respectively, as follows: $2,928,000, $4,680,000, $7,273,000, $10,707,000, and $12,370,000. Operating supplies cost per ton show a slight decrease through automation progression. Maintenance supplies cost per ton increase slightly. Normally, maintenance supplies cost per ton will decrease as production increases; however, more sophisticated equipment and more machinery on the section lead to the predicted higher costs per ton. The ratio of maintenance supplies cost per clean ton to the investment per annual clean ton decreased slightly - 1:21, 1:20, 1:16, 1:14, and 1:13 - for the Present Stage through Stage IV, respectively.

The basis for the other cash costs are described in the following Table 7-14.

Cleaning Plant. The costs of wages and benefits for cleaning plant employees are included in the calculations for the entire operation. The total cost per raw ton for cleaning plant employees wages and benefits is $0.50, $0.50, $0.40, $0.34, and $0.33, respectively, for the Present Stage through Stage IV. The operating and maintenance supplies are estimated to be $0.20 and $0.40 per ton, respectively, for the Present Stage. Both decrease slightly as automation progresses. On a raw-ton basis, the total cleaning plant operating costs are $1.10, $1.07, $0.94, $0.86, and $0.83, respectively, for the Present Stage through Stage IV. However, the annual dollars available for total

Table 7-13. Basis of Other Cash Costs

1. Power: $0.40 per ton for the Present Case with 60% fixed monthly cost and 40% varying with production.
2. Mine Extension: $0.20 per raw ton
3. Administrative: $0.60 per raw ton
4. Legal Penalties: $0.02 per raw ton
5. Property Taxes: $0.30 per raw ton
6. Insurance: $0.10 per raw ton
7. Royalty and Selling Fee: 4% of the selling price

Table 7-14. Operating and Maintenance Supplies Cost ($/raw ton)

	Present	Stage I	Stage II	Stage III	Stage IV
Operating					
Lubrication & Hydraulic Oil	.10	.10	.10	.10	.10
Bits	.15	.15	.15	.15	.15
Roof Support	.55	.55	.55	.55	.55
Power Distribution	.05	.04	.03	.02	.02
Water Supply & Drainage	.05	.04	.03	.02	.02
Haulage	.10	.09	.08	.07	.06
Rock Dust	.10	.10	.10	.10	.10
Ventilation	.20	.20	.20	.20	.20
Other	.15	.15	.15	.15	.15
Total Operating Supplies	1.45	1.42	1.39	1.36	1.35
Maintenance					
Continuous Miners/AES	.60	.70	.70	.70	.75
Shuttle Cars/Mobile Convy.	.15	.15	.20	.20	.20
Roof Bolters	.05	.04	.03	.02	.02
Scoop	.05	.04	.03	.02	.02
Belt Feeders	.05	.05	.05	.05	.05
Conveyors	.05	.05	.05	.05	.05
Locomotives	.10	.09	.08	.07	.06
Power Distribution Equip.	.10	.09	.08	.07	.06
Water Supply & Drainage	.05	.04	.03	.02	.02
Cables	.10	.10	.10	.10	.10
Batteries & Chargers	.05	.05	.05	.05	.05
Supply Cars	.05	.05	.05	.05	.05
Portal Buses & Jeeps	.05	.04	.03	.02	.02
Other	.20	.20	.20	.20	.20
Supply Vehicle	-	-	.05	.05	.05
Conveyor Moving Machine	-	-	.05	.05	.05
Stopping Emplacer	-	-	.05	.05	.05
Piped Rock Dust System	-	-	.05	.05	.05
Monitoring Systems	-	-	-	.10	.10
Computers	-	-	-	.10	.10
Total Maintenance Supplies	$1.75	$1.69	$1.89	$2.02	$2.05

cleaning plant operating costs from the Present Stage through Stage IV, respectively, are $1,350,000, $1,610,000, $2,085,000, $2,724,000, and $3,024,000. Consequently, if the coal did not require cleaning the raw-ton costs would decrease by a sum approaching these amounts. However, some monies would be required for outside raw coal handling and storage facilities.

Table 7-4 reports the total operating costs on a raw-ton basis. Converted to clean tons, the total costs per ton including depreciation for the Present Stage through Stage IV are: $21.90, $20.20, $18.24, $16.91, and $16.34.

Depreciation. The straight-line method of depreciating the initial and replacement capital on a dollars per ton basis is used to develop the necessary information for the income tax computation. The sum of the initial and replacement capital is divided by the total tons to be mined over the 25-year life of the study for the respective cases. It has been previously recognized that varying amounts of reserve dedication are required for the various stages.

Selling Price

The amount of income that would result in a 15 percent rate of return over the entire life of the study for the Present Stage was calculated by testing various selling prices until the correct realization figure of $31.50 per clean ton was established. The selling price reflects the requirements of a new deep mine including plant site, development openings, and preparation plant. The result is a rather high initial investment per annual ton at a relatively low productivity level of 11.3 tons clean coal per man day. However, this figure is nearly 20 percent above the 1975 national average productivity for underground coal mining. It is recognized that underground mines are not achieving such a high realization for their coal. However, they were probably either developed before inflation raised mine installation costs to current levels, have lower mining costs, or may not be achieving a 15 percent rate of return after FIT over the life of the mine.

The selling price calculated for the Present Stage is utilized as the realization for Stages I through IV. This constant selling price allows a direct comparison of rates of return on investment after FIT for all five cases. All monies are in 1976 constant dollars and disregard the impact of future inflation.

Income Tax

The method used to calculate federal income tax is a standard procedure and is documented by Weir. (81) The Present Stage through Stage IV computations of income taxes are presented in Tables 7-15 through 7-19. Depreciation (from Table 7-4) is included in the production cost figure. Coal mining is allowed a deduction for depletion. It is calculated at 10 percent of that gross selling price after royalty, or 50 percent of the net income, whichever is less. As noted in the tables, the income tax at full production increases from $3.14 to $5.81 per clean ton as automation progresses to Stage IV.

Table 7-15. Calculation of Present Stage Federal Income Tax per Clean Ton.

	Year 1	Year 2	Year 3	Years 4-25
Gross Sales	31.50	31.50	31.50	31.50
Less Royalty	-1.00	-1.00	-1.00	-1.00
Net Sales	30.50	30.50	30.50	30.50
Production Cost	32.48	23.37	22.43	21.90
Less Royalty	-1.00	-1.00	-1.00	-1.00
Adjusted Production Cost	31.48	22.37	21.43	20.90
Net Income	---	8.13	9.07	9.60
Depletion @ 10% of Net Sales		3.05	3.05	3.05
Depletion @ 10% of Net Income		4.07	4.53	4.80
Gross Sales	31.50	31.50	31.50	31.50
Production Cost	32.48	23.37	22.43	21.90
Net Income	---	8.13	9.07	9.60
Less Depletion Allowance	-3.05	-3.05	-3.05	-3.05
Taxable Income		5.08	6.02	6.55
Income Tax @ 48%		2.44	2.89	3.14

Table 7-16. Calculation of Stage I Federal Income Tax per Clean Ton

	Year 1	Year 2	Year 3	Years 4-25
Gross Sales	31.50	31.50	31.50	31.50
Less Royalty	-1.00	-1.00	-1.00	-1.00
Net Sales	30.50	30.50	30.50	30.50
Production Cost	29.93	21.56	20.69	20.20
Less Royalty	-1.00	-1.00	-1.00	-1.00
Adjusted Production Cost	28.93	20.56	19.69	19.20
Net Income	1.57	9.94	10.81	11.30
Depletion @ 10% of Net Sales	3.05	3.05	3.05	3.05
Depletion @ 10% of Net Income	0.79	4.97	5.41	5.65
Gross Sales	31.50	31.50	31.50	31.50
Production Cost	29.93	21.56	20.69	20.20
Net Income	1.57	9.94	10.81	11.30
Less Depletion Allowance	0.79	3.05	3.05	3.05
Taxable Income	0.78	6.89	7.76	8.25
Income Tax @ 48%	0.37	3.31	3.72	3.96

Table 7-17. Calculation of Stage II Federal Income Tax per Clean Ton.

	Year 1	Year 2	Year 3	Years 4-25
Gross Sales	31.50	31.50	31.50	31.50
Less Royalty	-1.00	-1.00	-1.00	-1.00
Net Sales	30.50	30.50	30.50	30.50
Production Cost	27.16	19.53	18.73	18.29
Less Royalty	-1.00	-1.00	-1.00	-1.00
Adjusted Production Cost	26.16	18.53	17.73	17.29
Net Income	4.34	11.97	12.77	13.21
Depletion @ 10% of Net Sales	3.05	3.05	3.05	3.05
Depletion @ 50% of Net Income	2.17	5.99	6.39	6.61
Gross Sales	31.50	31.50	31.50	31.50
Production Cost	27.16	19.53	18.73	18.29
Net Income	4.34	11.97	12.77	13.21
Less Depletion Allowance	-2.17	-3.05	-3.05	-3.05
Taxable Income	2.17	8.92	9.72	10.16
Income Tax @ 48%	1.04	4.28	4.67	4.88

Table 7-18. Calculation of Stage III Federal Income Tax per Clean Ton

	Year 1	Year 2	Year 3	Years 4-25
Gross Sales	31.50	31.50	31.50	31.50
Less Royalty	-1.00	-1.00	-1.00	-1.00
Net Sales	30.50	30.50	30.50	30.50
Production Cost	25.12	18.05	17.32	16.91
Less Royalty	-1.00	-1.00	-1.00	-1.00
Adjusted Production Cost	24.12	17.05	16.32	15.91
Net Income	6.38	13.45	14.18	14.59
Depletion @ 10% of Net Sales	3.05	3.05	3.05	3.05
Depletion @ 50% of Net Income	3.19	6.73	7.09	7.30
Gross Sales	31.50	31.50	31.50	31.50
Production Cost	25.12	18.05	17.32	16.91
Net Income	6.38	13.45	14.18	14.59
Less Depletion Allowance	-3.05	-3.05	-3.05	-3.05
Taxable Income	3.33	10.40	11.13	11.54
Income Tax @ 48%	1.60	4.99	5.34	5.54

Table 7-19. Calculation of Stage IV Federal Income Tax per Clean Ton

	Year 1	Year 2	Year 3	Years 4-25
Gross Sales	31.50	31.50	31.50	31.50
Less Royalty	-1.00	-1.00	-1.00	-1.00
Net Sales	30.50	30.50	30.50	30.50
Production Cost	24.22	17.44	16.73	16.34
Less Royalty	-1.00	-1.00	-1.00	-1.00
Adjusted Production Cost	23.22	16.44	15.73	15.34
Net Income	7.28	14.06	14.77	15.16
Depletion @ 10% of Net Sales	3.05	3.05	3.05	3.05
Depletion @ 50% of Net Income	3.64	7.03	7.39	7.58
Gross Sales	31.50	31.50	31.50	31.50
Production Cost	24.22	16.44	15.73	15.34
Net Income	7.28	14.06	14.77	15.16
Less Depletion Allowance	3.05	3.05	3.05	3.05
Taxable Income	4.23	11.01	11.72	12.11
Income Tax @ 48%	2.03	5.28	5.63	5.81

Profitability Index

The previously computed items for all five cases (production, income, capital investment, operating expense, and income tax) are used to compute the cash flow shown in Tables 7-20 through 7-24. First the income is determined by multiplying the selling price per ton ($31.50) by the annual production increment. Then the total expense (operating expense before decpreciation plus income tax) is presented year-by-year. The difference between the income and total expense is the annual cash flow.

In Tables 7-20 through 7-24 the present value of the summed annual initial replacement capital expenditures at selected interest rates is entered in column A and the present value of the annual cash flows at the same interest rates are entered in column B. Instead of calculating the present worth year-by-year when the cash flow or expenditure is constant for several years, the discounting factors were summed over that period and the total multiplied by the constant dollar amount. Both columns are totaled and the A/B ratio of present worth expenditures (A) to present worth income (B) is computed. The factors used to determine the present value of the incremental annual expenditures and receipts are listed in Reul's article. (59) The assumptions of continuous compounding and continuous receipt and expenditure of funds are built into these present worth factors.

Since it is highly unlikely that any of the interest rates selected will produce the unity A/B ratio desired - except the 15 percent rate for the Present Case - the graph in Figure 7-1 was constructed to

Table 7-20. Calculation of the Profitability Index for the Present Stage

Year	Thousand Annual Clean Tons	Initial Capital (Thousand Dollars)	Replacement Capital (Thousand Dollars)	Income @ $31.50/ton (Thousand Dollars)	Expense Before Depreciation (Thousand Dollars)	Depreciation $3.50/ton (Thousand Dollars)	Income Tax (Thousand Dollars)	Total Expense (Thousand Dollars)	Cash Flowback (Thousand Dollars)	A 10%	B 10%	A 20%	B 20%	A 15%	B 15%
P-3		1750								2249		2888		2548	
P-2		9787								11275		13340		12263	
P-1		10012								10533		11083		10803	
1	220	11067		6930	6376	770	--	6376	554	10536	527	10038	502	10281	515
2	550	10100		17325	10930	1925	1342	12272	5053	8696	4351	7484	3744	8070	4037
3	770	1415		24255	14573	2695	2225	16798	7457	1102	5809	860	4534	974	5130
4	990			31185	18216	3465	3109	21325	9860						
5	↓			↓	↓	↓	↓	↓	↓						
6	↓			↓	↓	↓	↓	↓	↓						
7	↓			↓	↓	↓	↓	↓	↓						
8	↓		2500	↓	↓	↓	↓	↓	↓						
9	↓		↓	↓	↓	↓	↓	↓	↓						
10	↓		↓	↓	↓	↓	↓	↓	↓						
11	↓		↓	↓	↓	↓	↓	↓	↓						
12	↓		↓	↓	↓	↓	↓	↓	↓						
13	↓		↓	↓	↓	↓	↓	↓	↓						
14	↓		↓	↓	↓	↓	↓	↓	↓						
15	↓		↓	↓	↓	↓	↓	↓	↓						
16	↓		↓	↓	↓	↓	↓	↓	↓						
17	↓		↓	↓	↓	↓	↓	↓	↓						
18	↓		↓	↓	↓	↓	↓	↓	↓						
19	↓		↓	↓	↓	↓	↓	↓	↓						
20	↓		↓	↓	↓	↓	↓	↓	↓	2500x		2500x		2500x	
21	↓		↓	↓	↓	↓	↓	↓	↓	3.859=		1.171=		2.088=	
22	↓		2500	↓	↓	↓	↓	↓	↓	9648		2928		5220	
23	↓			↓	↓	↓	↓	↓	↓		9860x		9860x		9860x
24	↓			↓	↓	↓	↓	↓	↓		6.587=		2.711=		4.095=
25	990			31185	18216	3465	3109	21325	9860		64948		26730		40377
Total	23320	44131	37500	734580	432631	81620	71965	504596	229984	54039	75635 A/B = 0.714	48621	35510 A/B = 1.369	50159	50059 A/B = 1.002

Table 7-21. Calculation of the Profitability Index for Stage I

Year	Thousand Annual Clean Tons	Initial Capital (Thousand Dollars)	Replacement Capital (Thousand Dollars)	Income @ $31.50/ton (Thousand Dollars)	Expense Before Depreciation (Thousand Dollars)	Depreciation $3.25/ton (Thousand Dollars)	Income Tax (Thousand Dollars)	Total Expense (Thousand Dollars)	Cash Flowback (Thousand Dollars)	A 15%	B 15%	A 20%	B 20%	A 25%	B 25%
P-3		2017								2937		3328		3778	
P-2		11280								14134		15375		16446	
P-1		11539								12451		12774		13108	
1	273	12755		8600	7285	887	101	7386	1214	11849	1128	11569	1101	11288	1074
2	682	11640		21483	12489	2217	2257	14746	6737	9300	5383	8625	4992	8020	4642
3	955	1631		30083	16652	3104	3553	20205	9878	1122	6796	991	6006	876	5304
4	1228			38682	20815	3991	4863	25678	13004						
5															
6															
7															
8			2882												
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20										2882x		2882x		2882x	
21										2.088=		1.171=		0.680=	
22			2882							6018		3375		1960	
23											13004x		13004x		13004x
24											4.095=		2.711=		1.884=
25	1228			38682	20815	3991	4863	25678	13004		53251		35254		24500
Total	28926	50862	43230	911170	494356	94010	112897	607253	303917	57811	66558	56037	47353	55476	35520
											A/B =		A/B =		A/B =
											0.869		1.183		1.562

Table 7-22. Calculation of the Profitability Index for Stage II

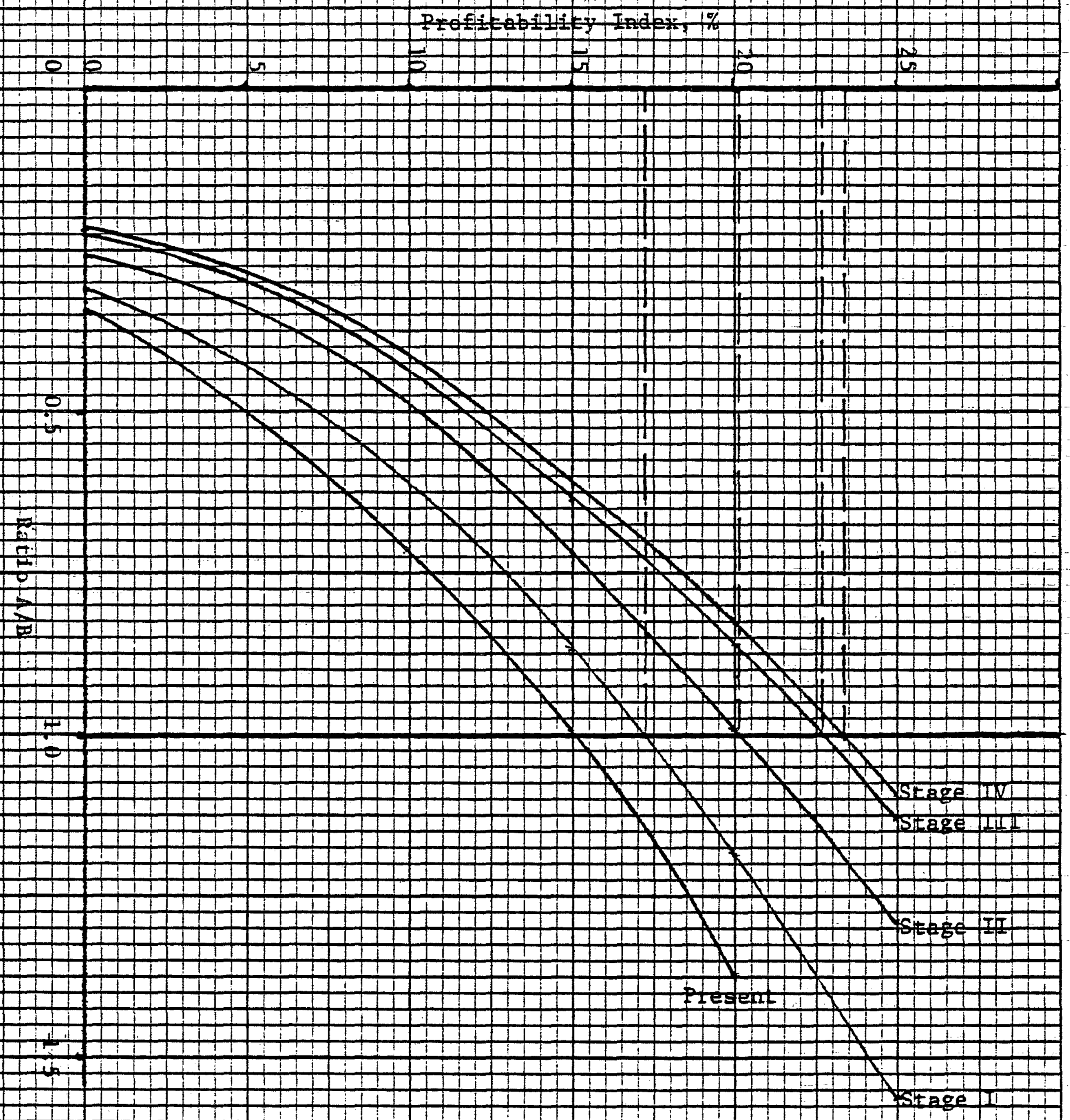
Year	Thousand Annual Clean Tons	Initial Capital (Thousand Dollars)	Replacement Capital (Thousand Dollars)	Income @ $31.50/ton (Thousand Dollars)	Expense Before Depreciation (Thousand Dollars)	Depreciation $2.86/ton (Thousand Dollars)	Income Tax (Thousand Dollars)	Total Expense (Thousand Dollars)	Cash Flowback (Thousand Dollars)	A 15%	B 15%	A 20%	B 20%	A 25%	B 25%
P-3		2634								3835		4346		4933	
P-2		14732								18459		20080		21479	
P-1		15071								16262		16684		17121	
1	405	16659		12758	9840	1158	421	10261	2497	15476	2320	15110	2265	14743	2210
2	1012	15203		31878	16868	2894	4331	21199	10679	12147	8533	11265	7913	10475	7358
3	1417	2130		44636	22490	4053	6617	29107	15529	1465	10684	1295	9442	1144	8339
4	1822			57393	28113	5211	8891	37004	20389						
5	↓			↓	↓	↓	↓	↓	↓						
6	↓			↓	↓	↓	↓	↓	↓						
7	↓			↓	↓	↓	↓	↓	↓						
8	↓		3764	↓	↓	↓	↓	↓	↓						
9	↓		↓	↓	↓	↓	↓	↓	↓						
10	↓		↓	↓	↓	↓	↓	↓	↓						
11	↓		↓	↓	↓	↓	↓	↓	↓						
12	↓		↓	↓	↓	↓	↓	↓	↓						
13	↓		↓	↓	↓	↓	↓	↓	↓						
14	↓		↓	↓	↓	↓	↓	↓	↓						
15	↓		↓	↓	↓	↓	↓	↓	↓						
16	↓		↓	↓	↓	↓	↓	↓	↓						
17	↓		↓	↓	↓	↓	↓	↓	↓						
18	↓		↓	↓	↓	↓	↓	↓	↓						
19	↓		↓	↓	↓	↓	↓	↓	↓						
20	↓		↓	↓	↓	↓	↓	↓	↓	3764x		3764x		3764x	
21	↓		↓	↓	↓	↓	↓	↓	↓	2.088=		1.171=		0.680=	
22	↓		3764	↓	↓	↓	↓	↓	↓	7859		4408		2560	
23	↓			↓	↓	↓	↓	↓	↓		20389x		20389x		20389x
24	↓			↓	↓	↓	↓	↓	↓		4.095=		2.711=		1.884=
25	1822			57393	28113	5211	8891	37004	20389		83493		55275		38413
Total	42918	66428	56460	1351918	667684	122747	206971	874655	477263	75503	105030	73188	74895	72455	56320
											A/B =		A/B =		A/B =
											0.719		0.977		1.286

Table 7-23. Calculation of the Profitability Index for Stage III

Year	Thousand Annual Clean Tons	Initial Capital (Thousand Dollars)	Replacement Capital (Thousand Dollars)	Income @ $31.50/ton (Thousand Dollars)	Expense Before Depreciation (Thousand Dollars)	Depreciation $2.63/ton (Thousand Dollars)	Income Tax (Thousand Dollars)	Total Expense (Thousand Dollars)	Cash Flowback (Thousand Dollars)	A 15%	B 15%	A 20%	B 20%	A 25%	B 25%
P-3		3490								5081		5759		6537	
P-2		19519								24457		26604		28459	
P-1		19968								21545		22105		22684	
1	581	22072		18302	13065	1528	930	13995	4307	20505	4001	20019	3906	19534	3812
2	1452	20143		45738	22397	3819	7245	29642	16096	16094	12861	14926	11927	13879	11090
3	2033	2822		64040	29862	5347	10856	40718	23322	1942	16046	1716	14180	1515	12524
4	2614			82341	37328	6875	14482	51810	30531						
5	↓			↓	↓	↓	↓	↓	↓						
6	↓			↓	↓	↓	↓	↓	↓						
7	↓			↓	↓	↓	↓	↓	↓						
8	↓		4987	↓	↓	↓	↓	↓	↓						
9	↓		↓	↓	↓	↓	↓	↓	↓						
10	↓		↓	↓	↓	↓	↓	↓	↓						
11	↓		↓	↓	↓	↓	↓	↓	↓						
12	↓		↓	↓	↓	↓	↓	↓	↓						
13	↓		↓	↓	↓	↓	↓	↓	↓						
14	↓		↓	↓	↓	↓	↓	↓	↓						
15	↓		↓	↓	↓	↓	↓	↓	↓						
16	↓		↓	↓	↓	↓	↓	↓	↓						
17	↓		↓	↓	↓	↓	↓	↓	↓						
18	↓		↓	↓	↓	↓	↓	↓	↓						
19	↓		↓	↓	↓	↓	↓	↓	↓						
20	↓		↓	↓	↓	↓	↓	↓	↓	4987x		4987x		4987x	
21	↓		↓	↓	↓	↓	↓	↓	↓	2.088=		1.171=		0.680=	
22	↓		4987	↓	↓	↓	↓	↓	↓	10413		5840		3391	
23	↓			↓	↓	↓	↓	↓	↓		30531x		30531x		30531x
24	↓			↓	↓	↓	↓	↓	↓		4.095=		2.711=		1.884=
25	2614			82341	37328	6875	14482	51810	30531		125024		82770		57520
Total	61844	88014	74805	1939582	886540	161944	337635	432175	737407	100037	157932	96969	112783	95999	84946
											A/B =		A/B =		A/B =
											0.633		0.860		1.130

Table 7-24. Calculation of the Profitability Index for Stage IV

Year	Thousand Annual Clean Tons	Initial Capital (Thousand Dollars)	Replacement Capital (Thousand Dollars)	Income @ $31.50/ton (Thousand Dollars)	Expense Before Depreciation (Thousand Dollars)	Depreciation $2.63/ton (Thousand Dollars)	Income Tax (Thousand Dollars)	Total Expense (Thousand Dollars)	Cash Flowback (Thousand Dollars)	A 15%	B 15%	A 20%	B 20%	A 25%	B 25%
P-3		3940								5737		7380		6501	
P-2		22037								27612		32152		30036	
P-1		22544								24325		25610		24956	
1	660	24919		20790	14252	1736	1340	15592	5198	23150	4829	22053	4600	22602	4715
2	1650	22742		51975	24431	4340	8712	33143	18832	18171	15047	15669	12975	16652	13955
3	2310	3186		72765	32575	6075	13005	45580	27185	2192	18703	1711	14598	1937	16528
4	2970			93555	40719	7811	17256	57975	35580						
5	↓			↓	↓	↓	↓	↓	↓						
6	↓			↓	↓	↓	↓	↓	↓						
7	↓			↓	↓	↓	↓	↓	↓						
8	↓		5631	↓	↓	↓	↓	↓	↓						
9	↓		↓	↓	↓	↓	↓	↓	↓						
10	↓		↓	↓	↓	↓	↓	↓	↓						
11	↓		↓	↓	↓	↓	↓	↓	↓						
12	↓		↓	↓	↓	↓	↓	↓	↓						
13	↓		↓	↓	↓	↓	↓	↓	↓						
14	↓		↓	↓	↓	↓	↓	↓	↓						
15	↓		↓	↓	↓	↓	↓	↓	↓						
16	↓		↓	↓	↓	↓	↓	↓	↓						
17	↓		↓	↓	↓	↓	↓	↓	↓						
18	↓		↓	↓	↓	↓	↓	↓	↓						
19	↓		↓	↓	↓	↓	↓	↓	↓						
20	↓		↓	↓	↓	↓	↓	↓	↓	5631x		5631x		5631x	
21	↓		↓	↓	↓	↓	↓	↓	↓	2.088=		0.680=		1.171=	
22	↓		5631	↓	↓	↓	↓	↓	↓	11758		3829		6594	
23	↓			↓	↓	↓	↓	↓	↓		35580x		35580x		35580x
24	↓			↓	↓	↓	↓	↓	↓		4.095=		1.884=		2.711=
25	2970			93555	40719	7811	17256	57975	35580		145700		67033		96457
Total	69960	99368	84465	2203740	967076	183993	402689	1369765	833975	112945	184279	108434	99206	109468	131655
											A/B =		A/B =		A/B =
											0.613		1.093		0.831


Profitability Index, %
0
5
10
15
20
25
Ratio A/B
0
0.5
1.0
1.5
Stage IV
Stage III
Stage II
Present
Stage I

interpolate between the selected interest rates for the proper rate of return at unity. The rates of return for each case resulting from the calculations and graphical interpolation are 15 percent, 17 percent, 20 percent, 22.5 percent, and 23 percent for the Present Stage through Stage IV, respectively. This is a 53 percent increase in the PI rate of return between the Present Stage and Stage IV.

Results

Table 7-25 summarizes the economics of automation and remote control for the case study mine. If automation technology were applied to the mine described as the Present Stage, it is anticipated that the figures listed for Stages I through IV would result. Even though the number of employees and the capital investment increases through the automation progression, gains in production improve both tons per manshift and investment per annual ton.

Table 7-25. Economic Summary (Clean Coal Basis)

Stage	Annual Production Tons (M)	Tons/man shift	Initial Investment (M)	Initial Investment/ Annual Ton	Total Cost/Ton*	PI Rate of Return**
Present	990	11.3	$44,131	$44.58	$21.90	15%
I	1228	13.0	$50,862	$41.42	$20.20	17%
II	1822	15.6	$66,428	$36.46	$18.29	20%
III	2614	19.6	$88,014	$33.67	$16.91	22.5%
IV	2970	21.8	$99,368	$33.46	$16.34	23%

* Including depreciation

** After federal income taxes

Chapter 8
PSYCHOLOGICAL AND ORGANIZATIONAL IMPACT

Introduction

Automation and remote control will increase the importance and change the nature of the mine workers' job, vary the structure of management, and modify the interrelations between many groups of employees. It is difficult to predict how miners and mine operators will be affected or exactly what their reactions will be. However, by combining the experience of the effects of automation in other industries with the technological advancements and resulting variations in job functions, personnel deployment, productivity, safety, and economics reported herein, many beneficial changes as well as changes that could cause problems can be postulated.

Upon being made aware of possible problem areas, research investigations and discussions among concerned industry representatives can propose actions to prevent or minimize the anticipated negative effects. The authors' advance several general solutions based on their knowledge of the subject, but more specific in depth investigation is required.

Studying the effects of the introduction of automation technology on the human factors in other industries does not tell the whole story of what will happen in underground coal mines. Most written reports of the psychological and sociological impacts stem from manufacturing plants and assembly line operations. Mining, with its inherent mobility, restricted working space and unpredictable hazardous environment creates problems that manufacturing industries have not had to face. Consequently, the changes in worker psychology are not exactly the same.

However, certain generalities are similar. The automation of aircraft presents more similarities. Even though a product - other than passenger transportation - is not produced in aviation, mobility of equipment and variable environmental conditions (nature) exist and require guidance and environmental sensing systems.

Another aspect of mining automation that has important human factor implications is its variation in degree or level of technology applied to different job functions. Some jobs, such as cutting and loading are more obviously benefited by automation in a profitability sense than others such as laying pipe or installing trolley wire. Therefore, workers controlling a highly automated machine will be interacting with manually or mechanically oriented occupations. Further investigation is needed to identify the extent to which lesser job levels can be economically automated to produce safer, easier, more profitable job functions.

It must be remembered that automation is not expected to replace the work of man, but rather to change its nature to a more pleasant environment with increased safety and productivity. In this manner new technology will assist in meeting the future increased demand for coal at more competitive prices. It will definitely improve the marketing position of underground coal in relation to that from strip mines and other competitive energy sources.

For automation to be successful, cooperation between management and the union is essential. If both groups do not recognize the potential mutual benefits and honestly try to make the new technology work, it won't be profitable. In addition to the most obvious benefits of safety, more comfortable working conditions, less physical labor, improved pay, and better job security,the union miner will be in a position similar to the pilot of a modern jet airplane. In the later stages of automation, he will be spending much time in a comfortable, environmentally pleasant control station observing the feedback output data from several monitoring systems in the working area with occasional periods of service and machine adjustment. The initial stages of automation will result in jobs that are very similar to the present, and the method and rate of introduction are important parameters in the transition period.

The transition period or time is the administration and indoctrination from the present manual methods of operation to the requirements of an efficient automated system. It presumes the prior successful research and development of automated equipment and monitoring system. It would include such items as -

Defining and describing new roles and job functions.

Training employees utilizing well-conceived resource material.

Introduction and programming of automation technology and monitoring systems.

Establishment of sophisticated maintenance and supply control systems.

The transition period, progressing from the Present to the later stages of automation, will be a time of adjustment before the long-range benefits of automation and remote control can be enjoyed. It may be a difficult period because of the changing roles, responsibilities, and interactions between employees. Improved communication and attempts to anticipate problems on all levels of management and in the union is essential to a smooth transition. In order to avoid a large amount of insecurity and anxiety, workers must understand their new jobs. That is, adequate planning and training are extremely important.

Effect on Union Workers

In order to anticipate what human factors problems might occur, it is necessary to postulate how technological innovation might affect workers' behavior. Occupational prestige is a big factor in job satisfaction. Prestige depends on such factors as skill levels, training requisites, wages, extent of job control, responsibility, and working environment. To be satisfied in his job, a worker should have some freedom and control. In addition, he should be impressed with the purpose and function of his work and his place of work. Another important factor is promotion on the basis of merit. If these things are present in acceptable degrees, the worker tends to evaluate his job positively which enforces his desire to do it well. The effects of automation on these factors should be positive to obtain worker cooperation. We will now discuss how these factors are affected by automation.

Returning to the similarities with the pilot of a modern jet plane, it is obvious that like the pilot a miner controlling a machine will supervise several operations simultaneously. For example, the extraction machine operator will monitor the cutting and loading functions and their interface with haulage and roof-control. Additionally he will have to be aware of the mechanical, hydraulic and electrical condition of the machine. Environmental and roof-control monitoring system output data will also be available to him. Consequently, he will be impressed with the purpose of his work because he will have an overview of several operations. He is not like an assembly line worker, that is, restricted to methodically performing one small part of the total operation.

Nevertheless, dealing with several functions at one time stresses the importance of communication and cooperation. The extraction machine operator must exchange data with fellow workers responsible for the roof control and haulage functions. He must consult with the foreman and/or mechanical and electrical service if trouble develops. Many other interactions are possible which in addition to the few mentioned indicate cooperativeness and communication are essential to a smooth running automatic system.

The control of a large, expensive extraction system will give the worker a larger sense of self-value, and rightfully so: he is very important. On the other hand, he has a large responsibility because minimizing delay time in such an expensive system is paramount. This may result in mental or nervous fatigue if not properly arranged and accommodated. The foreman and other workers should be arranged close at hand for consultation and sharing of the responsibility when trouble develops. In this manner the extraction machine operator reduces mental stress by sharing problems with others.

As jobs are transferred and upgraded during the transition period, workers may accept responsibility and decision-making reluctantly. They may want to force the foreman to make all the decisions. The reluctance may arise from a feeling of insecurity or lack of understanding about the new job. They may not comprehend its functions at the outset. Therefore, adequate and thorough training is extremely important. In addition, the workers may not want to share the consequences of an incorrect decision. They will probably require the foreman to be responsible and properly so; the total section is his responsibility. Again, training will smooth the issue.

The concept of a production period and a service period during the shift has several interesting consequences. First, physical labor is reduced when the men are in the section control station during production. But their jobs are not entirely confined to the control station because they are required to travel to the working area for the service period. This somewhat divides the day into a mental and a physical activity period. Consequently, boredom and monotony, which sometimes plagues workers involved with automation jobs in manufacturing plants, is reduced. Some rest, relaxation and personal time will be provided for the workers through job scheduling with coworkers. In addition times will be provided for planning and discussion with the foreman.

Another factor that workers may have difficulty adjusting to is a machine that controls itself. It might be hard for a miner to accept the fact that an automatic machine will do its job better if it is left alone - providing it is not malfunctioning. The operator may attempt to adjust or change things that are perfectly all right to show his dominance over the system or because he can't accept the fact that the machine doesn't need his help. This problem reportedly occurred during earlier automation experiences with the Joy Pushbutton Miner (61).

The operator will not be able to directly observe the machine during the remote controlled production period. He must rely on a coded form of machine actions and position plus TV viewing to determine its status. This is a very different position from the current operations where feel, sound and sight are used to determine the necessary control. Consequently, the operator will be tempted to shut down the system and enter the face area if he doesn't trust the feedback data from monitoring system sensors. Training and proper control station design (both of which are discussed later in this section) will minimize this problem.

Undoubtedly, one of the greatest benefits of automation is improved safety. The section workers will be in the secure control station during production periods. The control station area, in addition to providing a safe environment should also improve working conditions. It should be roomy, comfortable, clean, dry and have temperature, noise, and dust control. This will improve the overall health of the workers besides protecting them from roof falls and isolating them from dangerous machinery. Monitoring systems will provide data about the condition of the working section environment that miners have never had available before. Instead of relying solely on their own senses and variable states of awareness for advance warning of hazardous situations, workers will be able to add knowledge gained from sensor data to their own sensory perceptions. Men should benefit considerably from working in a safer, cleaner, more comfortable environment. Again, the worker becomes - during the production period - somewhat like a modern jet pilot with copilot and navigator companions for assistance.

A workers' self-evaluation of his job many times reflects what his close friends and family as well as society in general regard his job to be. If it is a dangerous, labor intensive, and dirty occupation, it may not be held in high esteem. Better conditions from automation should improve the concept and regard that many people have about underground coal mining. As a result, the coal miner's social standing will be considerably upgraded.

Another positive social aspect stems from the reduction of physical labor. The underground coal mining industry should be a more desirable place for women to work. Also, handicapped persons may find more job opportunities in mining. However, any person employed underground must have the training and capacity to deal effectively with the emergency situations which may arise in coal mining.

Finally workers could be affected by possible variations in shift length and number of consecutive days worked. Even though the analysis contained in this report was entirely based on an eight-hour day and five days per week, this doesn't mean that it is the most efficient schedule for an automated mine. With the reduction in physical effort and increase in capital expenditure per machine, longer shifts and modifications in days per week may be a more productive system. However, it is recognized that the agreement and the consent of the union is necessary to initiate a different schedule successfully.

Effect on Management

Automation and remote control will also produce changes in management. It will place much greater emphasis on the planning and service support activities that management performs. And especially during the transition period, the changing roles of both union and management can cause considerable friction if not well-planned and coordinated. In fact many of the changes will occur in areas not common to the document upon which most union - management relations exist - the United Mine Workers Contract. Therefore, arbitration may be necessary in a broader range of union-management disputes unless provisions are made in the contract for the advancements in technology proposed in this report. An in-depth study of possible conflict areas and ways of modifying the existing wage agreement to reduce the friction that will occur during the transition period is needed.

The transition phase will magnify the need for clear communication between labor and management. Managers must think of new innovations impact on workers and what will result within the framework of the contract. Both sides must spend more time discussing the possible implications of future advancements and attempt to "iron-out" problems before they develop rather than waiting for a violation of the contract to sit down and talk. In short, more meetings must be held for the purpose of planning and informing with the hopeful outcome of reducing grievance meetings.

One of the most interesting areas of change in the management role is preparing workers to accept more responsibility and make more decisions. In other words, supervision will be more subtle. Foremen will provide workers with the materials and training necessary to accomplish a task; for example, control the AES machine. Then the foreman must not interfere unless the worker requests assistance or is obviously doing the job incorrectly. In effect, the foreman is no longer a "pusher" because automated machinery will operate at the predetermined pace without worker or management interference. Rather management becomes an instructor and a resource person who is available to the technical servicemen in time of trouble.

In order to properly utilize automation technology a number of nonsupervisory technicians will be added to the management ranks. These people will specialize in certain aspects of automation technology - for example - computer technicians. Engineers, another nonsupervisory management group, will also increase in number (refer to Table 5-2). Increased technical staff is a direct result of increased sophistication in equipment such as monitoring systems and computers. Miners would not be expected to calibrate sensors or program computers.

With the introduction of a greater amount of sophisticated equipment and the increased capital expenditure for such equipment, maintenance becomes more important. Additionally, present mining machines keep on producing some coal even when they aren't functioning properly. This probably will not be the case with remote controlled, automated equipment. There are many additional items on automated machines that could result in delay time - sensors, for instance. The increased possibility for delays and the additional cost associated with them will increase both the number and the rank of maintenance supervisors in management. In fact, the maintenance department will need several mechanical, electrical, and design engineers to provide information and control for the more complicated machines and monitoring systems. (Again refer to Table 5-2.) The experience of most manufacturing and processing industries verifies the increased scope and importance of the maintenance department in an automated plant (1). Referring again to the aviation industry, when the mechanics say "don't fly it" the plane is grounded. The same will probably apply in an automated mining section. However, the operation of only two out of three available shifts per mining section and the availability of a spare section when not moving gives relocation areas for crews in the event of a major equipment outage. However, this requires close coordination with other mining services such as maintenance and supply.

Automation will probably require a higher level of technical understanding of supervisors. However, if the front line supervision can call on engineering assistance at will this problem may not be severe. On the other hand, supervisors may need engineering backgrounds to maintain the technical competence necessary in the more complicated system.

The large amount of data available from the sensing systems can be used both as feedback for controlling mining systems and to inform management of conditions which will improve the decision making process. Computers are required to process the data quickly so immediate action can be taken if required or to store the data as a historical basis for comparison studies. Utilizing a computer in this fashion will eliminate a considerable amount of clerical work particularly if it is used in the supply-inventory-purchasing and worker check-in jobs. Computers can't provide the answers to mining problems that require the judgment of a man or the experience of a practical miner, but they will be an integral part of the decision making process by providing data that compliments experience and helps to form opinions.

Computer programming as well as data processing will become a significant new job at an automated mine. The initial programming time required during the transition period will be minimized if research projects develop universal programs. Initially, however, decisions on which programs should be produced are necessary. Obviously, the data from environmental and roof-control monitoring systems needs to be interfaced with the data describing the operation of the section equipment. Programs which can be used to order supplies for the sections that automatically dictates inventory and purchasing are also advantageous. Maintenance data banks that printout necessary preventative maintenance orders and store maintenance history descriptions of all pieces of equipment would be beneficial. A system of checking men in and out of the mine which automatically keeps track of time and computer wages is another useful program. There may be many others. Reprogramming and computer maintenance will prove to be ongoing jobs after the transition period has resulted in the initial program installations.

If supervisors know the areas that computers can aid them, better decisions and more comprehensive future planning will be the consequence. This points to training managers, not in computer programming since technicians can be utilized, but in how to use computers effectively to produce information that can help them make more profitable decisions and plans. One of the biggest hinderances to managers in the mining industry today is lack of quantitative information. Automated mining sensing systems and computerized data processing and storage should improve the situation immensely.

Training

The increased importance of training for workers in automatic systems has already been discussed. In review, the transition period where job functions and work roles are changing, training is extremely important to reinstill self-confidence and achieve an acceptable level of performance from the new equipment. Also, a lack of personnel having the essential skills will impede the advancement of automation. Finally, automation technology will probably advance quickly even after the transition period, requiring continued training.

Management and union employees will require training in a number of areas. Some of the most obvious are discussed here. Management must be knowledgeable in the field of computer science. Specifically, they should be able to direct computer technicians to provide the necessary information to assist them in total job preplanning and forecasting, evaluation of equipment performance, decision making for new projects, and operating costs analyses. This does not imply that managers should be computer programmers, but they should be aware of the potential usefulness of the computer in providing information to them. They should understand the capabilities and restrictions of various computer systems so they can select the one best suited to their needs.

Since the burden of forming good labor-management relations usually falls on management, a considerable amount of training must be done in this area. The changing roles of both managers (supervisors and technical staff) and union workers will require improved communication channels to discuss differences. Consequently, supervisors should be trained in how to conduct meetings with their workers, because the amount of discussion necessary for both sides to understand the problems of the other will result in increased meeting time. So production does not suffer excessively, the meetings must be conducted efficiently to get the maximum information exchange in the shortest possible time.

Supervisors and union workers will also be involved in several one-to-one sessions concerning the changing roles of both parties. Preparation about how to react and handle these situations involves another training exercise. In particular, the supervisor should be informed of the probable psychological consequences of automation on his crew members. He should be able to anticipate these reactions and be prepared to deal with them. Specifically, the supervisor might be trained to help union employees adjust to controlling a system rather than one machine, communicating and cooperating with other workers in their work group, accepting responsibility for an expensive mining system, transferring to a new job role, making decisions based on information, not interfering with an automatic machine, and accepting a coded form of machine actions rather than direct visual contact.

Training should be initiated to those persons responsible for preventing, participating in, and arbitrating grievances of possible UMWA contract violations. The current contract does not envisage a large scale transition to automation in the underground coal mining industry.

In other words, new job titles, work functions, and the changing position between labor and management are not anticipated in the contract. Therefore, as automation is introduced, several disputes may arise for which there are no clear-cut agreements and no set precedents. This will lead to a need for training as to what contract provisions might apply and how the worker's immediate supervisor should handle such a situation to prevent initiating a grievance proceeding or hastily setting a precedent that would be unfair to either party.

Labor-management relations will improve if union workers are trained in the several areas previously alluded to in this chapter. Training that will prepare workers to review information from monitoring systems, utilize the information to make decisions about service and maintenance schedules and to be willing to perform this type of work in place of the current hands-on-the machine manual control jobs. Instruction in communication skills are needed for union workers who will have to interface and share data with other employees, specifically explain machine condition problems to supervisors, and read section maps and electrical-mechanical-hydraulic blue prints.

The union worker controlling a mining system must be constantly aware of the various information outputs that are available to him. He must be trained to anticipate certain occurrences if the data outputs form a recognized pattern. And he must be able to adapt to unprecedented information patterns and occurrences. In other words, he must be trained to be responsive to the environment of a remote-control station. Quick scanning and interpretation of data is a specific training subject that will be important for the machine controller.

In addition to the remote-control operation, the machine must be operated during the service period from a direct visual observation position for turning crosscuts and changing entry position. So he must be trained in manual operation mode of automatic equipment as well as remote mode. The combination of the two operating positions may give the operator enough confidence in the automatic machine that he will let it alone during the production period. If not, a training program to assist the operator to develop confidence in the machine's self-control capabilities is required to prevent him from interfering with the automatic operation.

Since there is a shortage of skilled mechanics and electricians at present in the underground coal industry, the introduction of more sophisticated equipment will compound the problem. Training programs in electrical (including solid state technology), mechanical, and hydraulic systems for automatic mining equipment are definitely necessary.

Particular emphasis should be paid to diagnosis because component change-out rather than repair will be the most practical maintenance technique.

Before training programs can be developed, a step-by-step job description must be written for each new piece of automated equipment and monitoring system. Detailed operating, service, and maintenance manuals should be an integral part of every research program to develop automated equipment. In addition to specific job steps for each piece of equipment, the total section working group responsibilities including the interactions required between personnel must be defined. Workmen must be trained in a check procedure for hazardous conditions to be followed before anyone enters the face area immediately after a production period.

Once the detailed job steps are established, training programs can be developed and implemented. Again, similar to a pilot in the airline industry, surface training for miners compatible to the preflight instruction for new pilots could be utilized. This should be followed by "flight instruction," that is, underground operation of the equipment with a skilled operator instructor performing first and then observing by the trainee's side. Qualifications of operator instructions must be established.

Training efficiency, costs, and time can be improved by standardizing section layouts and equipment in addition to training everyone on the section to perform each job. Standardized equipment and monitoring systems (the same in every section) would make it easier to transfer men between sections which may be necessitated by absenteeism. Also, roving maintenance personnel would be easier to train.

At any rate, training costs will be significant in an automated mine. Consequently, prospective employees must be evaluated carefully. If not, uninterested trainees may eventally drop out or quit work after a short while with the company investment in training lost. Methods of determining the aptitude of prospective employees should also be utilized so a new worker is trained for a job he can do well as well as one he is interested in.

The attractive nature of the job and the job security it presents should enhance the worker's desire to participate in the necessary training programs.

Human Engineering in Equipment and System Design

Human engineering is very important in the design of automated equipment from the standpoint of acceptance by operators, improved operational efficiency, and maintainability. The adjustment that workers will have to make from present equipment to automated machinery will be easier if the automated equipment controls are easy for the worker to understand and adapt to.

In addition, the supervisory control data displays should be designed to produce an easily understood format that facilitates rapid reading and interpretation of data. So the operator does not have to continuously observe the data screens, audible warning signals and summary paper printouts will be necessary.

Computer graphics will aid the operator in understanding the machine position in relation to other equipment and the physical features of the mine. Also, graphic information, unlike television camera pictures, can be stored in a digital fashion for recall at a later time. This will aid foremen in communicating production and service job progress to each other when they change shifts. A comfortable, temperature controlled environment should be present in the remote console station to improve the efficiency of personnel and preserve the operating condition of the sophisticated electronic control equipment.

Equipment design should promote the concept of total mining system compatibility rather than a group of separate, distinct machines. If total system design including all of the 20 jobs listed in Chapter 3 is utilized and the sections are standardized, coordination between equipment operations within the section will be easier and more efficient. Training for operation, service, and maintenance will be simplified and worker performance will improve.

Equipment should be human engineered for ease of maintenance in addition to ease of operation. Simplified methods of troubleshooting and parts replacement with adequate working room will decrease maintenance period times. Sensors for monitoring should be easily moved and calibrated for the same reason. In addition, minor unimportant defects in equipment should not be allowed to stop production. They should be transmitted to the maintenance supervisor for scheduled repair.

Properly engineered, automated machinery may produce two very important results. First, the greater precision resulting in sensor controlled cutting limits should produce a more even roof and floor and a consistent intersection area. Consequently, ground control will be improved. Second, the operator will spend less time controlling the equipment and operator abuse should decrease. In fact, equipment should have built-in shutdown features that prevent abuse.

Chapter 9
SUMMARY

1. This study investigated the levels of mechanization, automation, monitoring, and remote control which may feasibly be applied to the various job functions in underground coal mining, based on health and safety, economic, and humanistic considerations.
2. It was found that an automated continuous mining coal production section will make significant improvements in:
    a. accident frequency,
    b. unit section production,
    c. productivity per manshift,
    d. rate of return on invested capital, and
    e. worker environment.
3. The concepts of job mechanization, work element automation, mining section condition monitoring, and machine system integration were logically applied with an engineering analysis of the effects on health and safety, economics, and human factors.
4. A case study of a hypothetical mine with a partial mining practice in the Northern West Virginia panhandle area was utilized. The measure used to evaluate the innovation of improvement of automation on the case study mine was the extent to which it permitted the mine to expand and approach its "theoretically possible" capacity in a safe, economical, and environmentally desirable working arrangement. Therefore, the case study mine was allowed to expand in total mine production as the unit shift production

for nine operating sections increased with the additional stages of mechanization and automation.

5. The development of automated continuous mining was projected to progress from the Present Stage of continuous mining through four distinct stages:

   Stage I - The National Mine Service Company AES type of machine combining cutting-loading, roof support, ventilation, and dust control are individually operator performed. Auxiliary services are similar to present.

   Stage II - The AES machine functions are activated by a single operator for automatic performance. Face haulage is by bridge conveyor. Other ancillary operations are increasingly mechanized.

   Stage III - The AES machine, face haulage and a limited amount of ancillary services are systems integrated for concurrent operation. Monitoring systems will be applied.

   Stage IV - A remote control mode of operation is applied to Stage III. Planned service and maintenance periods are scheduled in the shift for those ancillary operations that cannot practically be system integrated.

6. Twenty mining section job functions were identified and examined for projected impact of automation. These respective functions were:

   1. cutting and loading,
   2. face haulage,
   3. section roof control,
   4. section face ventilation,
   5. section ventilation,
   6. trailing power cable handling,
   7. moving section power center,
   8. section belt moveup,
   9. section belt cleanup,
   10. section rock dusting,
   11. roof testing,
   12. methane measurement,
   13. mine examinations,
   14. section supply handling,
   15. fresh water and drainage,
   16. equipment service,
   17. maintenance,
   18. monitoring systems,
   19. spillage and roadway cleanup, and
   20. miscellaneous.

7. The typical Present Stage production section equipment utilized was:
   1. 1-continuous miner,
   2. 1-pick up loader,
   3. 2-shuttle cars,
   4. 2-roof bolters on miner,
   5. 1-"touch-up" bolter, and
   6. 1-face fan.

8. The projected production section equipment and monitoring systems utilized in the respective future stages was:

Table 9-1. Projected Production Section Equipment

Stage I	Stage II	Stage III	Stage IV
1-AES Machine	1-AES Machine	1-AES Machine	1-AES Machine
---	3-Mobile Bridge Carriers	3-Mobile Bridge Carriers	3-Mobile Bridge Carriers
---	4-Mobile Bridges	4-Mobile Bridges	4-Mobile Bridges
2-Shuttle Cars	1-Shuttle Car*	1-Shuttle Car*	1-Shuttle Car*
4-Roof Bolters on AES	4-Roof Bolters on AES	4-Roof Bolters on AES	4-Roof Bolters on AES
1-"Touch-up" Bolter	1-"Touch-up" Bolter	1-"Touch-up" Bolter	1-"Touch-up" Bolter
2-Fans on AES	2-Fans on AES	2-Fans on AES	2-Fans on AES
		1-Face Equipment Integration System	1-Face Equipment Integration System
		Monitoring Systems	
		1-Roof Condition	1-Roof Condition
		1-Mine Environment	1-Mine Environment
		1-Electrical	1-Electrical
		1-Water	1-Water
		1-Equipment Status	1-Equipment Status

* Utilized for haulage at locations inaccessible to the bridge conveyor.

9. The typical present production was:

TABLE 9-2. Present Production

Production per Unit Shift	
Raw tons	310
Clean tons	250
No. Unit Shifts per day	18
Mine Tons per day	
Raw tons	5,580
Clean tons	4,500
Operating Days per year	220
Total Tons per year (000)	
Raw tons	1,228
Clean tons	990

10. The projected production for the respective stages was:

TABLE 9-3. Projected Production

	Stage I	Stage II	Stage III	Stage IV
Production per Unit Shift				
Raw tons	380	560	800	920
Clean tons	310	460	660	750
No. Unit Shifts per day	18	18	18	18
Mine Tons per day				
Raw tons	6,840	10,080	14,400	16,560
Clean tons	5,580	8,280	11,880	13,500
Operating Days per year	220	220	220	220
Total Tons per year (000)				
Raw tons	1,505	2,218	3,168	3,643
Clean tons	1,227	1,822	2,614	2,970

11. The projected effect of section automation on mine personnel and productivity was:

TABLE 9-4. Projected Productivity

		STAGES			
	Present	I	II	III	IV
Unit Tons per Shift, Clean Coal	250	310	460	660	750
Section Crew					
No Men	9	8	9	7	6
Tons per Shift man,cc	27.8	38.8	51.1	94.3	125.0
TOTAL MINE					
Total Men	400	430	531	607	618
Tons per man shift, clean coal	11.3	13.0	15.6	19.6	21.8

12. The calculated accident frequency summary for the Present Stage through Stage IV was:

TABLE 9-5. Accident Frequency Summary

	Frequency		Percent of Present Frequency	
	per 1,000,000 man hrs.	per 1,000,000 tons	per 1,000,000 man hrs.	per 1,000,000 tons
Present	42.8	30.4	100	100
Stage I	37.5	23.0	87	76
Stage II	33.7	17.3	79	57
Stage III	29.2	11.8	68	39
Stage IV	24.2	8.8	56	29

13. The initial investment, total cost per ton, and Profitability Index rate of return for the respective stages at a selected mine realization of $31.50 per ton was calculated to be:

TABLE 9-6. Profitability Summary (Clean Coal Basis)

Stage	Initial Investment (M)	Initial Investment/ Annual Ton	Total Cost/Ton*	PI Rate of Return**
Present	$44,131	$44.58	$21.90	15%
I	$50,862	$41.42	$20.20	17%
II	$66,428	$36.46	$18.29	20%
III	$88,014	$33.67	$16.91	22.5%
IV	$99,368	$33.46	$16.34	23%

* Including depreciation

** After federal income taxes

14. Two levels of monitoring and control stations are projected in automated remote mining. These are the section remote console, and the central mine console. The section shift operations are divided into two major components;

Production time - Personnel absent from the immediate face area. Machine operations are controlled from the section remote console station.

Service time - Personnel present in the immediate face area primarily for planned or emergency service and maintenance, machine turns, or place changes.

15. The psychological and organizational impact of automated continuous mining, due to its inherent mobility, restricted working space, and unpredictable hazardous natural environment is considered more similar to the mechanization and automation of the aviation industry than the assembly line operation of a manufacturing plant.
16. The mining job designations in the automated Stage IV operations of Technical Serviceman-Extraction, Technical Serviceman-Haulage, and Monitoring Systems Technician will be the underground version of the well-accepted jet age relationship of pilot, copilot and navigator. They perform as a team, acting at times interchangeably, and working together on solutions to problems. There will be considerable prestige, training, and sense of accomplishment associated with the operation of the automated mining system. All workers should benefit through the associated improvements in ancillary jobs and the working environment.
17. Automation in mining will also produce considerable changes in management. There will be increasing emphasis on the planning, training, service support, and technical analysis activities that management performs.
18. This study indicates there are considerable benefits for the union worker, mine management, and mine owners alike in the automation of continuous mining. It may well be the system of mine development necessary to permit full and effective use of high capacity production units such as shield type longwall or shortwall mining.
19. The following areas were identified as needing expanded research

19. - continued

in automated mining:

- Preventative maintenance
- Innovative productive mining concepts
- Rapid man transit systems
- Training
- Monitoring.

20. The safety and economic analysis of automating other types of mining systems such as longwall and shortwall should be investigated for their companion use with automated continuous mining.

Chapter 10
RECOMMENDATIONS

The following recommendations for implementation of automation and remote control in underground coal mines are made as a result of the analysis presented in this document. Several recommendations for additional research are included.

1. Automation and remote control can improve the safety and profitability of underground coal mines. The USBM, MESA, mine equipment manufacturers, mine operators, and the UMWA should cooperate in the development and implementation of feasible automated mining systems.
2. The USBM should initiate or continue research projects along the major lines of:
    a. Preventative maintenance
    b. Innovative productive mining concepts
    c. Rapid man-transit systems
    d. Training
    e. Monitoring

It is recognized that many of the subjects presented are presently under some level of investigation.

3. Detailed job definition, a listing of proper job steps, and the correct work procedures should be listed for each occupation in automated mines. The result would provide vital information for program development, resource material, and training programs. It should be undertaken from both viewpoints of safety and production.

4. The information gathered in item three should be utilized to produce stage development programs and training programs for union and management employees.
5. Roof bolting remains a production limiting factor in current mines and will apparently continue to be so in automated mines. Research similar to that proposed in Appendix F should be undertaken to improve roof bolting rates.
6. Research should be initiated to evaluate the place change time of the AES and recommend and implement improvements.
7. The correct balance of preventative and breakdown maintenance for automated systems should be determined in order to assure the least possible maintenance production delay times.
8. Methods of reducing mantrip times should be investigated.
9. Methods of automating the job functions that did not show a decrease in accident frequencies in order to improve the health and safety of these workmen should be evaluated. The investigation should determine which automation techniques would be most safety and cost effective. The occupations to be studied should be: belt and boom operators and crews, motormen, trackmen, bonders, wiremen, electricians, laborers and move crews, mechanics, oiler-greasers, rock dusters, ventilation men, foremen, and firebosses.
10. Up-to-date statistics in the proper format for the accident frequency analysis in Chapter 6 should be available on a printout from the MESA Health and Safety Analysis Center computer.
11. Alternatives to the economic analysis presented in Chapter 7 should be investigated. The alternatives might include varying mine sizes

to maintain constant production or the utilization of the AES as a development unit for varying mining systems such as longwall.

12. The sensitivity and impact of the economic analysis presented in Chapter 7 to such variables as percent reject, maintenance and other delays, personnel requirements and the cost of automated equipment and monitoring systems should be investigated.
13. Detailed human engineering evaluation and designing to improve human performance in the operator cabs of the AES machine, in the remote section control station, in the central mine station, in trouble shooting and repairing equipment, with the mobile conveyor units, with the supply handling vehicle, and with other items of automated quipment should be performed along with the development of each item.
14. Detailed cost analyses, including possible purchase price, should be a reporting consideration for all future automation equipment and monitoring system development contracts.
15. A detailed study of training in the aircraft industry, including the methods of funding, development, and implementation, and how it may be related to the mining industry would be useful.
16. The effect of automation technology on the union contract and the current grievance procedure should be evaluated.
17. Training programs should be developed to acquaint current mine management with the capabilities of computers and monitoring devices and their benefits in the mining industry.
18. Training programs and resource material should be developed to instruct current supervisors in improved communication skills, particularly for conducting group and one-to-one meetings.

19. In addition to training programs in proper machine operation, workers should be trained to be aware, adaptable, and to anticipate future systems operation. These qualities will be very important in an automated mine.

20. Training programs should be developed to teach machine operators how to scan and interpret data quickly.

21. Further training programs are needed in communication skills for workers as they will be required to transfer information to other workers and to supervisors.

22. Methods of evaluating the performance of prospective employees before they undergo expensive training programs should be developed.

23. An economic and safety analysis similar to this report should be undertaken for automation of other types of mining systems such as shortwall for comparative benefit purposes.

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APPENDIX A

PRODUCTION POTENTIAL OF THE AUTOMATED EXTRACTION SYSTEM

PRODUCTION POTENTIAL OF THE AUTOMATIC EXTRACTION SYSTEM

R. H. King
S. C. Suboleski
9/22/75

INTRODUCTION

This report summarizes the production potential and delay possibilities of the automatic extraction system (AES). The mining plan shown in Figure 1 is used. The average shift productions were obtained by computer with the Penn State University Underground Handling Simulator (UGMHS). The assumptions made in order to obtain the reported results are listed in Attachment I. See Attachment II for AES description.

STATEMENT OF THE PROBLEM

The production from the AES is to be compared with current production. Also maning and other variations in the normal mining cycle are to be discussed. The effect of using the automatic control feature and planks for additional roof support are to be investigated.

RESULTS

In order to simulate the AES production capacity, the elemental times shown in Table 1 were derived. Design information furnished by Mr. Don Freed of National Mine Service Co. was used as a basis for the times listed. The elemented times are also pertinent to the question of the usefulness of automatic control. The operator must perform each of the job elements in the time specified to equal the production from an automatic control. Steady, uninterruped movement from one element to

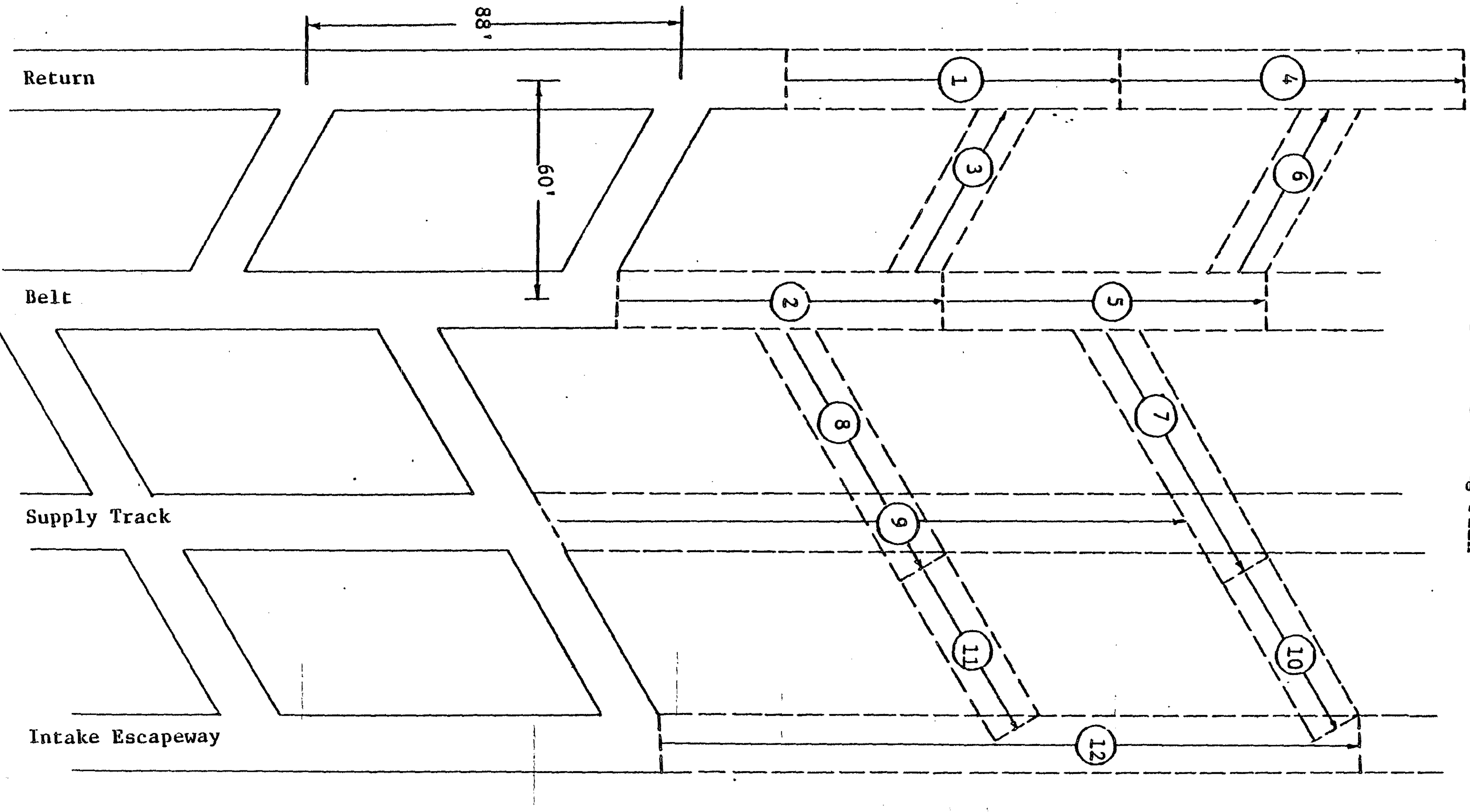


Figure A-1 Mining Plan

the next will require considerably more concentration and discipline than operating one control at the beginning of each sump shear cycle. The elements additional to normal continuous miner operation result from manuevering the roof support units. In addition, the automatic control will not allow sump and shear thrusts to exceed the machine design limitations, decreasing maintenance requirements.

The mining cycle job that will most probably cause delays is roof bolting. Four bolts must be installed during the dual sump shear cycles associated with a four-foot advance. If longer than 3.76 minutes is required to install bolts a delay will result. Table A-2 compares actual time study data with expected performance of the AES bolters. The average bolting times are below the 3.76-minute limit. However, a certain percentage of the bolts will require longer than 3.76 min.This percentage (33%) in addition to an average delay (.8 min) was calculated from actual performance at the mining division proposed for location of the AES unit.

It is interesting to note that only .3 min is available between cycles for preparing bolting materials. If the bolts are installed in the anticipated 3.4 minutes, the time available for changing bits, gathering bolts, unplugging steels, etc. is limited to .6 minutes. Therefore, the immediate presence of a large amount of bolting supplies (88 bolts for an 88-foot advance) is necessary to avoid materials handling delays. The capacity of dust collectors is also important.

The use of planks requires stopping the AES advance between cutting cycles for an estimated .5 minutes to slide a plank into position above the drills. Since storage for about six planks is available, additional planks must be brought up every six bolt rows causing an estimated 5-minute delay. These delays obviously interfere with the objective of improved production through continuous machine operation. The effect is demonstrated in Tables A-4 and A-5.

The production potential is listed in Table A-4. Table A-6 shows the effect of delay time on the system. Sixteen time studies from the proposed mining district are summarized in Table A-7.

A proposal to substitute 4-foot resin bolts for 6-foot shell anchor and eliminate planks resulted in gathering data for Table A-3. Installation of 4-foot bolts eliminates a steel charge, but the increased time from rotating and waiting for the resin to set brings the total bolting time to the 3.8-minute cutting cycle limit. Automatic timing control on the rotate cycle could reduce the overall time by .3 minutes since it would allow the operator to attend to the other chuck while the first bolt is rotated. An automatic cycle to lower and swing out the chuck after drilling is also recommended.

If the ventilation is adequate to allow 176-foot advance, the number of place changes and turnouts can be reduced. Combining cuts 1 & 4, 7 & 10, and 8 & 11 into 3 long runs will eliminate 2 crosscut turns and 3 place changes. The resulting increased mining time can raise the averave shift potential production by 50 tons.

TABLE A-1

Elemental Times for the AES Machine

Cutting Cycle Element	Time
1. Raise Supports	.25
2. Set Cutting Limits	.50
3. Start Cycle (operator time) & Lower Inner Support	.21
4. Sump	.40
5. Raise Inner Supports	.10
6. Shear	.67
7. Lower Inner Supports	.10
8. Trim Bottom	.15
9. Raise Head	.15
10. Advance 2'	.10
11. Repeat 3 trhough 9.	1.88
12. Lower Outer Supports	.10
13. Advance 4'	.10
14. Raise Outer Supports	.10
15. Repeat 3 through 13 until cut is completed (wait for shuttle car time element may occur in any of the above.)	4.81

TABLE A-2

Elemental Bolting Times

Six-Foot Shell Anchor

Current 11 CM Bolters

(Time to Install 2 bolts)

	Element	Time
1.	Install Board	.41
2.	Raise Board	.17
3.	Insert Steel	.08
4.	Raise Chuck	.11
5.	Hole Through Board	.18
6.	Drill (Starter)	.39
7.	Lower Chuck	.12
8.	Remove Steel	.09
9.	Insert Steel	.14
10.	Raise Chuck	.15
11.	Drill (Finisher)	.72
12.	Lower Chuck	.14
13.	Remove Steel	.15
14.	Insert Bolt	.13
15.	Install Wrench	.07
16.	Raise Chuck	.10
17.	Torque Bolt	.06
18.	Lower Chuck	.07
19.	Remove Wrench	.04
20.	Lower Jacks	.03
		3.35

AES Bolters

(Time to install 4 bolts)

	Element	Time
1.	Insert Steel	.1
2.	Raise chuck	.1
3.	Drill (Starter)	.4
4.	Insert Extension	.1
5.	Drill (Finisher	.7
6.	Lower Steel	.1
7.	Remove Steel	.1
8.	Lower Chuck	.1
9.	Swing out Chuck	.1
10.	Install Wrench	.1
11.	Install Bolt	.1
12.	Swing in Chuck	.1
13.	Install Plate	.1
14.	Raise Chuck	.1
15.	Torque Bolt	.1
16.	Repeat 6-15	1.0
	Time w/o plank	3.4
17.	Install Plank	.5
18.	Hole through Plank	.2

TABLE A-3

Elemental Bolting Times
Resin Bolts

Current 11 CM Bolters
(2 - Six-Foot Bolts)

	Element	Time
1.	Install Board	.41
2.	Raise Board	.17
3.	Insert Steel	.08
4.	Raise Chuck	.11
5.	Hole Thru Board	.18
6.	Charge Steel	.13
7.	Raise Chuck	.10
8.	Drill (starter)	.39
9.	Lower Chuck	.12
10.	Remove Steel	.09
11.	Change Steel	.14
12.	Raise Chuck	.15
3.	Drill (Finisher)	.72
4.	Lower Chuck	.14
5.	Remove Steel	.15
6.	Install cartridges	.15
7.	Insert Bolt	.13
8.	Install Wrench	.07
9.	Raise Chuck	.10
.	Rotate	.33
.	Wait to Set	.50
.	Lower Chuck	.07
.	Remove wrench	.04
.	Lower Jacks	.03
		4.50

AES Bolters
(4 Bolts Across)

	Element	6 Foot Time	4 Foot Time
1.	Insert Steel	.1	.1
2.	Raise Chuck	.1	.1
3.	Drill	.4	0
4.	Insert Extension	.1	0
5.	Drill	.7	.7
6.	Lower Steel	.1	.1
7.	Remove Steel	.1	.1
8.	Lower Chuck	.1	.1
9.	Swing Out Chuck	.1	.1
10.	Install Wrench	.1	.1
11.	Install Bolt	.1	.1
12.	Install cartridges	.1	.1
13.	Swing in Chuck	.1	.1
14.	Install Plate	.1	.1
15.	Raise chuck	.1	.1
16.	Rotate Bolt	.3	.3
17.	Repeat 6-16	1.3	1.3
18.	Wait to Set Up	.5	.3
		4.5	3.8

TABLE A-4

Production - No Planks

Shift	Tons/Shift	Wait for Gas SC (Min.)	Wait for Gas Test (Min.)	Set Limits (Min.)	Cutting (Min.)	Advance Bet. Cyc (Min.)	Bolt Delay (Min.)	Place Change (Min.)	Cuts
1	936.	62.2	33.0	5.3	212.8	16.8	14.4	39.6	1,2.
2	861.	91.2	33.0	4.5	195.7	15.6	14.4	30.4	3,4,
3	769.	74.2	30.0	2.3	174.8	13.8	12.0	68.7	6,7,
4	928.	73.2	33.0	3.8	210.9	16.8	15.2	31.3	9,10
5	757.	115.2	33.0	3.8	172.9	13.8	12.8	35.2	11,1
Ave	850.	83.2	32.4	3.9	193.4	15.4	13.8	41.0	-

TABLE A-5

Production - Planks

Shift	Tons/Shift	Plank Supply (Min.)	Plank Inst. (Min.)
1	811.	40.0	24.0
2	685.	30.0	20.5
3	661.	35.0	20.0
4	736.	35.0	22.0
5	752.	35.0	22.5
6	673.	35.0	20.5
Ave	720.	35.0	21.6

TABLE A-6

Delay Effect

Tons/Shift No Plank	Tons/Shift Plank	Delay (min/shift)	Necessary and Operating Time (min/shift)
850	720	0	342
776	657	30	312
701	594	60	282
627	530	90	252
552	467	120	222
477	404	150	192
403	341	180	162
328	278	210	132
254	215	240	102
179	152	270	72
105	88	300	42
30	25	330	12
0	0	360	0

TABLE A-7

Expected Delays

	Min.
Prepare to Start	20
Prepare to Leave & Early	20
Maintenance	75
Ventilation	10
Outby Haulage	20
Power Failures	5
Other	30
	180

Attachment I

Assumptions Made for Computer Program Analysis

1. There is enough time during advance between sump-shear cycles and shuttle-car changeouts for the 2 bolter operators to make up bolts, change bits, etc.
2. The ventilation system is adequate to eliminate stopping the machine for dust to clear.
3. Brattice men are available to install brattice in dead-end places and the AES machine is not idle during these periods.
4. A touch-up bolter is available so the miner is not tied up setting bolts at crosscut breakthroughs. The expected delay time to "plank through" a crosscut is 18.75 minutes if a touch-up bolter is not available.
5. A 3.0-minute time to check each place and remove safety chain is included in the place-change time.
6. The additional time for maneuvering and turning a crosscut is included in the place-change time. This is a requirement of the computer program.
7. Using time study information on bolt-time distributions and expected times for the AES bolters, an average delay of 0.8 minutes will be incurred on approximately 33% of the bolt rows installed.
8. A 50-minute round trip mantrip time, 30 minutes for lunch and 15 minutes to make the fire boss check at the start of the shift are deducted from 480 minutes to obtain available operating time.

9. The following development section manning is assumed:

3	AES operators
2	shuttle car operators
1	section mechanic
2	utility men (brattice and touch up bolting)
8	total

10. Improvements in the gathering head will eliminate cleanup time.
11. A pickup loader will not be used.
12. The shuttle cars dump directly on the belt. A feeder-breaker is not used.

Attachment II

Description of the Automatic Extraction System

A USBM contract has provided funds for the development of the Automatic Extraction System (AES) by National Mine Service Co. and Lee Engineering. The machine is a rotary drum continuous miner somewhat similar to the Marietta Drum Miner.

Four roof drills are mounted in front of the operators platform. Two operators, one for the left two drills and one for the right pair are required for bolting. The sump operation is accomplished by hydraulic cylinders rather than using cats, thereby allowing mining and bolting to occur simultaneously. An additional operator for the mining cycles is anticipated. Two hydraulically controlled roof support canopies provide protection for the operators and also immediate roof support after mining. The AES machine contains a ventilation fan which draws air from the face through ducts in the roof support canopies. Two shuttle cars will haul coal from the tail boom to the section conveyor belt. A pickup loader is not anticipated.

An automatic control cycle is proposed that will allow sump, shear, trim bottom, raise head and support advance job elements to be performed by one control activation. The inner roof support is automatically advanced after each two foot sump-shear cycle. The outer support is advanced every four feet and is not included in the automatic control feature. The operator can manually set upper and lower cutting limits as often as is necessary. Operator overide and emergency stop provisions are proposed.

Some pertinent design details are listed in the following table.

Overall Machine Length	35' 5"
Cutting Head Width - Mining	15' 0"
Cutting Head Width - Retracted	13' 4"
Weight	120,000 lb.
Cutter Drum Drive Motors (2)	200 HP ea. @ 1200 RPM
Drum Speed	57,63, or 70 RPM
Disc Type Gathering Head Motors (2)	15 HP ea. @ 1750 RPM
Conveyor Width	30"
Max. Loading Rate	13.75 TPM
Conveyor Swing Angle	60° right or left

Track Width	18"
Ground Contact Length	99"
Tram Speed	20 FPM, 40 FPM
Tram Motors (2)	7.5 HP @ 600 RPM
	30 HP @ 1800 RPM
Outer Roof Support Beam Dimensions	18" x 10'4"
Outer Roof Support Beam Capacity	51 PSI
Inner Roof Support Beam Dimensions	50' x 11'9"
Inner Roof Support Beam Capacity	53 PSI
Floor Pressure at Outer Roof Support Capacity	65 PSI
Roof Drill Feed Rate	33 FPM
Roof Drill Max. Torque	300 lb./ft.
Roof Drill Max. Thrust	8000 LB
Roof Drill Centers	4'
Hydraulic Pump Motor	200 HP @ 1200 RPM
Hydraulic Resevoir Capacity	150 Gal
Axial Ventilation Fans Capacity (2)	3000 CFM @ 12" w.g.

Production Potential of the Automatic Extraction System - Additional Results

S. C. Suboleski & R. H. King

January 12, 1976

Introduction

This report summarizes modifications to the plan and method of operation of the automatic extraction system (AES) as originally presented in the report dated September 22, 1975. These modifications include the elimination of the initial gas test, since it now appears that this function will be automated, and the introduction of a "long-run" mining plan which enables the miner to advance two cross-cut distances with only four major trams. Five entries were used in the latter plan to achieve the symmetry required.

Data

The equipment performance data used in both analyses is essentially that listed in the first report, with several exceptions. The gas test delay has been eliminated since it is expected that this function will be performed remotely and thus will no longer interfere with production. The bolt-delay time was also increased slightly; however this does not significantly affect the production rate. The tram time is also greater as a result of the addition of the time to "bolt through" where cut 9 intersects cut 8 and the inadvertent omission of the final tram on the previous analysis.

The mining plan used for the four-entry system followed that shown in the original report (and reproduced as Figure A-1 herein). The five entry or "long-run" mining plan is shown in Figure A-2. It consists of a series of cuts which effectively remove coal in the shape of an inverted Christmas tree outline. This reduces the necessity to tram the miner around the pillars from cut to cut; however, the distances from the faces to the belt tail are longer, on the average, for this type of plan. In addition, since the bolters are located at the rear of the miner, when the miner continues through the inby end of a cut it is necessary to bolt through (i.e., to bolt the remaining area of unsupported roof) the cut - an operation which is expected to require approximately 23 minutes. This is done eight times in the long-run plan- and only twice in the four entry "conventional" plan. Thus, there is a trade-off between the conventional plan and ram time and the long-run plan bolt-through time (which is shown as part of the tram time in the results).

The assumptions listed in Attachment I in the original report are reproduced as Attachment III herein. Two changes have been incorporated: the plank-through time has been increased to 23 minutes and the average delay for bolting has been increased to 1.0 minutes for 6-foot expansion shell bolts and 4-foot resin bolts, and to 1.4 minutes for 6-foot resin bolts.

Since it now appears that planking can be eliminated with the AES system this has not been evaluated. The 6-foot conventional bolt and 4-foot resin bolt systems are considered to be equivalent. The 6-foot resin bolt has been evaluated separately. All other data and assumptions can be found in the discussion in the September 9 report.

Results

Revised results for the four-entry system with conventional 6-foot bolts or resin 4-foot bolts are shown in Table A-8. These can be compared to the original results, shown in Attachment II. Average production has increased from 850 to 881 tons per shift, based on approximately 380 minutes available for production per shift. This increase results from the elimination of the gas check.

Results for the five-entry system with conventional six-foot or resin four-foot bolts are shown in Table A-2. With this plan production averaged 861 tons per shift, a decrease of 21 tons or 2.4% from the four-entry results. The place-change time per ton is slightly less with five-entry plan; however the wait-for-shuttlecar time per ton is nearly 10% higher. Using the present delay time per shift (180 minutes), expected production from the two plans is 464 and 453 tons per shift for the four-and five-entry plans respectively.

The four-entry system can be further improved by mining cuts 1 and 4, 7 and 10, and 8 and 11 in one continuous pass. The time saved in tramming by combining these cuts can be calculated directly from the plan. If the ventilation is sufficient to mine the two breakthrough lengths then production should increase an additional 4% to 916 tons at 380 minutes or to an expected value of 482 tons per shift.

Continuous Haulage

One additional means of improving production is with the use of a continuous haulage system. The benefits of continuous haulage can be calculated directly from the data in Tables A-8 and A-9 by simply eliminating the wait on shuttlecar time. All other times will remain the same. Doing this indicates that the four-entry plan could be mined in 3.84 shifts for an average production rate of 1124 tons per 380-minute shift, or an expected value of 592 tons per shift. For the five-entry system the equivalent figures are 5.01 shift, 1112 tons per 380-minute shift and 585 tons at the expected working time.

Probably the most popular and most successful form of continuous haulage in use today is the bridge conveyor - bridge carrier system. A mine using this system was visited to investigate the applicability of bridge carriers to the AES system. It was determined that, in its present form, the bridge carrier system could not maneuver around corners (60°, 45° or 90°) in an entry only 16-feet wide. This difficulty can perhaps be circumvented by using shorter bridges and additional carriers.

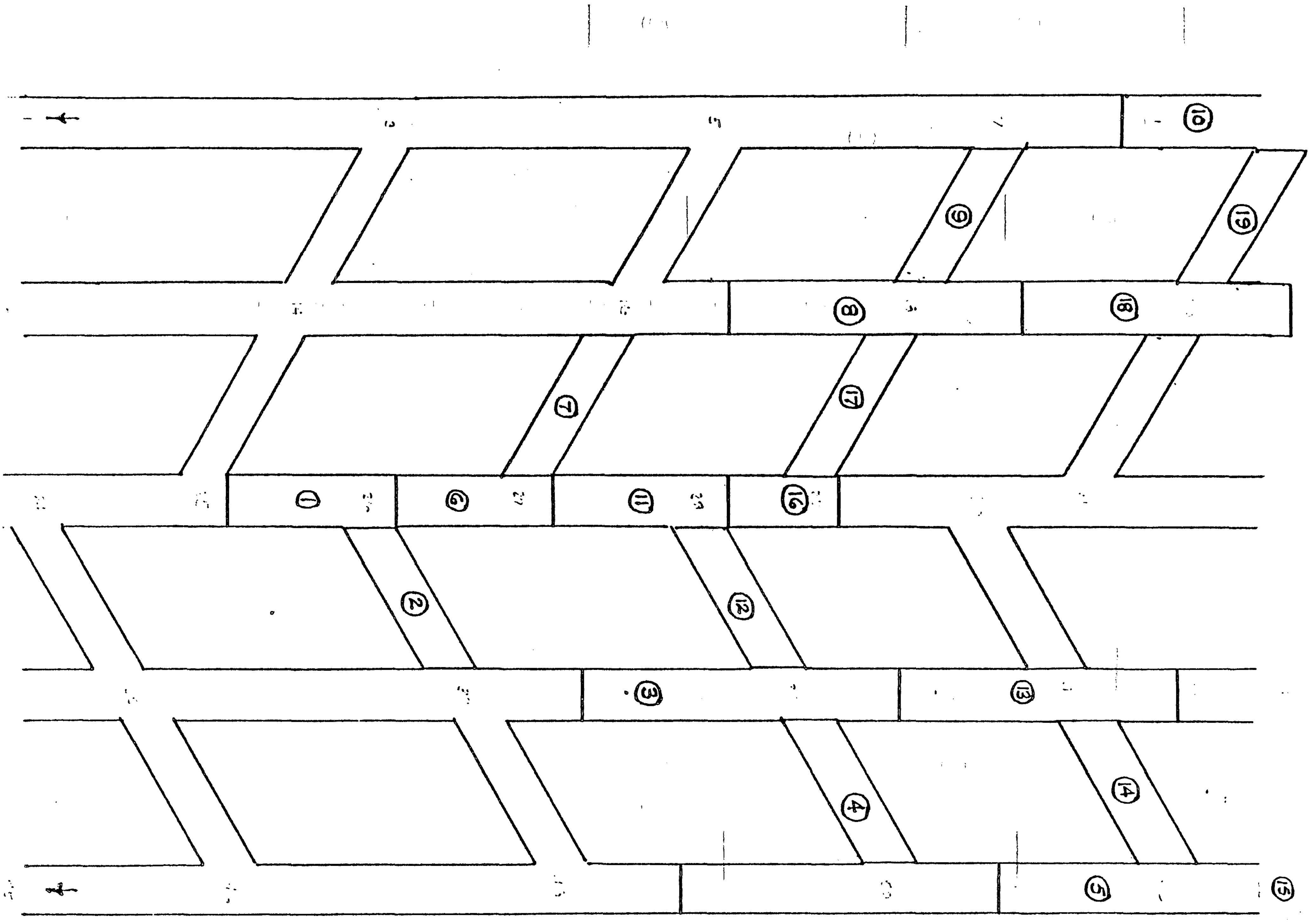


Figure A-2 Long Mining Length Cut Sequence for AES Mining System

Table A-8. Revised Results for Four-Entry Plan

Shift	Tons	Wait for S.C.	Set Limits	Cut	Advance Between Cycles	Bolt Delay	Place Change	Cut No.s
1	1003.4	73.1	5.3	228.0	18.0	20.0	40.6	1,2,3
2	886.4	100.2	5.3	201.4	15.9	17.0	41.4	4,5,6
3	919.8	61.0	3.0	209.0	16.5	19.0	76.5	6,7,8,9
4	819.5	87.8	3.0	186.2	14.7	16.0	74.7	9,10,11
5**	689.7	83.0*	3.0	157.7	12.3	14.0	73.1	11,12
4.90 shifts								
Total	4318.8	405.1	19.6	982.3	77.4	86.0	306.3	
Average	881.4	82.7	4.0	200.5	15.8	17.5	62.5	

TPM Cutting rate - 4.40
TPM Available Time - 2.30
Place Change/ton - 0.071 min.
Place Change/cut - 25.5 min.
Wait on car/ton - 0.094 min.

*Estimated
**0.90 shifts

Table A-9. Results for Base Five-Entry Plan

Shift	Tons	Wait for S.C.	Set Limits	Cut	Advance Between Cycles	Bolt Delay	Place Change	Cut No.s
1	836.2	103.7	3.8	190.0	15.0	16.0	56.9	1,2,3,4
2	836.2	76.5	3.8	190.0	15.0	17.0	82.9	5,6,7
3	953.3	78.7	4.5	216.6	17.1	19.0	49.1	8,9,10
4	869.7	75.6	5.3	197.6	15.6	17.0	73.0	10,11,12,13
5	819.5	88.9	3.8	186.2	14.7	17.0	72.9	14,15,16
6	897.2	85.9	5.3	205.2	15.9	17.0	62.9	16,17,18,19,20
7*	357.2	53.8	0.8	79.8	6.6	8.0	28.1	20
Total	5569.3	563.10	27.3	1265.4	99.9	111.0	425.8	
Average	860.8	87.03	4.2	195.6	15.4	17.2	65.8	

TPM Cutting rate - 4.40
TPM Available Time - 2.27
Place Change/ton - 0.070 min.
Place Change/cut - 19.52 min.
Wait on car/ton - 0.101 min.

*6.47 shifts

Table A-10. Revised Results for Four-Entry Plan With Six-Foot Resin Bolts

Shift	Tons	Wait for S.C.	Set Limits	Cut	Advance Between Cycles	Bolt Delay	Place Change	Cut No.s
1	986.7	70.7	5.3	224.2	17.7	26.6	39.7	1,2,3
2	869.7	98.5	5.3	197.6	15.6	25.2	41.4	3.4,5,6
3	886.4	62.8	2.3	201.4	15.9	23.8	76.1	6,7,8,9
4	821.9	87.0	3.8	188.1	14.7	23.8	74.6	9,10,11
5**	754.2	90.0*	3.0	171.0	13.5	21.0	73.0	11,12
Total	4318.8	409.0	19.70	982.3	77.4	120.4	304.8	
Average	869.0	82.3	4.0	197.7	15.6	24.2	61.3	

TPM Cutting Rate - 4.40
TPM Available Time - 2.26
Place Change/ton - 0.071
Place Change/cut - 25.40
Wait on car/ton - 0.095

*Estimated
**0.97 shifts

Table A-11. Results for Five-Entry Plan With Six-Foot Resin Bolts

Shift	Tons	Wait for S.C.	Set Limits	Cut	Advance Between Cycles	Bolt Delay	Place Change	Cut No.s
1	802.8	101.0	3.8	182.4	14.4	22.4	56.9	1,2,3
2	802.8	76.0	3.8	182.4	14.4	22.4	82.8	4,5,6,7
3	953.3	73.0	4.5	2.6.6	17.1	26.6	49.0	7,8,9,10
4	852.9	77.2	4.5	193.8	15.3	23.8	72.9	10,11,12,13
5	786.1	89.6	4.5	178.6	14.1	21.0	72.9	13,14,15
6	903.1	78.8	4.5	205.2	16.2	25.2	54.8	16,17,18,19
7*	468.4	65.6	1.5	106.4	8.4	14.0	40.6	19,20
Total	5569.4	561.2	27.1	1265.5	99.9	155.4	429.9	
Average	841.3	84.8	4.1	191.2	15.1	23.5	64.9	

TPM Cutting Rate - 4.40
TPM Available Time - 2.19
Place Change/ton - 0.077
Place Change/cut - 21.5
Wait on Car/ton - 0.101

*6.62 shifts

Table A-12.

Delay Effect

Necessary and Operating Time - Minutes	Minutes of Delay	Tons per Shift			
		(1.)	(2.)	(3.)	(4.)
380	0	881	861	869	841
350	30	811	793	800	775
320	60	741	725	732	708
290	90	672	657	663	642
260	120	603	589	595	575
230	150	533	521	526	509
*200	180	464	453	457	443 *
170	210	394	385	389	376
140	240	325	317	320	310
110	270	255	249	252	243
80	300	185	181	183	177
50	330	116	113	114	111

Notes:

(1.) Four-entry plan, six-foot conventional or four-foot resin bolts

(2.) Five-entry, long-run plan, six-foot conventional or four-foot resin bolts

(3.) Four-entry plan, six-foot resin bolts

(4.) Five-entry plan, six-foot resin bolts.

*Expected delay time

Attachment III

Assumptions Made for Computer Program Analysis

1. There is enough time during advance between sump-shear cycles and shuttlecar changeouts for the 2-bolter operators to make up bolts, change bits, etc.
2. The ventilation system is adequate to eliminate stopping the machine for dust to clear.
3. Brattice men are available to install brattice in dead-end places and the AES machine is not idle during these periods.
4. A touch-up bolter is available so the miner is not tied up setting bolts at crosscut breakthroughs. The expected delay time to "plank through" a crosscut is 23.00 minutes if a touch-up bolter is not available.
5. A 3.0-minute time to check each place and remove safety chain is included in the place-change time.
6. The additional time for maneuvering and turning a crosscut is included in the place-change time. This is a requirement of the computer program.
7. Using time-study information on bolt-time distributions and expected times for the AES bolters, an average delay of 1.0 minute will be incurred on approximately 33% of the bolt rows installed.
8. A 50-minute round-trip mantrip time, 30 minutes for lunch and 15 minutes to make the fire-boss check at the start of the shift are deducted from 480 minutes to obtain available operating time.

9. The following development section manning is assumed:

3	AES operators
2	shuttlecar operators
1	section mechanic
2	utility men (brattice and touch-up bolting)
8	total

10. Improvements in the gathering head will eliminate cleanup time.
11. A pick up loader will not be used.
12. The shuttle cars dump directly on the belt. A feeder-breaker is not used.

Attachment IV

Original Results - Four-Entry System, Six-Foot Shell Anchor Bolts

Shift	Tons/Shift	Wait for Gas SC (Min.)	Wait for Gas Test (Min.)	Set Limits (Min.)	Cutting (Min.)	Advance Bet. Cyc (Min.)	Bolt Delay (Min.)	Place Change (Min.)	Cuts
1	936.	62.2	33.0	5.3	212.8	16.8	14.4	39.6	1,2.3
2	861.	91.2	33.0	4.5	195.7	15.6	14.4	30.4	3,4,5
3	769.	74.2	30.0	2.3	174.8	13.8	12.0	68.7	6,7,8
4	928.	73.2	33.0	3.8	210.9	16.8	15.2	31.3	9,10
5	757.	115.2	33.0	3.8	172.9	13.8	12.8	35.2	11,12
Ave	850.	83.2	32.4	3.9	193.4	15.4	13.8	41.0	-

APPENDIX B

SPECIFICATIONS OF THE NATIONAL MINE SERVICE COMPANY'S AES MACHINE

INFORMATION
A. E. S.
AUTOMATED EXTRACTION SYSTEM

NATIONAL MINE SERVICE COMPANY

Clarkson Division

Nashville, Illinois

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

CONTRACT NO. HO155037

TABLE OF CONTENTS

NATIONAL MINE SERVICE COMPANY

AES DESIGN GOALS

I. A POTENTIALLY PRODUCTIVE MACHINE WITHIN THE CONFINES OF THE COAL MINE HEALTH AND SAFETY ACT OF 1969

II. DEVELOP A VIABLE, SALEABLE PRODUCT WHICH CAN BE MANUFACTURED AND SOLD AT A PROFIT

III. PROVIDE MACHINE CAPABILITIES NECESSARY FOR MINING BREAKTHROUGH TO BREAKTHROUGH WITHOUT PLACE CHANGING

- A. ON-BOARD TEMPORARY SUPPORT
- B. ON-BOARD ROOF BOLTING
- C. INTEGRAL FACE VENTILATION

IV. PROVIDE BETTER ROOF CONTROL THAN PRESENT SYSTEMS

- A. ON-BOARD TEMPORARY SUPPORT
- B. ON-BOARD ROOF BOLTING
- C. GOOD CONTROL OF ROOF AND FLOOR POSITION

V. PROVIDE SAFER ENVIRONMENT FOR OPERATOR

- A. TEMPORARY ROOF SUPPORT
- B. COMPLETE CANOPY PROTECTION
- C. DUST SUPPRESSION AND SCRUBBING
- D. ADEQUATE LIGHTING

VI. REDUCE LIKELIHOOD OF OPERATOR RELATED ERRORS AND DELAYS THROUG AUTOMATION OF REPETITIVE MACHINE FUNCTIONS

THE AES CONCEPT

The Automated Extraction System has been designed as a contemporary, composite solution to several interrelated problems which have existed for as long as coal mining and have been more or less successfully solved separately in the past. Although the AES, as originally conceived, would have displayed an instantaneous production rate substantially less than existing ripper-type continuous miners, the present design allows an instantaneous production rate competitive with current machines in the same seam size class. Rather than providing production equal to existing machines, it should allow greater production with increased safety.

The AES possesses many features which will allow it to produce more coal with less maintenance and far greater safety to personnel than any existing mining system. The current version is designed to provide a highly productive full face (15 feet) semi-automatic continuous mining system with excellent clean up, complete roof control (temporary support and bolting), maximum operator protection, effective auxiliary ventilation, dust suppression, and air scrubbing to restrict respirable dust to permissible levels, in seam heights from five to nine feet. The virtually continuous nature of AES production makes it a perfect partner for any of the pneumatic, hydraulic, or mechanical continuous haulage systems in use or under development. The AES's integral roof control will allow much higher average production with continuous or shuttle car ha since the continual time-consuming aggravation of moving a standard-type continuous miner from place to place to allow roof bolting is eliminated.

The integral roof control of the AES provides many benefits in additic to the obvious productivity increase. Reduction in maintenance on cat track crawler drives, and electrical systems is inherent in the reduction of the nu of moves required for a given amount of production. Decreased power consu tion (high speed tram and maneuvering requires high horse power and is com nonproductive) and decreased cable wear and tear (therefore, greater person safety, more uptime) are both fringe benefits of being able to keep the AES i the producing face. Better roof control is possible because the top is not al near as much time to weather since continuous production uncovers the top more quickly and is followed by continuous support and immediate bolting.

The drive components and electrical and hydraulic systems of the AE are of the same basic design and based on the same reliable design concept as the highly successful Marietta Drum Miner. The electric tram allows the utilization of a hydraulic system equipped with very durable and dependable low pressure components, which are completely compatible with fire resista water emulsion hydraulic fluids.

AES SPECIFICATION SUMMARY
MM 298

MACHINE ENVELOPE DIMENSIONS

Overall Machine Length		35' 5"
Cutting Head Width	Mining	15' 0"
	Retracted	13' 4"
Machine Width Outside Roof and Floor Beams		12' 4"
Weight		120,000 lb.
Face Area		75 to 135 sq. ft.
Coal/ft. advance		4.7 to 8.5 tons

TRACTOR FRAME

Ground Clearance	6"
Tracks	
Type	Piano Hinge
Width	18"
Ground Contact Length	99" Nominal
Area	3564 Sq. In.
Ground Pressure (Max. Tramming)	28 PSI
Tram Drive	
Type	Spur Primary Two Stage Planetary Final
Maximum Belt Pull	50,000 lb./side
Speed	13.3 ft./min.-40 ft./min
Motor (Two Water Cooled)	7.5 HP @600 RPM 30 HP @1800 RPM

CUTTER DRUM

Drum Outside Diameter		36"
Base Diameter		22"
Cutter Boom Height	Drum on Grade	42"
Cutter Drum Reach	Above Grade	10' 0"
	Below Grade (Max.)	10"
	With Gathering Head on Grade	5"

CUTTER DRUM DRIVE

Motors (Two Water Cooled)	200 HP ea. @1200 RPM
Drum Speed	57 RPM (63 and 70 option
Drive Type (2)	Bevel and Planetary
Bit Speed	535 FPM (595,660 option
Protection - Clutches (2)	Multi Disc, 600 HP Sli

AES Specification Summary (Continued)

GATHERING HEAD

Type		Disc
Gathering Head Width	Mining	15' 0" to 16' 0"
	Retracted	14' 0"
Disc Sizes	Large	4' 5"
	Small	2' 6"
Disc RPM	Large	70
	Small	117
Drive Motors (Two Water Cooled)		15 HP ea. @1750

CONVEYOR

Width	30"
Depth (Steel Sideboards)	5"
Sideboards (Flexible)	4"
Chain	2 5/8-inch Pitch
Drive	Rear Hydraulic
Speed	400 ft./min.
Loading Rate (Max. with 5" Depth)	13.75 T/min.
Tensioning	Automatic Load Sensitive Hydra
Swing Angle	60° Left or Right

ROOF SUPPORT/OPERATOR PROTECTION SYSTEM

Type	Longitudinal Roof Floor Beam
Support Cylinder	
Quantity	10
Bore	7"
Rated Pressure	3000 PSI
Capacity at Rated Pressure	57 Tons Each
Roof Beams - Outer	
Quantity	2
Width	18"
Length	10' 4"
Average Roof Pressure at Cylinder Capacity	51 PSI
Roof Beams - Inner	
Quantity	1
Width (At Narrowest Portion)	5' 0"
Length	11' 9"
Average Roof Pressure at Cylinder Capacity	53 PSI
Floor Beams - Outer	
Quantity	2
Width	18"
Length	97¼"
Average Roof Pressure at Cylinder Capacity	56 PSI

AES Specification Summary (Continued)

ROOF SUPPORT/OPERATOR PROTECTION SYSTEM (Continued)	
Outer Rear Support	
Quantity	1
Width	4' 0"
Length	5' 0"
Average Roof Pressure at Cylinder Capacity	33.7 PSI
Outer Rear Platform	
Quantity	1
Width	4' 0"
Length	5' 2"
Average Floor Pressure at Cylinder Capacity	41.5 PSI
LOW RANGE SUPPORT SYSTEM	
Minimum Tram Height	48"
Outer Floor Beam Ground Clearance	$4\frac{1}{4}$"
MINING RANGE (With 12" Tram Top Clearance)	5' 0" to 7' 4"
HIGH RANGE SUPPORT SYSTEM	
Minimum Tram Height	5' 1"
Outer Floor Beam Clearance	6"
MINING RANGE (With 12" Tram Top Clearance)	6' 1" to 10' 0"
PUMP DRIVE	
Motor (One Water Cooled)	200 HP @1200 RPM
Pumps	
Drills (4)	30 GPM Gear
Scrubbers (1)	30 GPM Gear
Cylinders (1)	0-37.6 GPM VV Piston
Vent Fans (1)	0-23 GPM VV Piston
Conveyor (1)	30 GPM Gear
Water (1)	30 GPM Gear
Gear Box	Spur Gear Water Coole
Reservoir Capacity	150 gal.
ROOF DRILLS	
Quantity	4
Feed Rate - Maximum	33 ft./min.
Torque Maximum	300 lb./ft.
Bolt Torque	250 lb./ft.
Thrust - Maximum	8000 lb.
Thrust - Torquing	200 lb.
Location	2' 0" and 6' either side of center line

APPENDIX C

RECOMMENDATIONS AND ABRIDGED SUMMARY
OF THE
AUTOMATED REMOTE CONTROLLED CONTINUOUS MINING

RECOMMENDATIONS AND ABRIDGED SUMMARY

of the

AUTOMATED REMOTE CONTROLLED CONTINUOUS MINING

(ARCCM) PROGRAM CONFERENCE

Dec 2-3, 1975

PMSRC, BRUCETON, PA.

by

R.L. Frantz

R.H. King

C.R. Bickerton

The Mineral Engineering Department of

The Pennsylvania State University

April 25, 1976

INTRODUCTION

This report results from the ARCCM Program Conference held at the PMSRC Bruceton facility December 2 and 3, 1975. Presentation of recommendations for improvement in the present research program is the purpose of this document; however, an abridged summary of the conference covering the purpose of current research, agenda, and summarized research results follow the recommendations list, providing background information for those who have not read the more detailed conference summary report which is available from Mr. Dick Farrar, USBM, 4800 Forbes Avenue, Pittsburgh, Pa. This abridged summary report is expressly written for circulation within the USBM where evaluation and recommendations concerning the ARCCM Program progress and organization are of more interest than a detailed summary of the research reports presented at the conference.

RECOMMENDATIONS

Excellent progress is being made in the development of hardware components for the ARCCM program. It is obvious that the increased engineering and operating complexities of ARCCM will require higher degrees of performance in areas that are currently limiting production even at present modest mechanization levels. Therefore, in our judgement research in the following areas are vitally needed to insure the ARCCM program Production goals:

1. management,
2. system integration,
3. training, and
4. maintenance,

Management Research

The section foreman's role has changed dramatically in the past six years as a result of more stringent health and safety legislation and modifications to the UMWA Wage Agreement. Nevertheless, a mine's production is the immediate result of the forman's actions. In fact, he is still the "captain of the ship" in the coal extraction process. Additionally, approximately 70% of the mines expected to be in production in 1985 are not in existence today. The expansion of production from 640 million tons in 1975 to 1.04-1.20 billion tons by 1985 will increase substantially the number of section foremen required. An expenditure of approximately $22 billion for new surface and underground mine capacity is expected over the period 1975-1985. This represents an immense capital investment that can be recovered by profits from production that is the responsibility of present and future front line management. Therefore, it is recommended that the following be investigated by future USBM research:

1. assessment of the role of front-line management (the section foreman) in improving productivity in the future mining industry,
2. determination of the most efficient mine management organization structure to respond quickly to the needs of the production section,
3. definition of those production bottlenecks which are really management deficiencies and recommendations for improvement, and
4. application of the above findings in demonstration projects. An example might be the separation of activities that are most concerned with maintaining maximum production from those duties which are not directly production related, by delegating the latter to an assistant.

System Integration Research

The future ARCCM operation will be economically unmanageable without extensive system integration because of:

1. complexity of the section foreman's duties,
2. intricacy of components in automated machinery,
3. interdependence between machinery and workers,
4. requirements of environmental monitoring,
5. inability to tolerate down time, and
6. necessity of equipment failure warnings for preventative maintenance.

Therefore it is recommended that an integrated control system be developed to efficiently monitor, measure, evaluate, and control all systems in a mining section. This should be applied in demonstration projects.

Training Research

Coal industry employment has expanded from approximately 124,000 people in 1969 to nearly 190,000 people today. The personnel expansion of more than 50% cuts across both union and supervisory ranks. In addition, the job bidding provision of the 1969 UMWA contract has resulted in significantly increased job transfers. Mine supervision ranks have been depleted to supply hundreds of inspectors to MESA. The authority and position of the section foreman has been eroded due to the uncertainty of some MESA interpretations, conflicts between state and federal regulations, and the threat of federal prosecution in the event certain violations occurred. All of this occurred at the end of two decades of receding profits in the coal industry, during which time employment declined from 425,000 persons in 1949 to 124,000 persons in 1969, and training programs were considered unnecessary because of the large panels of experienced labor.

Certainly a part of the decline in the underground coal productivity (tons per man day) can be attributed to the lack of adequate training programs for the new employees. Of additional importance today is the obvious need to fully define the skills, duties, and responsibilities of supervisors, engineers, inspectors, equipment operators, and maintenance personnel, and then accomplish their training in the most effective manner. In our opinion, which has been enforced by many coal operators, current training programs for improving production are inadequate. Considerable research and development will be required to produce effective training programs to increase production with current equipment and practices. More sophisticated and complicated systems, such as ARCCM, require an even greater effort. The reasons for improved productivity oriented training programs can be supported by the following:

1. not only do a greater number of accidents occur to workers in new job assignments resulting in loss of production and human suffering, but much production is lost with an untrained operator inefficiently

controlling an expensive machine;

2. new equipment development requires a clear definition of training deficiency vs. machine deficiency,

3. about 50% more miners must be added to the work force over the next 10 years and all experienced worker's panels are essentially depleted, which means training must attempt to replace experience;

4. the magnitude of capital investment in modern mining and the complexities of operations require greater emphasis on manpower training;

5. the shortage of comprehensive production oriented training programs over the past three decades compounds the need for research in training program requirements;

6. the changing characteristics of the modern miner (age, educational background) supports the need for research in training of mine workers. New employees in general are younger and better educated.

Therefore, it is recommended that the following be investigated by future research projects in training:

1. Define work activities and responsibilities of personnel in operations, maintenance, service, engineering, and management of present and future mining operations from the standpoint of improving productivity while maintaining a safe operation.
2. Define and develop the necessary training programs and techniques for efficient personnel instruction for work activities and responsibilities defined in part 1 above.
3. Demonstrate the training programs developed in part 2 at a mine.
4. Evaluate the results of training programs and recommend improved training techniques and programs.

Maintenance Research

A large portion of the delay time experienced on current continuous mining production shifts is due to machine breakdowns. A preventative maintenance program may decrease the amount of time spent during the production shift to troubleshoot and repair equipment if it is applied effectively to current mining machinery. Moreover, with the introduction of automation and remote control the importance of decreasing downtime on expensive equipment is increased. Machinery complexity and combination of functions increases the probability of maintenance delays. That is, a machine such as the AES which combines roof support and ventilation with cutting and loading will cease producing when maintenance is required on the auxillary attachments for roof support or ventilation. This cannot be tolerated for the numerous minor malfunctions which may occur in the individual components of the expensive AES system.

Therefore, the following maintenance research programs are recommended:

1. The training program in maintenance outlined earlier is vitally needed to reduce maintenance delays.

2. Analysis to develop recommendations for improved machine maintainability is needed.

3. Development of the requirements for a workable preventative and breakdown repair maintenance program is needed.

4. Demonstration projects of effect of the following to improve coal production is desired:

   a. maintenance training,
   b. preventative maintenance, and
   c. improved machine maintainability.

ABRIDGED CONFERENCE SUMMARY

Agenda

The agenda of speakers was:

1. ARCCM Objective and Philsophy--Howard Parkinson, USBM, PMSRC-
2. Data Flow Requirements for Remote Control of Continuous Miners--Robert Lagace, Arthur D. Little, Inc.
3. Assessment of Automated Remotely Controlled Controlled Continuous Miners and Ventilation for Rapid Face Advancement--Bruno A. Fichna, John T. Boyd Company
4. Human Factors and Operational Constraints Relative to an Automated Continuous Mining Section--R. H. King and S. C. Suboleski, Penn State University

5. Automated Extraction System--Don L. Freed, Jr., National Mine Service, Co.
6. Continuous Mining Systems Industrial Engineering Study--James Davis, J. J. Davis Associates
7. Evaluation of Conventional Mining Equipment--Albert Herhal, Ketron, Inc.
8. Feasibility Test of Microwave System for Determining Coal Thickness--D. A. Ellerbruch, National Bureau of Standards
9. Evaluation of Coal Thickness Sensors--Greg Riley; Foster Miller Associates, Inc.
10. Evaluation of National Coal Board Gamma-Ray Backscatter Coal Thickness Sensor--Bert Nagy, USBM, PMSRC
11. Analytical Studies of Electromagnetic Sensing of Coal Properties--Mike Pazuchanics, USBM, PMSRC
12. Report on NASA-Marshall Space Flight Center and General Electric Company Work on Horizon Control for Automated Longwall Mining--Bruce Broussard, NASA
13. Miner-Bolter Status and Review of Bolting and Flexible Drill Programs--R. K. Dorman, USBM, Spokane Mining Research Center
14. Remote Controlled High Production Continuous Miner and Joanne Mine Tests of a Continuous Miner--Kelly Strebig, USBM, Twin Cities Mining Research Center
15. Ventilation--Eugene Palowitch, USBM, PMSRC
16. Dust Control--W. G. Courtney, USBM, PMSRC
17. Lighting--George Bockosh, USBM, PMSRC
18. Methane Monitoring--Mike Pazuchanics, USBM, PMSRC
19. Materials Handling--Steve Ojala, USBM, PMSRC
20. Haulage--Steve Ojala, USBM, PMSRC
21. Noise Control--J. A. Burks, USBM, PMSRC
22. Guidance and Control--Tom Fisher, USBM, PMSRC
23. Logistics Study of Continuous Miners--Franz Mogdis, Bendix Corporation
24. Hydraulic Oil Contaminants--L. R. Allen, USBM, PMRC
25. Training--James Ault, USBM, PMSRC
26. Summary-R. L. Frantz, Penn State Universtiy

Research Purpose

The purpose of the ARCCM conference was to transfer technology among USBM contractors and USBM personnel directly or indirectly related to ARCCM. The usefulness of each project in achieving the ARCCM goal of increasing production was emphasized.

The project overview analyses (presentations 2-4 in the agenda) are investigating the effects of automation and remote control on present continuous mining and providing technical support in the specific areas listed in the agenda.

The AES prototype machine, (described in presentation 5) combining the mining functions of roof control and ventilation with a programmed cycle of coal extraction and machine advancement, is the present hardware development for evaluating the ideas and recommendations of the ARCCM researchers to date in a demonstration project.

The productivity measurement studies (presentations 6 and 7) are to evaluate present mining methods effectiveness and determine the contributions that the AES and ARCCM programs may make to improve production.

The objectives of coal-rock interface sensor research projects (presentations 8-12) are detecting the interface and measuring coal thickness. The sensor facilitates automation of the cutter head by communicating information used in controlling the top and bottom positioning.

USBM research projects related to ARCCM were described in presentations 13-21. Much of the information gained from the research has been utilized in designing the AES machine.

The guidance and control project (presentation 22) objective is improved safety and efficiency of operation by automatically maintaining the machine on a desired horizon and center.

Minimizing down-time and extending working life through better information about machine reliability is the objective of the reliability project described in presentation 23.

Improving machine reliability through measurement and elimination of hydraulic oil contaminants was reported in presentation 24.

The goal of training analysis (presentation 25) is the improvement of training hardware and techniques for utilization, particularly through use of the Lincoln Training Center.

Research Project Summarized Results

The data-flow requirements for remote supervisory control of an automated continuous mining process will be very complex due to the interaction between the different machines. Data-flow rate requirements is a manageable problem according to Arthur D. Little, Inc., but the development of sensors and microcomputers for directing the machinery, which must survive in the underground mine environment, may present problems.

Remote controlled continuous miner performance to date indicates transferring the operator position from the hazardous face area can be accomplished with present technology, but production is limited by ancillary operations.

Initial results of the Human Factors contract point to requirements for training that will allow automated equipment to be serviced, maintained and operated efficiently.

National Mine Service Company has completed the basic design of the Automated Extraction System (AES) machine and are currently investigating special design problems with roof control, ventilation, methane diffusion, methane monitoring and dust suppression. A large nubmer of component parts are presently being manufactured and assembled for underground testing in September 1976.

Preliminary continuous mining industrial engineering study results indicate that currently used semiremote control provides production and safety advantage in retreat mining.

The NBS frequency modulated-continuous wave (FM-CW) sensor system produced positive interface results in coal thicknesses up to 18 inches. Foster Miller Associates has begun evaluating the pulsed radar, a sensitized drill, and coal/shale light reflectance for determining coal/rock interfaces. The National Coal Board Gamma-Ray Backscatter Coal Thickness Sensor is currently the only operational sensor; however, measurement error occurs if there is an air gap between the sensor and the roof. Electromagnetic sensors are good indicators of vertical nonuniformity in the roof and of lateral nonuniformity along the roof surface according to University of Colorado researchers. NASA is studying radioisotopes, radar, acoustics, cutting power monitoring, reflectometers, impact potentiometers, and sensitized picks. General Electric is experimenting with the use of shock and vibration analysis on a longwall shearer.

Five different flexible drills, capable of drilling an eight-foot roof bolt hole in a 30- to 48-inch seam at four-feet per minute, will soon be ready for underground testing according to Spokane researcher Robert Dorman.

The fabrication and underground demonstration of a materials handling supply vehicle with an anthropomorphic manipulator for grasping and lifting supplies weighing less than 260 pounds is projected for mid-1976.

Haulage related research projects include development of wire guidance for ramcars and bridge conveyor trains, benefits of automating underground rail haulage, and development of hydraulic transport systems component parts.

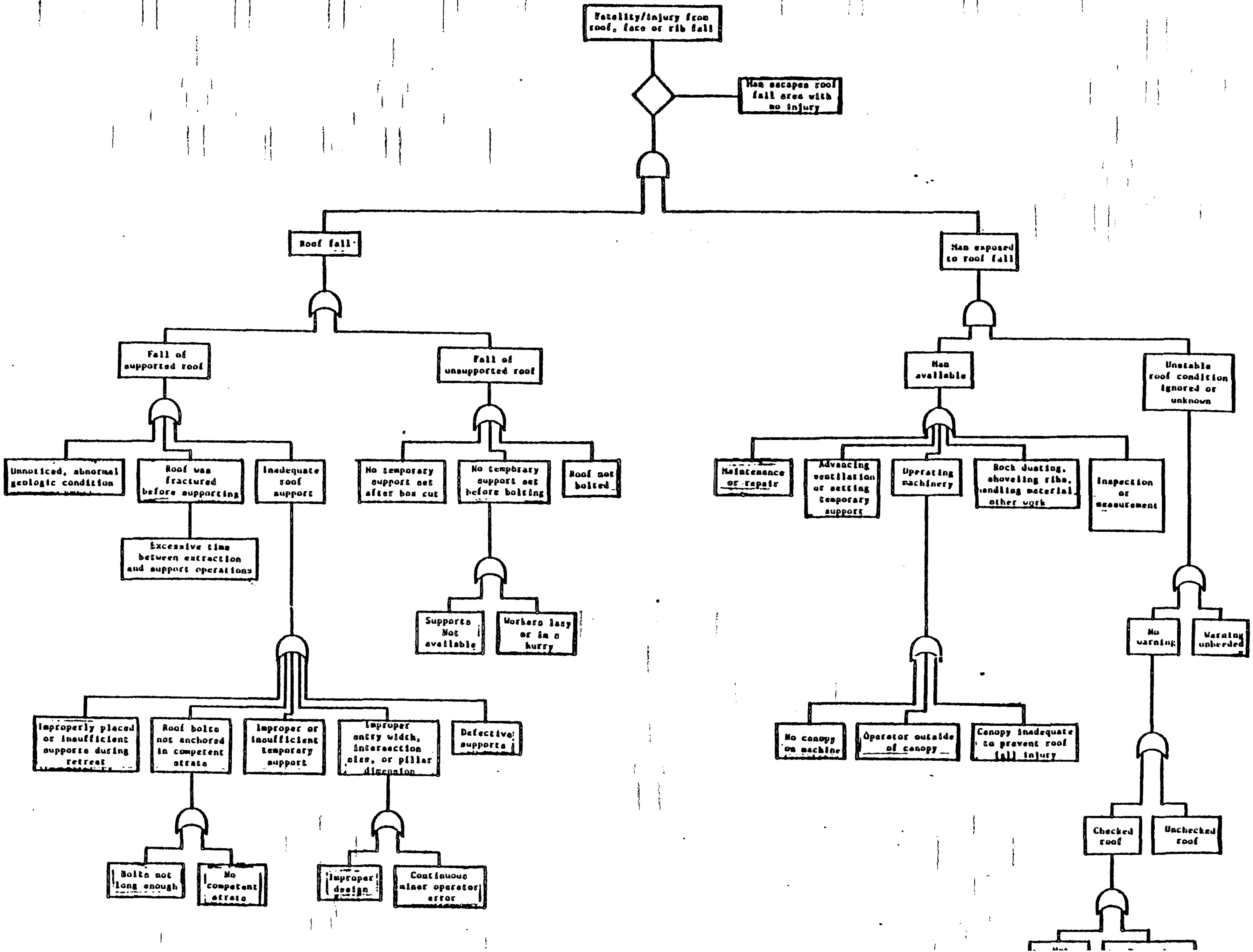
Results of the logistics study of continuous miners suggests preventative and scheduled maintenance programs will increase machine availability and reduce overall corrective maintenance costs.

USBM personnel anticipate that metallic oil contaminant identification will allow detection of hydraulic system problems.

The Air Force Lincoln Training System is being examined for mine personnel training applications. Dragline and shuttlecar operator trainers are also under development.

APPENDIX D

FAULT TREE DIAGRAMS


Fatality/injury from roof, face or rib fall
Man escapes roof fall area with no injury
Roof fall
Man exposed to roof fall
Fall of supported roof
Fall of unsupported roof
Man available
Unstable roof condition ignored or unknown
Unnoticed, abnormal geologic condition
Roof was fractured before supporting
Inadequate roof support
No temporary support set after box cut
No temporary support set before bolting
Roof not bolted
Maintenance or repair
Advancing ventilation or setting temporary support
Operating machinery
Rock dusting, shoveling ribs, handling material, other work
Inspection or measurement
Excessive time between extraction and support operations
Supports Not available
Workers lazy or in a hurry
No warning
Warning unheeded
Improperly placed or insufficient supports during retreat
Roof bolts not anchored in competent strata
Improper or insufficient temporary support
Improper entry width, intersection size, or pillar dimension
Defective supports
No canopy on machine
Operator outside of canopy
Canopy inadequate to prevent roof fall injury
Checked roof
Unchecked roof
Bolts not long enough
No competent strata
Improper design
Continuous miner operator error

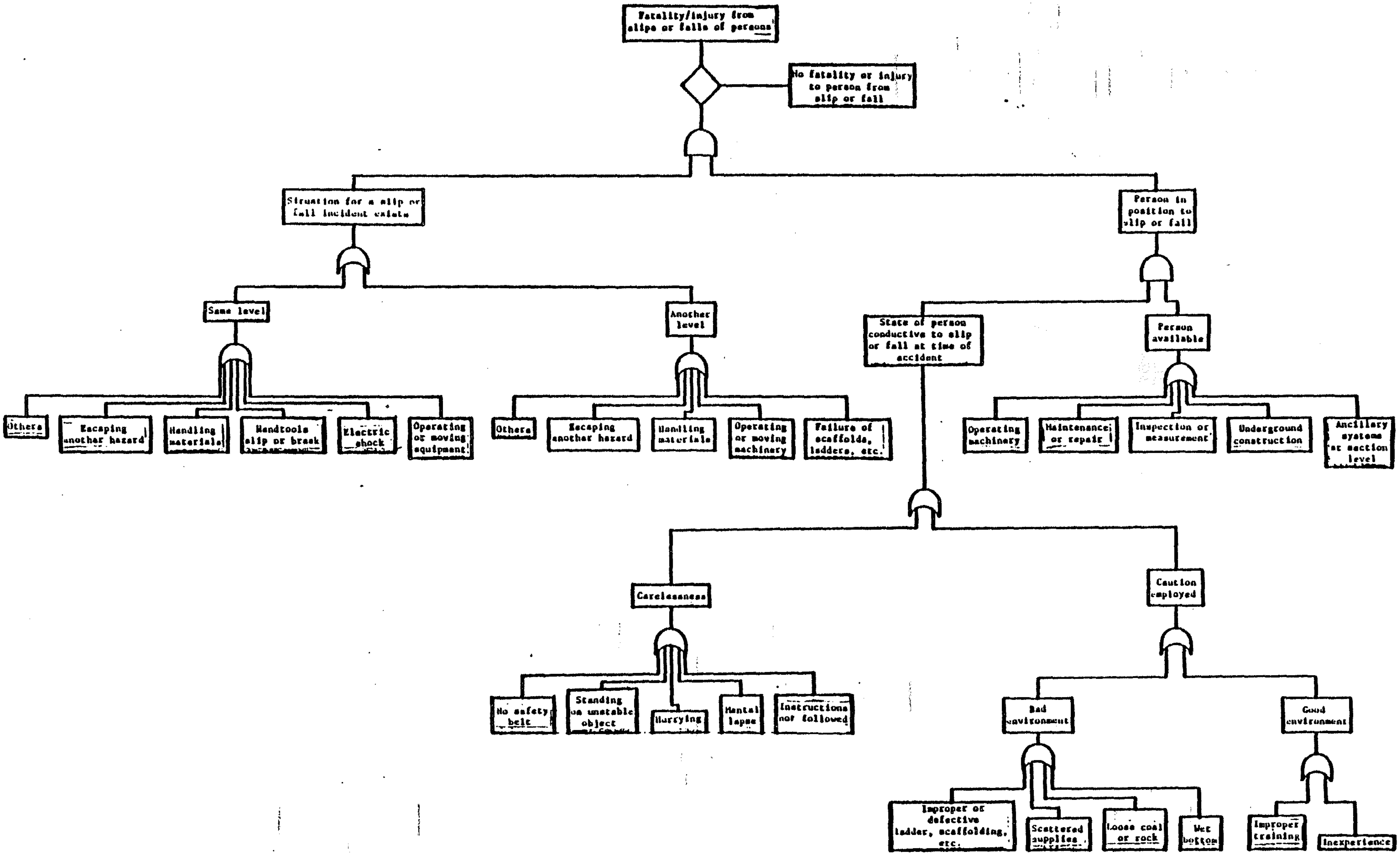


Figure D-2.
Slips or Falls of Persons
Injury Fault Tree Diagram.

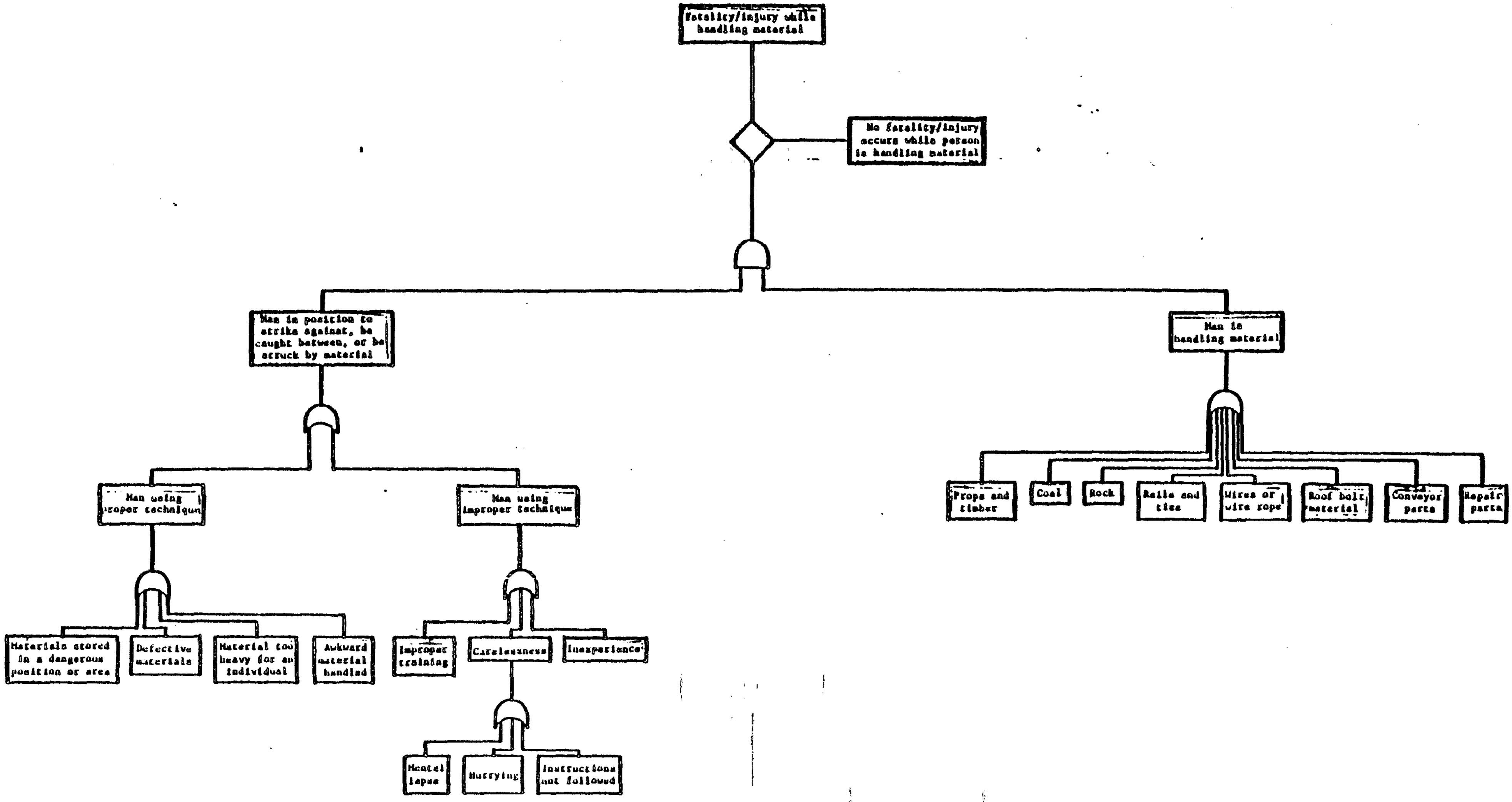

Fatality/injury while handling material
No fatality/injury occurs while person is handling material
Man in position to strike against, be caught between, or be struck by material
Man is handling material
Man using proper technique
Man using improper technique
Materials stored in a dangerous position or area
Defective materials
Material too heavy for an individual
Awkward material handled
Improper training
Carelessness
Inexperience
Mental lapse
Hurrying
Instructions not followed
Props and timber
Coal
Rock
Rails and ties
Wires or wire rope
Roof bolt material
Conveyor parts
Repair parts

Figure D-3.

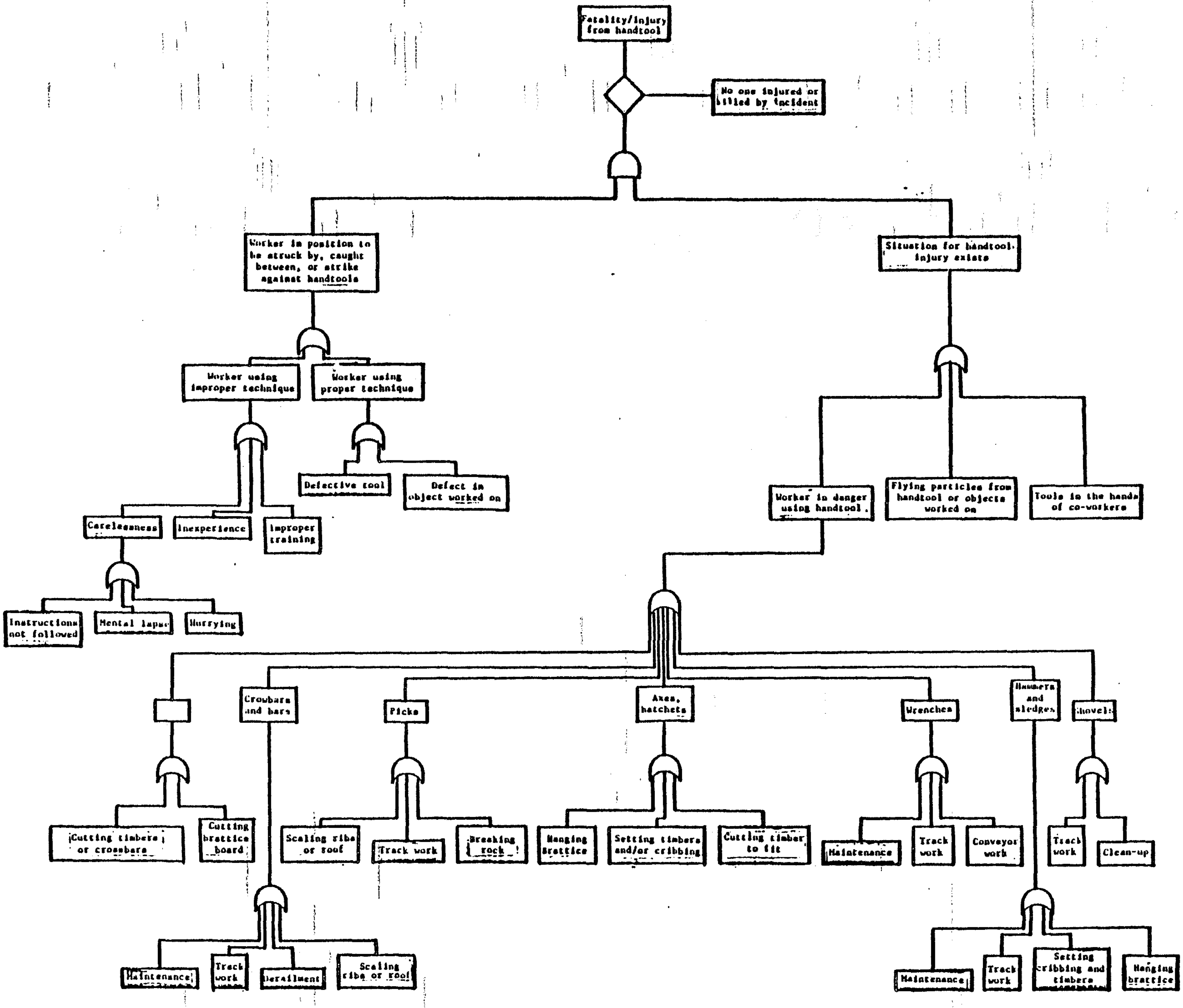


Figure D-4.
Hand Tool Injury
Fault Tree Diagram

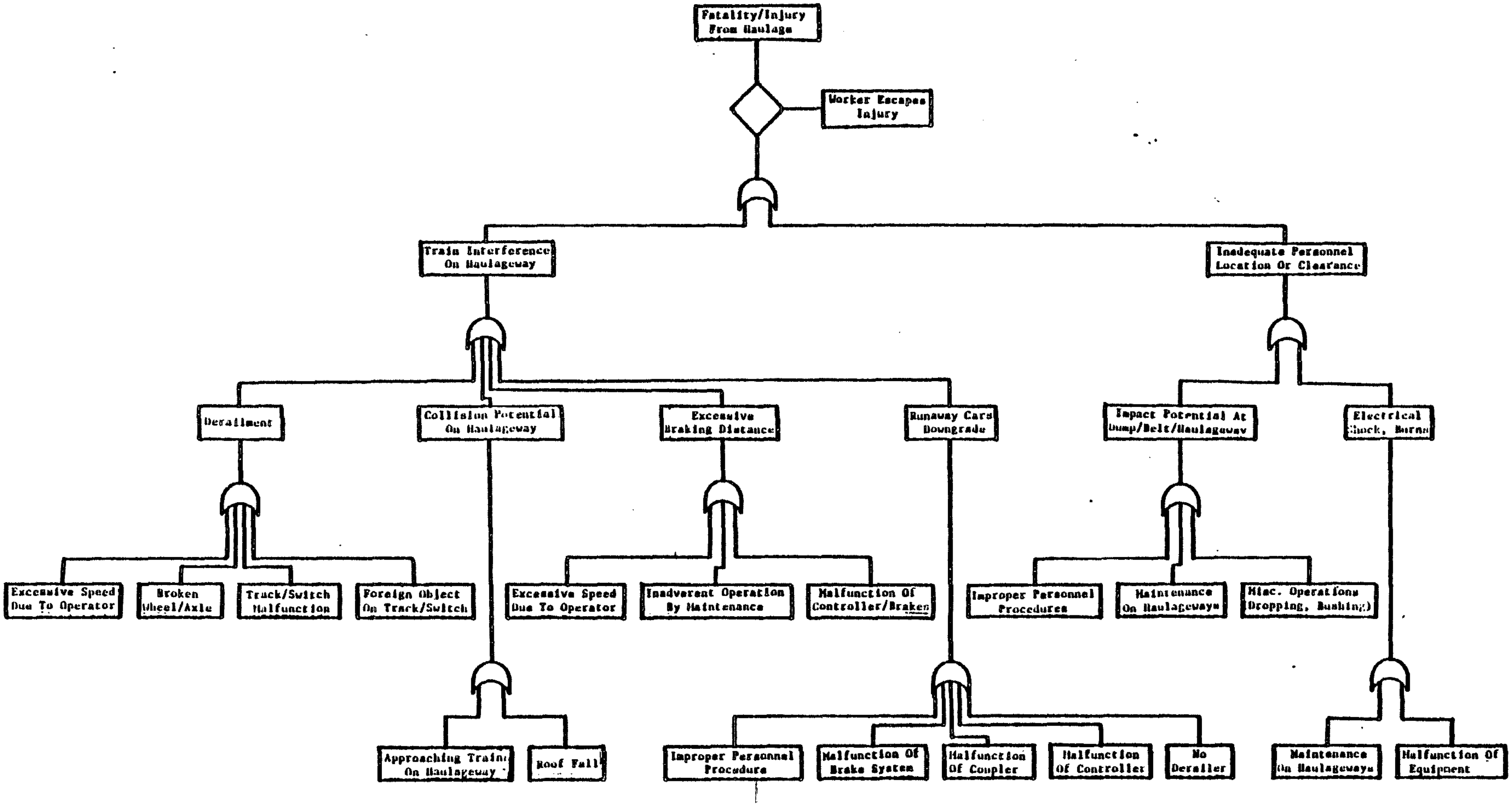


Figure D-3
Haulage Injury
Fault Tree Diagram
Extracted from Elliot and Dalechi
Phase II Report, USBM Contract
HO242011

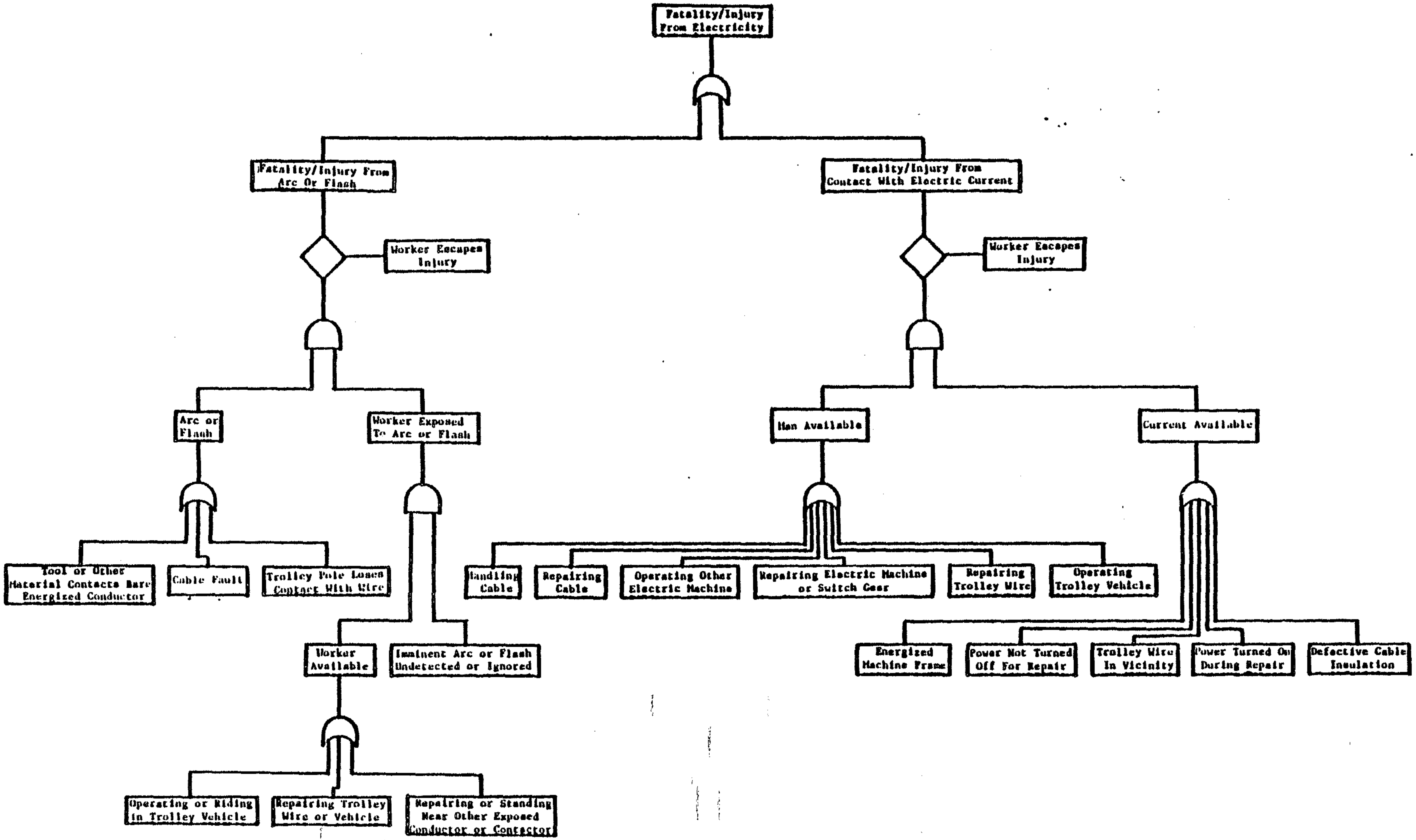


Figure D-6
Electricity Injury
Fault Tree Diagram

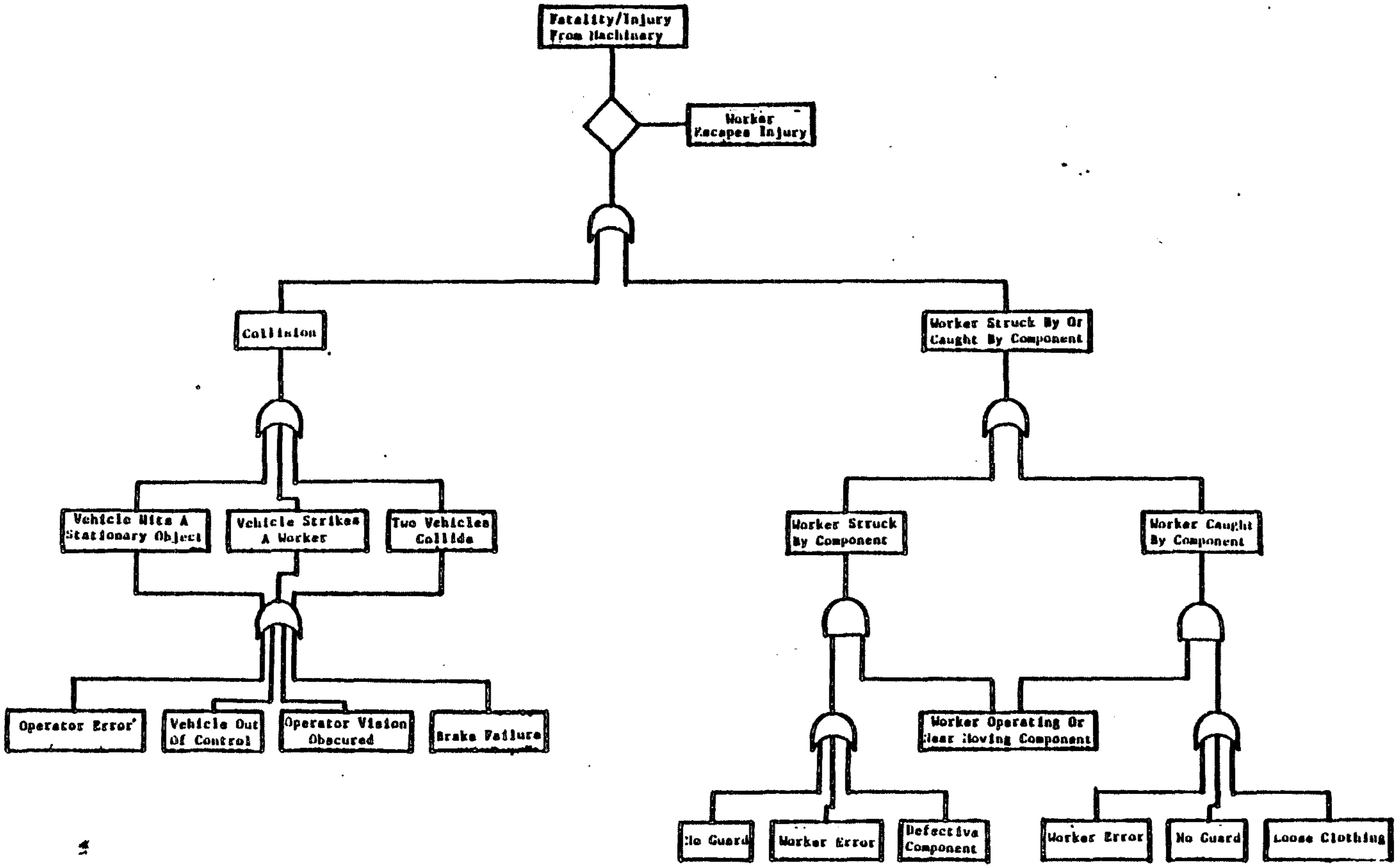


Figure D-7
Machinery Injury
Fault Tree Diagram

APPENDIX E

ARCCM PROGRAM ROOF BOLTING REQUIREMENTS

ARCCM Program Roof Bolting Requirements

The object of this report is to specify roof-bolting requirements for proposed high-production, automated, remote-controlled continuous mining systems. Unfortunately, the problem of specifying roof-bolting requirements is a complicated one since there are numerous roof-bolting cycle elements that utilize many materials in both mechanical and manual operations. Roof-bolting cycle elements are affected by human, environmental, and machine systems which further complicate specifications. Consequently, specifications cannot be simply stated but must evolve from a detailed analysis of the present roof-bolting operation.

It is anticipated that production from future automated mining equipment will depend on (1) the rate of mining, (2) the duration of production before the machine must be stopped for service and maintenance, and (3) the duration of service and maintenance time. Providing the machine has a roof-bolting system, the mining or advance rate may be limited by the bolting rate. Such is the case with the Automated Extraction System (AES).

The AES machine is capable of advancing four feet in 3.56 minutes at the low cutting rate and in approximately 2.00 minutes at the high rate. Consequently, four bolts must be installed in 3.56 or 2 minutes for the AES operation. Moreover, it is estimated that 3.4 minutes are required to install four bolts across the entry by the AES bolters. Unless bolting rates improve, future mining systems with higher mining rates may be severely restricted.

In order to provide preliminary recommendations for research scope and objectives to improve roof-bolting rates, the elemental times for present operation should be considered.

Table E-1. lists approximate elemental times for a roof bolter mounted on a continuous miner.

Table E-1. Roof-Bolting Elements

Element	Approximate Time
1. Insert Steel	.1
2. Raise Chuck	.1
3. Drill (Starter)	.5
4. Lower Chuck	.1
5. Change Steel or Add Extension	.1
6. Raise Chuck	.1
7. Drill	.8
8. Lower Chuck	.1
9. Remove Steel	.1
10. Insert Bolt	.1
11. Install Wrench	.1
12. Raise Chuck	.1
13. Torque Bolt	.1
14. Lower Chuck	.1
15. Remove Wrench	.1

Several possibilities for research to improve technology for faster bolting are evident:

(a) install several bolts at once,
(b) eliminate some of the job elements,
(c) increase the drilling rate,
(d) increase the rate of other job elements, or
(e) reduce the number of bolts that must be installed.

The AES system proposes to install four bolts simultaneously across an entry using two operators. The bolting machines are manually tended, so it is impossible for both bolts to be placed simultaneously; therefore, rather than installing four bolts in 2.6 minutes, the anticipated installation time is 3.4 minutes. Selective reliable automation of certain elements may improve bolting rates. For example, if the steel were automatically lowered, removed, and the chuck swung out on one of the two bolting units, the operator could tend the other unit during the time, saving 0.4 minutes. Therefore, even though automatic chuck tending is slower than manual performance, time can be saved by automating certain elements.

Eliminating job elements seems to be a remote possibility unless a completely innovative roof bolting technique is developed.

The drilling rate may be increased by research to control the rotation speed, thrust and percussion rate automatically; thereby improving efficiency over operator "feel" and experience. Technology improvements in drill bit design and cooling methods may also be beneficial in improving drill penetration rate. Moreover, the dust collection system should be upgraded to avoid limiting drilling rates.

Increasing the speed of job elements other than drilling rate would probably involve more expense than the probable time gains could justify. It would be easier to justify attempts to eliminate certain steps.

A particularly beneficial study may be to develop machinery, mining methods, and entry designs that would reduce the amount of bolts required for safe roof support. For example, upgrading the cutting and loading rates of a heading machine similar to the Dosko and Alpine (that would leave an arched roof) and install one or two bolts in the center of the entry may be a possibility.

Even if research can significantly improve roof-bolting rates, delays could contribute significantly to increasing roof-bolting cycle times. For example, our third of the bolts installed by the AES machine will require longer times than the mining cycle due to delays. Numerous possibilities for delay exist as a result of the many job elements that must be performed and the amount of material required. Delays in any of the job elements listed in Table E-1 could result from man, machine or environmental causes. The delay possibilities are diagrammed in several fault-tree charts (Figures E-1,2,3,4,5 and 6). Due to lack of information for probability of occurrence and average duration of delay, the charts are only quantitative at this point; however, time-study data from several mining operations could provide estimates that would allow an approximate average delay per roof bolting cycle to be computed. The normal fault tree, boolean algebra, computations can be made by summing probabilities at "or" gates (◠) and multiplying probabilities at "and" (◇) gates. Research projects could then be initiated to eliminate the most probable and time consuming delays.

In summary, the roof-bolting rate should be increased to maintain the current AES machine 4-foot advance rate in 3.56 minutes. One year from now the advance rate should be doubled and in two years tripled. This is obviously a guess, but if roof-bolting rates are not limiting factors, it just may be accomplished. Several possibilities that exist to improve bolting rates, in order of probable effectiveness, are:

1. reduce bolting delays,
2. install several bolts simultaneously,
3. reduce the amount of bolts required through improved mining plan and entry design,
4. increase the drill penetration rate,
5. eliminate some of the job elements, and
6. increase the rate of performing job elements in addition to drilling.

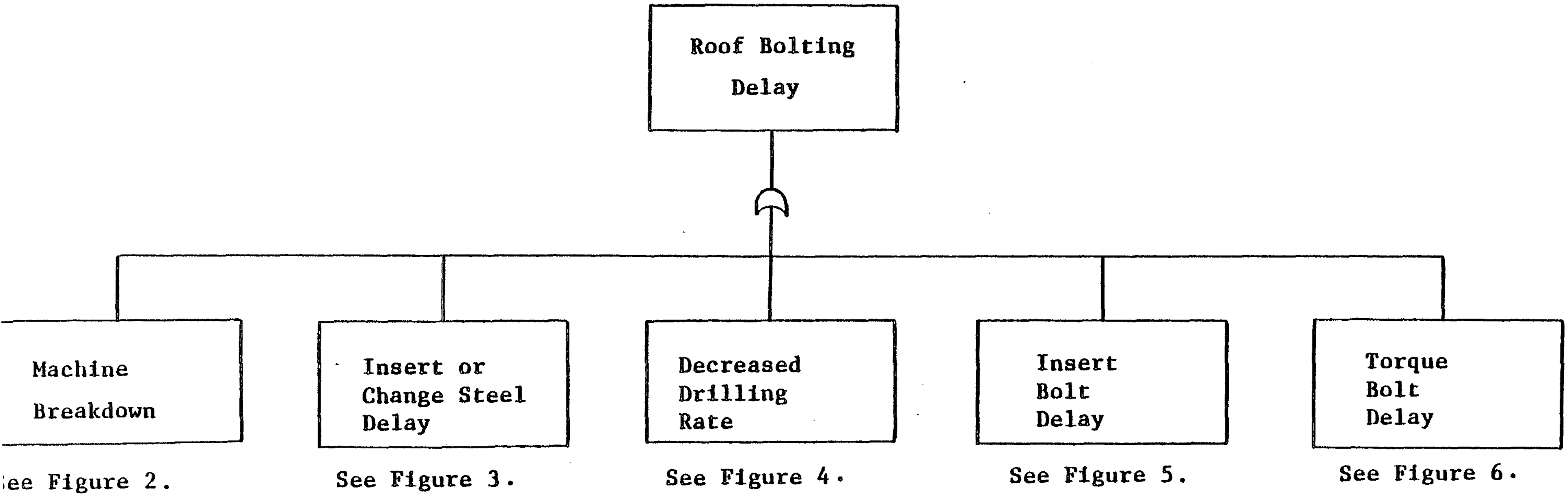


Figure E-1 Roof-Bolting-Delay Fault Tree.

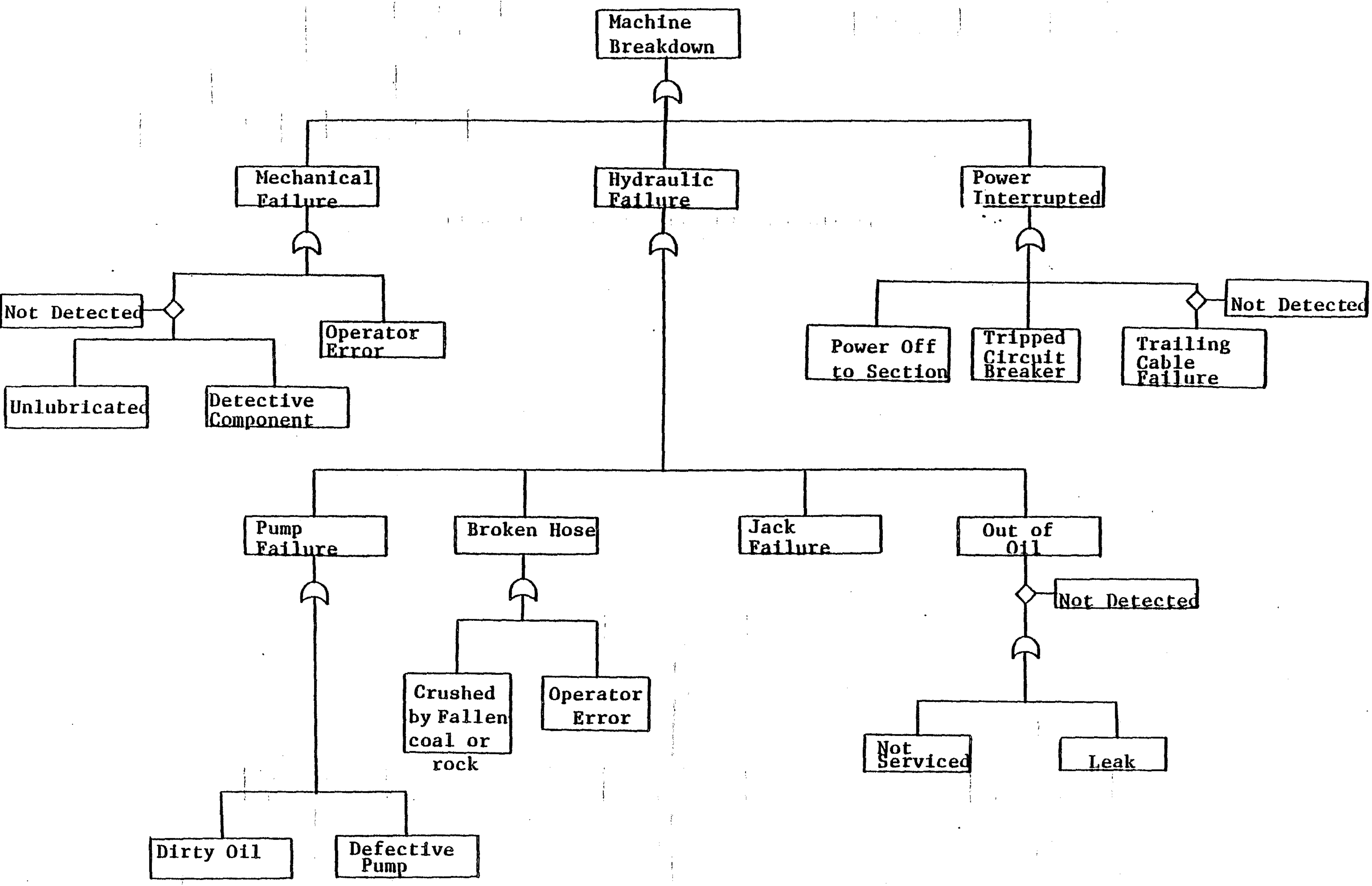


Figure E-2 Machine Breakdown Fault Tree.

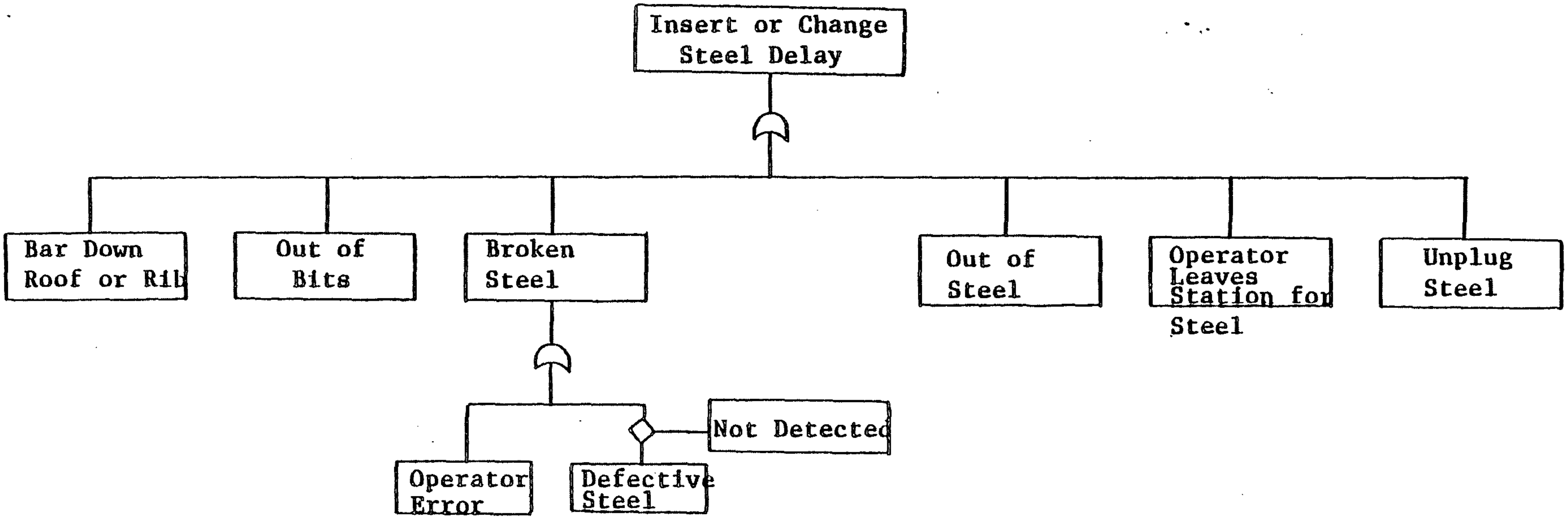


Figure E-3 Insert or Change Steel Delay Fault Tree.

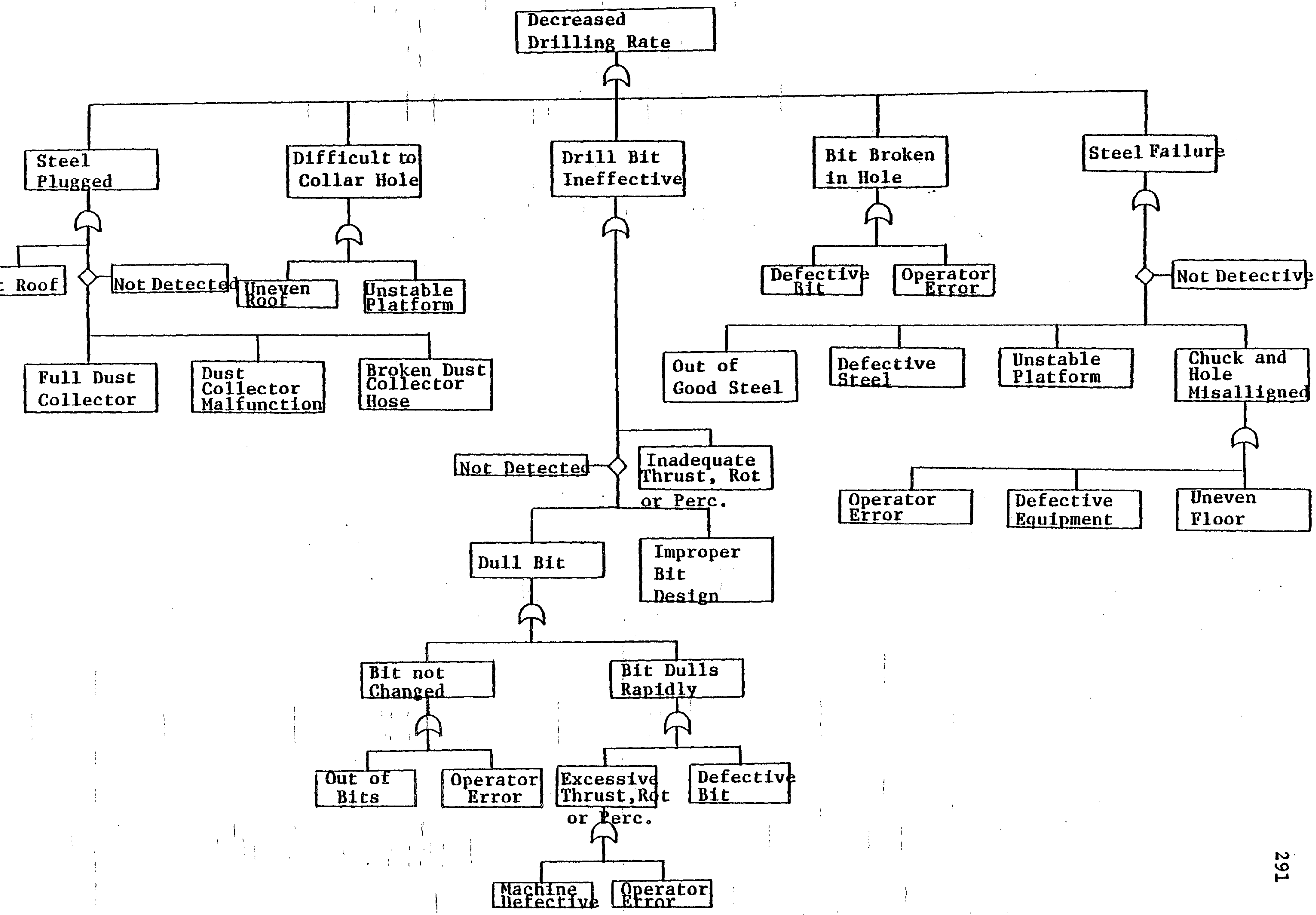


Figure E-4 Decreased-Drilling-Rate Fault Tree.

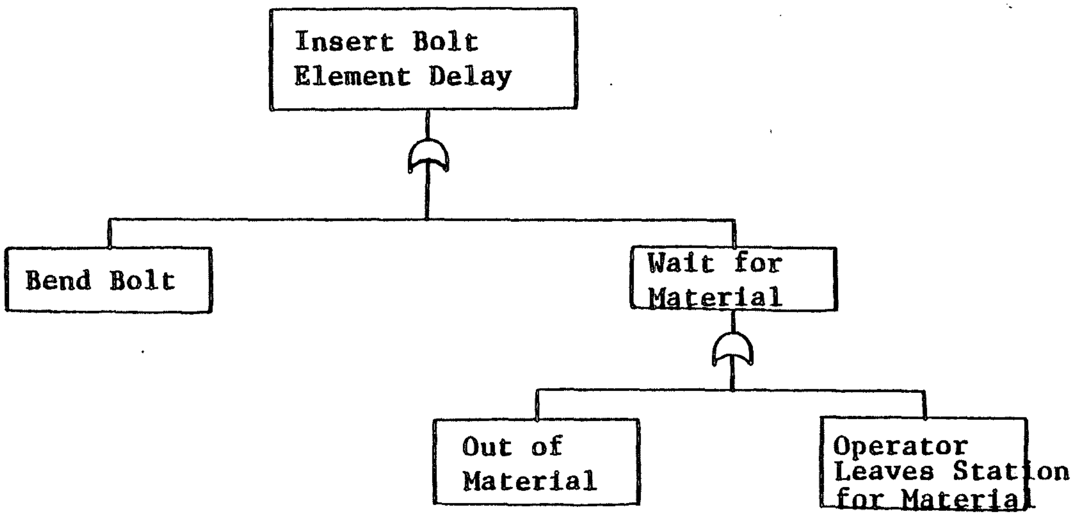


Figure E-5 Insert-Bolt-Element-Delay Fault Tree.

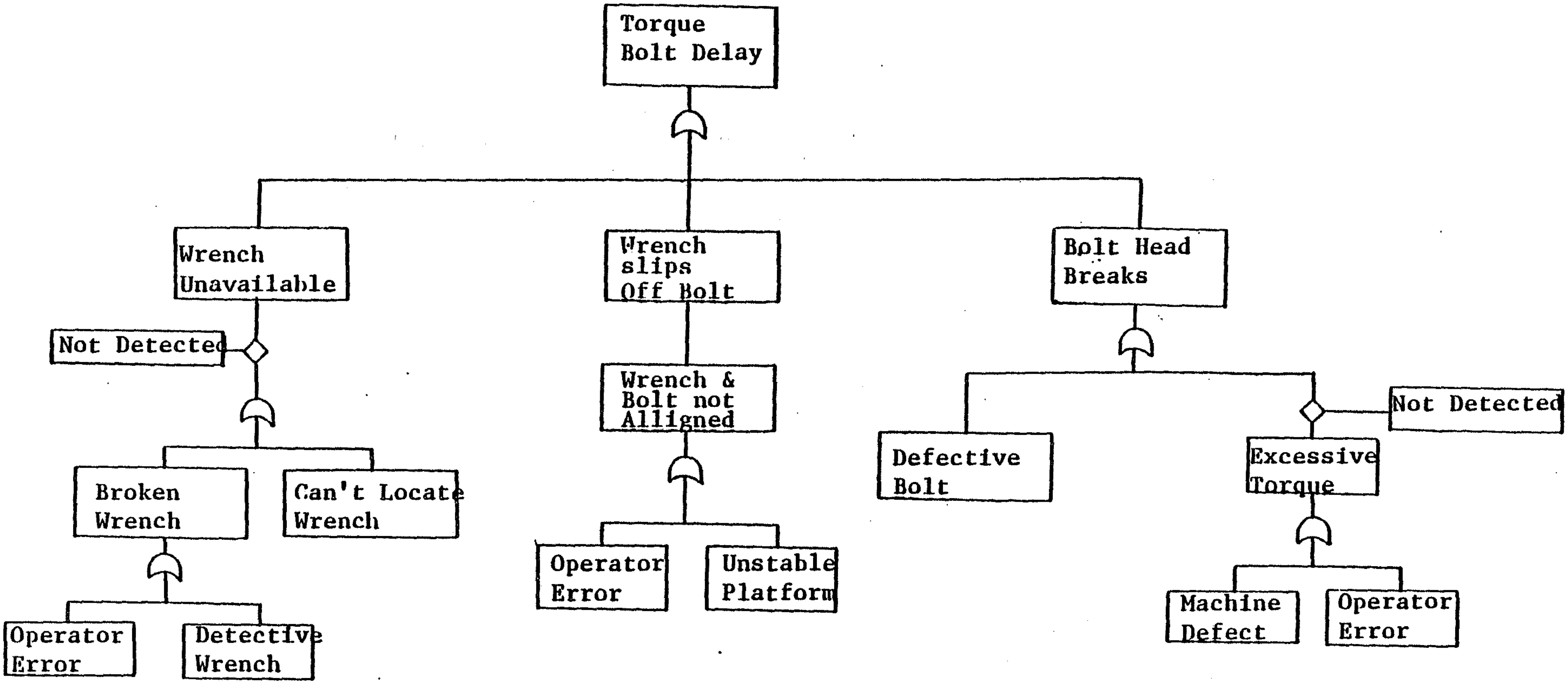


Figure E-6 Torque-Bolt-Delay-Fault Tree.