Investigation, Analysis, and Modeling of Longwall Face-to-Face Transfers

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Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Mining and Minerals Engineering

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ABSTRACT

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This dissertation reports on research efforts to investigate, analyze, and model longwall face-to-face transfers through the use of operations research techniques. The purpose is to reduce overall transfer time and the variation of transfer times among operations within the U.S. longwall industry. The research includes: (1) investigation of existing longwall transfers to determine standard and variant procedures; (2) development of comprehensive activity sequence models of existing longwall transfers; (3) generation of a simulation model for longwall transfers in various geological and mining conditions; and, (4) investigation of the economic feasibility of time-cost tradeoffs in the transfer procedure. Face transfer field data were collected from three eastern U.S. mining operations. From these data, general operational characteristics, transfer personnel utilization, and transfer procedures are described. A comparison of methods provide a breakdown of transfer activities, identify critical activities, and establish the state-of-the-art in transfer technology. Project scheduling models are developed for each operation using precedence networking analytical techniques and are applied through a computerized commercial software package. The project scheduling models accurately represent each of the operations' transfer procedures and provide information on the criticality of transfer activities and estimated project duration. Simulation models are developed, using Monte Carlo techniques, to combine analytical project scheduling with probability-based transfer activity durations. The simulation models closely match the results of the project scheduling models and provide information on the statistical tendencies of critical activities, paths, and project durations. The economic feasibility of reducing transfer time is analytically evaluated by collapsing critical activities and attempting an alternative roof control method. When compared to the lost production potential of longwall mining systems, the two time-cost trade-off procedures are proven, by the transfer simulation model, to be economically viable. This research is expected to contribute to the longwall mining industry by offering an objective approach that can be used in the prediction, planning, preparation, and implementation of longwall face equipment transfers.

Acknowledgements

I wish to thank my dissertation committee, Dr. Osman Balci, Dr. Mario Karfakis, Dr. Michael Karmis, Dr. G.T. Lineberry, and Dr. Richard Lucas, for ideas and directions contributing to this research. My sincere thanks to the committee for the time spent reviewing the research and this writing. My deepest gratitude goes to Dr. E. Topuz, my advisor and chair of the dissertation committee, for his encouragement and guidance through all the phases of this dissertation. His honest and patient review of this work has been invaluable. A special thanks is extended to Dr. G.T. Lineberry for countless hours reviewing and editing the dissertation. I thank the Department of Mining and Minerals Engineering and Virginia Polytechnic Institute and State University for the opportunity to work toward my doctorate. Additionally, this research was partially supported by the Mining and Minerals Resource Research Institute, MMRRI, U.S. Bureau of Mines. Their assistance and cooperation is gratefully acknowledged. Finally, I must thank my wife, Martha, and two sons, Kyle and Evan. This dissertation would not have been possible, if not for the encouragement and patience of my family, especially my wife. Thank you, Martha.

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I. INTRODUCTION

1.1 Research Background

Longwall mining systems offer the potential for improved safety and productivity, better ground control, higher levels of coal recovery and lower unit production cost. In addition, the ongoing trend towards concentration of mining activities into fewer sections of a coal mine, as well as application of automation and remote control technologies, favor utilization of the longwall mining method.

Longwall mining began in the early 1800's in Europe and now accounts for about 50% of that continent's coal production. In the United States, it was not until the early 1950's that experimental application of longwall mining began. Since that time, the use of longwall systems in underground coal mining has increased greatly. Over 25% of U.S. underground coal is produced by longwall mining, as compared to just 5% in the late 1970's (Merritt, 1984, 1992; Sprouls, 1986, 1990). The present trend indicates that an ever increasing number of mine operators have given consideration to installing longwall sections in their mines. If this trend continues, a very large portion of future U.S. underground coal production will be mined by longwall systems.

The driving factor for increased interest in longwall mining is high productivity potential. From 1985 to 1991, the average productivity of U.S. longwall systems increased substantially from about 1,000 to more than 2,325 tons per shift (Combs, 1993). Several longwall units have produced as much as 6,500 clean tons per shift (Combs, 1990), and have retreated longwall faces at a rate of 30 feet per shift. The utilization of more powerful equipment, higher equipment availabilities, larger longwall panels, better planning and organization, and the experience gained in longwall mining were the major contributing factors to productivity improvements (Combs and Lineberry, 1992; Dunlap, 1990; Duan, 1990).

High productivity of a longwall system comes at the expense of about two million dollars per 100 linear feet of face installed. An investment of this magnitude requires careful optimization of time and resources to maintain economic feasibility. Non-productive activities must be held to a minimum. A major source of non-productive time is the transfer of longwall equipment from a worked-out to a new panel. Minimizing face-to-face transfer time, therefore, is a critical concern of coal mining companies.

1.2 Statement of the Problem

A non-producing longwall costs the mine owner from \$45 to over \$100 per minute in lost production time (Hedges, 1984; Tucker, 1985). Face-to-face equipment transfers, which involve disassembling longwall equipment in a panel, transporting, and then reassembling it in a new longwall panel, are, for many companies, the largest single source of longwall non-productive time. This, in addition to a move cost of over \$100,000, makes reduction and control of face transfer times a paramount concern.

Transfers are highly skilled operations and differ considerably from the normal production at the face. A transfer operation can be roughly divided into four activities: pre-move preparation, move preparation, move and installation, and completion (Peng and Chiang, 1984). Each of these activities, however, vary a great deal from face to face and company to company depending upon the geological conditions, mine and face layouts, type of face equipment, specialized equipment used during transfer operation, skill level of workers, and planning and implementation of the transfer process.

The variation in move time among U.S. longwall operations is well documented. In 1991, the number of days for a longwall move varied from 5 to 28 days, with a 15 day average (Combs, 1993). From 1983 to 1991, the average move time per year required from 1,024 to 1,559 worker-shifts, with an increase over the last several years. During this period, the time per individual move decreased slightly, while the move frequency per year increased as a result of increasing longwall production rates. Despite past successes in the reduction of face transfer times for some companies, it is evident that large variations in move times from company to company still exist.

Several techniques have been attempted to reduce transfer time. The most successful efforts are in the areas of increased panel sizes, extra or spare equipment, specialized move equipment, and higher efficiency. Increased panel sizes have been applied successfully in several operations. However, panel size is restricted by technical factors such as maximum belt length and geological conditions (Peng and Chiang, 1984). A number of companies have reported success using limited types of spare equipment on the new panel. However, a detailed economic analysis of the viability of different types of spare equipment has not been reported.

Most attempts to reduce transfer times have involved development and utilization of specialized equipment transport vehicles (Morris and Hampshire, 1986; Cox, 1987), improved worker/management training and cooperation (Evans, 1985), efficient equipment planning and method of recovery (McKay, 1985), and predriven recovery room designs (Bauer, Listak, Berdine, 1989). While these techniques have provided improvement in transfer times, there has not been a uniform reduction in transfer times throughout the industry because of the disparity of their use. In addition, the primary purpose of these methods has been to increase the efficiency of state-of-the-art, rather than attempting innovative move methods.

In order to maximize operational effectiveness and to establish a basis of planning, several authors and longwall mining companies have developed network flow models to represent face-to-face transfer processes (Ketron, 1982; Nash, et al., 1983; Peng and Chiang, 1984). Published network models utilize activity-on-arrow diagrams with simple finish-to-start relationships amongst activities. A more comprehensive network plan, utilizing precedence networking methodology, is required to better represent the complex activity relationships which exist in a face-to-face transfer. In addition, a need exists for time-cost trade-off analyses where the cost of collapsing critical activities is compared to the savings from project time reduction.

Previously developed move techniques have helped the U.S. industry to reduce transfer times and has aroused the interest of both British and West German coal mining companies (Monks, et al., 1985; Evans, 1985; Newton, 1985). However, a large variation still exists in face transfer duration among mining companies, and no analytically based models are currently available, which predict transfer times with a reasonable degree of accuracy. Analysis and modeling of longwall face equipment transfers under varying geological and mining conditions will permit companies to examine their particular situations and predict transfer times and costs, thus enhancing their overall efficiency.

1.3 Research Objectives

The research analyzes and models longwall face-to-face transfers through the use of systems engineering techniques. The objective is to reduce overall transfer time and the variation of transfer times among mining operations within the U.S. longwall industry.

The research had three main objectives:

- To investigate existing longwall face transfers and to develop comprehensive network models;
- To generate a simulation model of longwall face transfers for various conditions; and,
- To conduct an economic analysis of the time-cost trade-offs in the transfer procedure.

To accomplish the stated objectives, the project was divided into several discrete tasks:

- Conduct a detailed analysis of the operational relationships between various activities, which make up the equipment recovery and transfer process.
- Gather face transfer data from various longwall operations, choose three operations for detailed analysis. Investigate the transfer processes, from the obtained data and literature research, to establish standard and variant activities and to determine those activities critical to the reduction of transfer times.
- Using project scheduling capable of precedence networking techniques, construct network models of individual move processes.
- Verify the credibility of the project scheduling process with longwall transfer "experts" at locations from which the data originated.
- Make recommendations to improve the investigated face transfers utilizing existing and innovative techniques.
- Develop a simulation model of the precedence network scheduling process with probability-based inputs to represent activity time variations.
- Apply the simulation model to differing face transfers using probability distributions to represent transfer activity durations.

- Develop and examine time-cost trade-offs which, could reduce the duration of the most critical transfer activities, thereby reducing overall face-to-face transfer time.

The research is expected to contribute to the longwall mining industry by offering an objective approach that can be used in the prediction, planning, preparation, and implementation of longwall face equipment transfers. The potential implication of a successful study is a substantial savings of both time and money in the design and operation of a longwall mining operation. As a result, this research effort may enable mine operators to evaluate, more objectively, the methods and equipment currently used in longwall face transfers, and may thus contribute to improvements in both the productivity and economic viability of this highly productive method. The coal market has changed to a point where only the most cost efficient mining companies are able to maintain their competitive positions in the market, rendering a study such as this not only timely, but necessary.

II. LITERATURE REVIEW

The studies of longwall mining face-to-face transfers can be categorized into three areas: (1) evolution of U.S. transfer techniques, (2) analyses of methods and equipment to optimize transfer time, and (3) surveys of the U.S. longwall mining industry. The major works in these areas are summarized below.

2.1 Evolution of U.S. Transfer Techniques

Experimental application of longwall mining in the U.S. began in the early 1950's and use of longwalls has increased extensively in the last four decades. One of the main reasons for this increase is the high productivity potential of a longwall system as compared to room and pillar mining methods. To fully realize this potential, the longwall must maintain high efficiency and reduce non-productive time. As a major source of non-productive time in a longwall system, face-to-face transfers have always been and remain a critical issue.

In a survey of U.S. longwall faces, Combs (1993) reported an average of 1.82 moves per year with an average move time of 835 man-shifts, or 18.56 three-shift, days for a crew size of fifteen. This represents a 14% loss in production time for 240 working days annually. Dunlap (1990), in an extensive study of longwall availability, found average system availability for twelve longwall sections to be 67.5%, including scheduled and unscheduled delays during the production interval. While the overall system availability included mechanical, geological, and organizational delays, the two top sources of equipment downtime were the shearer and outbye haulage at 8.9% and 4.3%, respectively. Both equipment types represent less downtime than that of face-to-face transfers. Deems (1990) and Reid (1990) state that face-to-face transfers are the "most significant delay" encountered in a longwall mining operation.

More scrutiny was placed on face transfers in the mid-1970's with the introduction of shield type roof supports in the United States. Prior to this time, lighter weight chock type supports were widely used, and face-to-face transfer techniques were similar to those in European longwall mines. In April 1975, the first shield type supports were installed in Consolidation Coal Company's Shoemaker Mine in Northern West Virginia (Mack and Stovash, 1981). Initially, shields were moved by the European method for chock support retrieval. This involved installing track from the headgate entry to the tailgate and winching supports to a headgate transport dock. A generalized description of this technique was given by Bussmann (1983). Oitto et al. (1977) provided a detailed description of the move procedure at Kaiser Steel's York Canyon Mine, in which the largest and heaviest shields in the U.S. at the time were moved by the European method. The move was completed in 48 shifts over a 32 day period. Curth and Cavinder (1977) cited a similar move at Mine No. 24 of Old Ben Coal Company in southern Illinois. Over ten weeks passed before the move was completed.

Increasing efficiency of moving shield supports became paramount to reduce transfer times. The technique of using two or three walking or recovery shields turned parallel to the longwall face to aid in the recovery of the remaining shields was soon initiated in this country. In 1979, Brooks reported on Consolidation Coal's Shoemaker and McElroy operations utilizing recovery shields to accomplish face-to-face transfers in ten to 23 days. This technique provided great improvement over the move times resulting from the European method of support recovery. The recovery shield procedure has become a generally accepted practice for U.S. companies. In fact, after 1981, the literature describes utilization of recovery shields in all U.S. longwall moves.

The European longwall community gave increasing attention to the improvement in face-to-face transfer times as a result of U.S. move techniques. The British were especially interested because face-to-face transfers in the U.K. take, at best, four weeks and often more than four months (Mills and Jones, 1985). Several British mining scholars reported on varying aspects of the U.S. longwall industry after visits to U.S. mining companies in 1983 and 1984. Upon observing three moves in progress in the eastern United States, Evans (1985) found several reasons for the remarkable transfer times, by British standards. These were: (1) transport systems ideally suited to handling longwall equipment; (2) specialized handling equipment including low height outbye transport vehicles and free-steered vehicles for face equipment transport; (3) multi-entry development, which allowed easier access to the face area and additional room for storage of equipment; and, (4) detailed planning and careful organization of the move.

A face-to-face transfer at Mine 26 of Old Ben Coal Company was observed by Monks, Hodgkinson, and Ferris (1985), three British engineers. A detailed account of the move was given, with emphasis placed on specialized move equipment. The authors concluded that successful face salvage operations were the result of the: (1) multi-entry system which provided flexibility and storage, (2) narrow roof bolter for quick recovery area bolting, (3) work done prior to the move to reduce time-wasting operations, (4) specialized free-steered vehicles to remove equipment from both ends of the face, and (5) flexible labor practices and good supervision. Stace (1985) reported, after visiting ten longwall mines in eastern United States, that rapid face-to-face transfers were the result of modern transport facilities, detailed pre-planning and room available in which to operate. In another related work, clearance provided by roof bolting the recovery area with narrow bolters and use of specialized transport vehicles were cited as the primary reasons for rapid face transfers in the U.S. (Tucker, 1985).

2.2 Analyses of Methods & Equipment to Optimize Transfer Time

A longwall face-to-face transfer is a series of complex activities occurring in an encumbered environment. A number of factors contribute to efficient, safe, and rapid transfers. Pavlovich (1981) encompassed the aim of most companies with the statement: "Key factors in optimizing longwall move time are extensive planning, precise execution, utilization of proper tools and equipment, good communication, and just plain, old hard work."

As the U.S. longwall industry has progressed, a number of ideas have been proposed to increase efficiency and reduce non-productive time. Reduction of development and move time by varying the U.S. method of retreat longwall mining to the advancing system was the subject of a 1977 Coal Age article ("Developing Efficient, Economical Longwall Plan," 1977). Bond (1982) reported on the technique of swinging longwall faces 180° around a pivot point in the Bagworth Colliery in England. This article also referred to the advancing system of longwall mining. Advancing systems are essentially restricted in the U.S. because of the regulatory requirements, primarily in the area of ventilation, needed to develop longwall panels via multiple entries.

A concept was suggested by Peng and Chiang (1984) which is similar to swinging faces on a pivot point for a retreat longwall system. A Z-type layout was proposed in which the moving distance was reduced by directly lining up the recovery area of the old panel with the setup area of the new. According to Peng and Chiang, "When the longwall face for Panel 1 reaches the termination point, all face equipment is moved along the shortest straight-line distance to the setup room of the second panel, which is directly across the panel entries from the recovery room of the first panel. In this case, the moving distance is approximately equal to the width of the panel entries and the width of the new panel."

A radical change in the design of the longwall system was presented by Faulders (1976). He suggested the use of a mobile continuous miner integrated with a longwall shield and lateral conveyor, connected in series with similar units along a wide block of coal. Another suggestion was to mount segments of a longwall system (15 - 20 supports wide) on mobile transport vehicles with a modular conveyor and shearer provided for each segment. Decreasing non-productive time by making the longwall system more mobile was the key to both of Faulders' ideas; however, neither concept was adopted by the U.S. longwall industry.

Longwall moves, as a major source of non-productive time, have undergone extensive examination. Several conceptually different techniques have been used by the longwall industry. Lightweight polymer grid sheets have replaced wire mesh for roof control during moves for some mining companies (Travis, 1991). The grid sheets are reported as much lighter yet as strong as the wire mesh commonly used. In another innovative method, Stewart (1985) discussed the use of polyurethane injection into the roof of the recovery area. This procedure successfully maintained roof conditions during the move of a 1000-foot longwall face at Kitt Energy's No. 1 Mine in northern West Virginia.

The U.S. Bureau of Mines investigated the use of pre-driven recovery rooms for expediting equipment removal operations (Bauer et al., 1989). Beth Energy's Mine No. 60 in southwest Pennsylvania used a predriven area which was heavily supported with roof bolts, wire mesh, fly ash-cement piers and fibrous crib blocks. The longwall face mined directly into the pre-driven area through the piers and crib blocks. The roof was maintained in spite of the build up of extensive front abutment pressures in the recovery area as the longwall face approached. In the report, the cost of pre-driven rooms was offset by savings from the increased productivity and time saved on the move.

In a more recent study (Wynne et al., 1993), a successful 36-foot wide, predriven recovery room was reported. The Mettiki Coal Corporation Mine D, near Deer Park, Maryland, utilized the predriven room to alleviate severe spalling problems during wire mesh installation, due to a friable roof and a soft coal face. Specialized Jenmar Corporation roof bolt and truss systems were used in combination circular concrete cribs in the design of the recovery room. Extensive rock mechanics instrumentation was performed via stressmeters in pillars, roof-to-floor convergence, strain-gaged roof bolts, load cells on bearing plates of roof bolts, and a borehole stratascope. The longwall cut into the recovery room with no roof control problems. While previous transfer times were not available, a seven day move was reported. This was an inferred obvious improvement over previous moves.

Pre-driven recovery rooms, when applied, have been reported as a very successful roof support method. However, current application is limited primarily due to the costs and risks involved in establishing rooms that work well every time. In a study of fourteen longwalls transfers, researchers from MSHA's Pittsburgh Safety and Health Technology Center found no use of predriven recovery rooms (Gray and Evanto, 1993).

A number of computer-based models, simulations, and optimization techniques have been presented for increasing the efficiency of longwall systems. The manner in which these packages deal with longwall face-to-face transfers varies, with only a few designed specifically for transfers. One such model, developed by Nash et al. (1983), utilized a critical path planning and scheduling routine. It included time and resource constraints, such as manpower, machinery, supplies, work space, and transportation routes. The model's utilization was followed by a 50% move time reduction at a longwall panel at the Emery Mining Corporation of Utah.

Most computer packages were designed to optimize longwall panel layout and dimensions by minimizing total mining costs. Grayson and Peng (1986) conducted a linear programming optimization of longwall panel layout in which transfers were analysed using estimates of move duration and cost per panel. Output from this model included the required number of production shifts for a longwall move.

Other programs consider moves indirectly by reducing longwall productive time or by increasing non-productive time. One research program involved the microcomputer-based evaluation of innovative development schemes for longwall mining systems (Bise and Schroeder, 1986). Move times were indirectly included as part of the total time to mine a panel. Chatterjee et al. (1987) included move times by the input of a number of production "days off" in a longwall panel.

Substantial work has been done to aid the longwall industry in face-to-face transfers. In a comprehensive book on longwall mining, Peng and Chiang (1984) devoted a chapter to face moves. The chapter is divided into four face move "steps" plus a section on reduction of move time and frequency. The move steps are: pre-move preparation, move preparation, move and installation, and completion.

The most comprehensive analysis of U.S. longwall moves, to date, was conducted by the Ketron Corporation under contract by the U.S. Department of Energy in 1980-1981. Pimentel et al. (1982) conducted a detailed study of four face-to-face moves. In the study, the authors examined available data from move schedules, post-move reports, foreman shift reports, CPM networks, and/or time studies. Each move was recounted and improvements to problem areas were suggested. This study resulted in a handbook for face-to-face moves, which reported state-of-the-art techniques used by U.S. longwall companies (Adam et al., 1982). The handbook was presented as a guide for longwall moves under varying U.S. mining conditions.

A multitude of factors contributes to rapid face-to-face transfers in the United States. The predominant factors found in the literature are: specialized equipment transport vehicles, precise planning and organization, and spare equipment.

Most authors agree that specialized equipment greatly enhances the efficiency of moves in U.S. longwall mines. Longwall operators and equipment manufacturers have worked together to provide rubber-tired pullers and movers, rail-mounted, low-height heavy equipment carriers, and narrow roof bolters for the recovery area, as well as other machinery specifically designed for longwall moves. As early as 1978, Barnes & Tucker Mining Company and Kersey Manufacturing Company designed and built a chock support transport scoop (Davis, 1978a). Design of a shield puller and shield carrier originated with two of Clinchfield Coal Company's operations managers (Anon., 1983).

Free-steered vehicles, especially those used as support movers, have provided great flexibility and speed to the move process. An outline of the design concept and pattern of development for free-steered vehicles in the underground environment was provided by Morris and Hampshire (1986). A focal point were those vehicles designed to carry heavy loads, such as roof supports. Newton (1985) described two basic design criteria for equipment movers: the ability to pull, lift, and carry face equipment; and the profile and turning radius for recovery room access. Longwall equipment movers, including the Simmons Rand 610 roof support mover, with a maximum capacity of twenty tons, were highlighted in a review of U.S. underground transport systems (Cox, 1987). Deems (1990) provided a detailed description of four types of specialized equipment used by Consolidation Coal Company. These were the: (1) longwall face roof bolter, (2) battery- or diesel-powered roof support scoop, (3) rubber-tired shearer dolly with recessed rail wheels for outbye transport, and (4) shield recovery F-bar. A narrative and drawing were provided for each type of equipment.

Longwall panel lengths and related move distances between adjacent panels average nearly 6,000 feet with a maximum of 13,500 feet (Combs, 1993). These long distances typically require the use of rail transportation to convey heavy longwall equipment from the old panel to the new. Rubber-tired vehicles are commonly used for hauling other equipment to transfer points in a gate entry for transport to the new panel. The first reported rail transportation system in the U.S. specifically designed for longwall systems negotiates grades as high as 25% (Jackson, 1984). This system was installed by the Carbon County Coal Company in Hanna, Wyoming, to move 21-ton shields to new longwall panels.

The withdrawal rate of roof shields is greatly dependent on the rate of transport between the old panel and the new one (Brass, 1989). This requires a great deal of planning and organization for the most efficient move. Most mining companies recognize planning and organization as the key to quick, successful longwall moves. Specific moves described in the literature follow a general sequence common throughout the industry. Mack and Stovash (1981) identified this sequence as: (1)

preparation of new face, (2) establishment of ventilation controls and preparing the moving route, (3) gathering of supplies and equipment needed for the move, (4) wire meshing the recovery room, (5) face conveyor removal and face roof support, (6) shield recovery, and (7) completion of new face installation. Later, McKay (1985) provided a more detailed sequence specifically for longwall equipment. Today, these sequences are typical in U.S. longwall mines.

Most mines were already utilizing the previously described move sequence before its published presentation. Davis (1978b) gave a time-line chart of a move performed by the Gateway Coal Company in Greene County, Pennsylvania. Gateway's experience from eight previous moves made planning easier and the time-line chart allowed real-time modifications to the plans. The move took 24 days. Another 24-day move occurred at Inland Steel Coal's Lancashire No. 25 Mine in western Pennsylvania (Hedges, 1984). The interaction of excessive water with a clay shale immediate roof and fireclay immediate floor made this five-mile face transfer very difficult. Subsequently, planning began two months prior to the move. To improve efficiency, assignments related to safety, ventilation, electrical, drainage, maintenance, rebuilds, and track transportation were divided among various supervisors. Hedges provided a shift-by-shift breakdown of the move with details of the difficulties which arose and suggestions for later move improvements. While move time was the same as in the Gateway Mine, an overall improvement in move time at Lancashire can be plausibly attributed to the adverse conditions and long move distance.

Elimination of the face transfer problem is possible by providing a fully equipped longwall face ready to mine when the old panel is completed. However, in the highly competitive U.S. coal market, having a complete extra set of face equipment is economically impractical. It would tie up enormous amounts of capital that could otherwise be used for other projects, and the cost of financing a non-productive investment at any one mine would greatly increase the cost of production. On the other hand, holding certain pieces of equipment in reserve has been economically justified by a number of U.S. companies. Many companies purchase extra shearers, stage loaders and drives, and/or face conveyors. Some companies have spares of all components with the exception of the high-cost roof supports.

The Pursglove Mine of Consolidation Coal Company uses a spare face conveyor, stage loader, shearer, hydraulic power pack, and electrical control package (Martin, 1985). Brass (1989) reported that Mine No. 5 of Jim Walter Resources has sufficient spare equipment to enable everything to be installed on the new face except the shield supports. In a 1987 Bureau of Mines survey of eight of the highest producing U.S. longwall sections, the four operations with spare panlines and shearers had an average move time of nine working days; those without spare equipment averaged twenty days (Organiscak et al., 1988).

Studies on the impact of individual pieces of spare equipment on face-to-face transfers were reported by Deems (1990). In fact, Deems states, "The most significant factor in minimising face transfer is the use of spare equipment." The following time savings were reported for particular spare components:

- Face conveyor (drives included) - 6.0 days
- Stage loader - 2.0 days
- Impact crusher - 0.5 days
- Mobile belt tailpiece - 1.0 days
- Electrical controls (cables included) - 2.0 days
- Emulsion pump and tank station - 1.0 days
- Shearer - 2.0 days.

The use of spare equipment not only decreases move time but also improves production availability. Several factors contribute to improvement in availability. Spare equipment has less downtime than quickly rebuilt equipment. The rebuilding process is not rushed, insuring that a dependable job is done. Setup of spare equipment on the new panel can be scheduled while the old panel is still in production, making placement and connection of spares less hurried and more likely to be error free. According to Deems (1990), the use of spare equipment has increased Consolidation Coal Company's longwall production availability from 75% to 95%. Economic justification of spare equipment is provided through the reduction of non-productive days required to move the longwall and improved equipment availability.

In order to determine the extent of spare equipment utilization in U.S. longwall transfers, the author arranged several additional questions to be added to an annual longwall industry survey (Combs, 1993). This survey, conducted by Trigg Combs, Mining Consultants, was modified to reflect the use, type, and number of person-shifts to install spare equipment. Of the 48 survey respondents, 28 (58%) used at least one type of spare equipment. Of those, seventeen (35%) had spares of all major components, except shields. The survey results cannot be assumed to accurately represent the total industry; however, the economic feasibility of spare components is shown for a significant number of operations.

2.3 Surveys of the U.S. Longwall Mining Industry

Statistics on U.S. longwall operations have been collected since 1969 (Merritt and Brezovec, 1980). An annual census of longwall production capabilities and equipment employment has been conducted by Coal magazine (Anon., 1986; Merrit, 1984, 1985, 1991, 1993; Sprouls, 1987, 1989, 1990). Collection of data on U.S. longwall panel dimensions, productivity, and face-to-face transfers, through the use of industry surveys, began in 1983 (Combs, 1987, et seg.; Peake, 1984, 1985, 1986).

The survey results are classified within working seam height ranges of below 49 inches, 49 to 79 inches, and 80 to 120 inches. The ranges are further divided to show an average, high, and low figure for each data category. An overall average is also given as a combination of the three height ranges. The data categories are:

- Cutting height (inches)
- Panel length (feet)
- Panel width (feet)
- Operating shifts per year
- Total tons per year
- Tons per shift
- Total person-shifts per year
- Face tons per person-day
- Shifts to move
- Move person-shifts per year
- Face tons per person-day - all shifts

The categories "Shifts to move" and "Move person-shifts per year" are specifically related to face-to-face transfers. According to Combs (1991), the current survey originator,

> "Shifts to Move" are the number of person-shifts required to complete a move including the installation of spare equipment while the face to be moved may still be operating

and

> "Move Person-Shifts Per Year" are the Shifts to Move (multiplied) by the number of reported moves that year.

The number of moves performed per year, on average, is obtained by dividing "Move Person-Shifts Per Year" by "Shifts to Move".

During the period 1983 to 1993, the survey has exhibited the following trends:

- Longwall productivity increased significantly, with only a slight drop in 1989 and 1991 from previous years. Overall, productivity increased 100% in terms of tons per shift and nearly 150% for tons per person-day. Increased productivity increases the rate of advance, thus increasing move frequency.
- Cutting height (working seam height) has increased only marginally from 68 inches in 1983 to 81 inches in 1991. Higher cutting heights provide more clearance for moves, thus reducing move time.

- Face widths have steadily increased, increasing the amount of equipment transferred during a move.
- Panel lengths have increased each year, since 1984, probably due to better mine planning, more reliable, longer lasting equipment, and the desire of operators to decrease the number of moves required each year.
- The shifts to move, move person-shifts per year, and resulting number of moves per year have varied widely since 1983.
- The shifts to move trends downward while move person-shifts per year trends upward, possibly an indication of more personnel being dedicated to moves in order to reduce move time.
- Moves per year changed from an upward to a downward trend in 1986, probably due mostly to longer panel lengths.

2.4 Summary

This review presented an abundance of literature related to longwall face-to-face transfers. The amount of published material indicates the importance of efficient and safe longwall moves to a mining operation. The review was divided into three main categories. The first category dealt with the historical development of U.S. longwall moves. The second presents some move techniques currently practiced. The majority of articles in the second category reported dated techniques for moving longwalls. A small number of the articles gives current practices of certain U.S. longwall operations which could be deemed as state-of-the-art. Surveys present nearly a decade of limited data on U.S. longwall moves. This data includes representative data on move times and personnel requirements during moves throughout the U.S. longwall industry.

III. FACE TRANSFER INVESTIGATION

3.1 Introduction

A longwall mining system is large, complex, and has many parts. Because the longwall mining system is heavily reliant on the total systems activities of ground control, bulk handling activities, life support (e.g., ventilation), and normal support (e.g., power), an "encumbered" environment is inevitable (Lineberry and Adler, 1987). Production activities in this system are hazardous, transitory, and expensive. A longwall face-to-face transfer combines all these factors with a short-duration requirement, further complicating the process. The transfer process is a set of interrelated activities, which often times occurs simultaneously and can change from one transfer to another.

All companies operating longwall mining systems have developed detailed procedures to perform a face transfer. The transfer involves a multitude of activities and identifying individual activities on a micro-basis is not difficult. However, given the myriad of activity relationships and interactions, executing the move on a macro-basis can be overwhelming. The transfer takes place 24 hours a day, seven days a week, with many decisions and multiple variables that can and do change. Following the move on a day-to-day, let alone an hour-to-hour, basis is extremely difficult and can cause an increase in the overall time in which the move is performed.

The complex characteristics of a longwall face transfer make it a difficult process to analyze and model. In order to effectively study face transfers, a thorough understanding of the state-of-the-art is essential. This chapter describes, compares, and constrasts the transfers of several companies highly active in longwall mining.

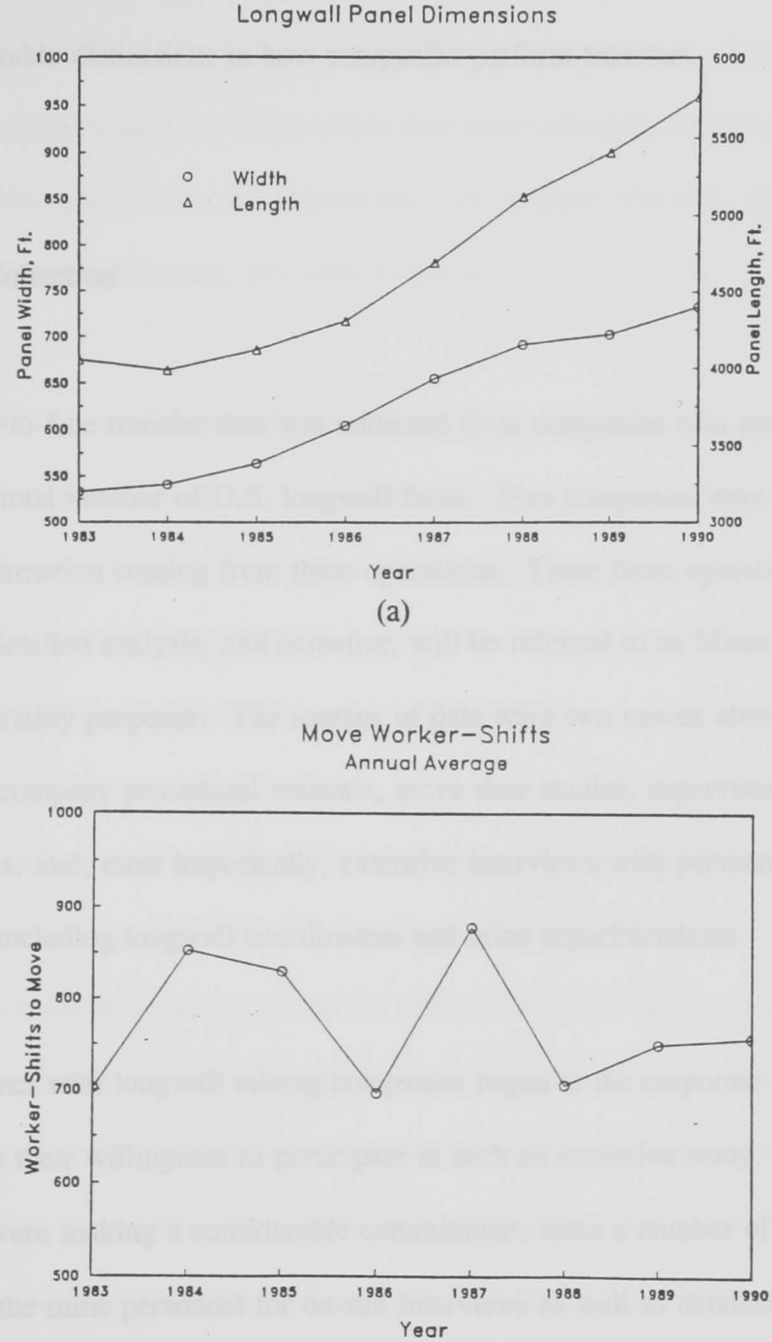
3.2 Background

A longwall face transfer differs considerably from normal face production. The general sequence of transfer activities is similar throughout the U.S. longwall industry. However, this sequence can vary significantly depending upon the geological conditions, mine and face layout, type of face equipment, specialized transfer equipment utilized, worker experience, and degree of planning and organization of the transfer process.

Major advances have been made, especially in the last decade, in the areas of specialized move equipment development, worker experience, and move planning. Shield-carrying scoops, rail-mounted flat cars, and narrow bolting machines have facilitated quicker and safer transfers. Increased transfer experience of management and workers has played a significant role in improving efficiency. Companies have also realized the critical importance of proper planning and organization of a move.

The safety and efficiency of U.S. transfer techniques have increased greatly since the first experimental longwalls in the early 1950's. The industry has gone from relatively lightweight chock supports and plow mining machines to much larger shield supports and shearing machines. The increases in size and weight are the result of deeper and more complex mining conditions and increased ruggedness to provide better equipment reliability. Longwall panel size has also increased steadily over the years. Increasing panel width directly affects transfer time, since more equipment must be moved. Figure 3.1(a) shows the increase in average U.S. panel width and length from 1983 to 1991. During this same time, the average transfer time has held relatively constant, as shown in Figure 3.1(b). Since average transfer time has changed little, while equipment size and quantity has increased, the inference is that the ability to execute a transfer has improved. However, large variations in transfer times exist from company to company.

In 1991, reported transfer times ranged from 240 to 3128 worker-shifts (Combs, 1993). While some of this variation can be attributed to differing move



(a)

(b)

Figure 3.1 Longwall Panel Dimensions and Transfer Time (Combs, 1993) crew size and whether spare equipment is used, such a large variation suggests that there are notable distinctions in how companies perform transfers.

3.3 Data Collection

Face-to-face transfer data was collected from companies who operate over 35% of the total number of U.S. longwall faces. Five companies were involved, with detailed information coming from three operations. These three operations were chosen for detailed analysis, and hereafter, will be referred to as Mines A, B, and C for confidentiality purposes. The sources of data were two moves observed by the researcher, company procedural manuals, move time studies, supervisor shift and move reports, and, most importantly, extensive interviews with personnel responsible for moves, including longwall coordinators and mine superintendents.

Contact with longwall mining companies began at the corporate level in order to determine their willingness to participate in such an extensive study. Participating companies were making a considerable commitment, since a number of hours were required of the mine personnel for on-site interviews as well as detailed information on transfer techniques, equipment, supplies, and personnel. Each company was guaranteed confidentiality and was provided the results of the research.

The determination of collected data type was primarily influenced by the intent to analyze individual company transfer procedures, compare and contrast transfer procedures among companies from which data were collected, and determine transfer practices which are common throughout the U.S. longwall industry. It was determined that the following data were required:

- Mining conditions and environment,
- Transfer planning and training methods,
- Transfer activity sequence and timing details,
- Transfer equipment type and utilization, and
- Transfer personnel and supply requirements.

To facilitate data collection, an information sheet was created and utilized during mine visits (see Appendix A). At least two visits to each mine were made, one for data collection and the second for network schedule verification. Existing company transfer documents were gathered and on-site interviews with key management personnel were conducted. At one site, underground visits to observe two separate moves were made. Both visits were made during the recovery portion of the moves, the first during equipment disassembly and the second during shield removal. This gave the researcher a feel for the transfers' comprehensive nature, hectic execution, and equipment and personnel utilization.

Upon completion of the data collection process, precedence networking techniques were utilized to generate transfer sequence diagrams and bar charts of each mine's general transfer procedure. A second visit was then made to each mine to verify the diagrams/charts, activity durations, and personnel/supply requirements. After processing the results of the second visit, sequence diagrams and bar charts were sent to each mine for future use.

Two types of transfer sequence diagrams were used: pure logic diagrams and bar charts. Pure logic diagrams are in the form of activity-on-the-node diagrams commonly used in CPM/PERT diagramming. Activities are represented by boxes or circles with relationships between particular activities shown with arrows. A bar or Gantt chart is a line graph that depicts activities by rectangles with lengths proportional to the duration of each activity. The horizontal placement of the activity depends on its position in time. Network scheduling analysis is contained in Chapter 4.

3.4 Operational Characteristics

A description of general characteristics is given for each mine in the study. Included are data on longwall panel layout, seam properties, production, and equipment (see Table 3.1). Transfer descriptions and comparisons follow this section.

Table 3.1. Mine Operational Characteristic Comparison

Parameter	*Mine A*	*Mine B*	*Mine C*
Location	Northern WV	Southwest VA	Southwest VA
Seam	Pittsburgh #8	Pocahontas #3	Pocahontas #3
Cut Height	66 inches	72 - 78 inches	70 inches
Gate Entries	4	4	4
Panel Width	600 feet	585 feet	730 feet
Panel Length	6000 - 7600 feet	4000 - 5000 feet	6900 feet
Overburden	500 feet average	1500 - 2400 feet	1800 feet average
Immediate Roof	Soapstone, 3 feet	Sandy shale	Sandy shale
Immediate Floor	Hard shale	Clayey shale	Sandy shale
Prod. Crew Size	8	5	9
Prod. Shifts/Day	2	3	3
Prod. Days/Week	5	5	5
R.O.M. Prod./Shift	4000 tons	3000 tons	3700 tons
Move Supervisor	Superintendent	LW Coordinator	LW Coordinator
Avg. Moves/Year	2	2	2
Shifts to Move	48	15	48
Worker-Hours to Move	Not Available	1500 (not including spares)	2380 total
Avg. # Workers on Recovery	12 (17 for wire mesh)	12	12
Shield Mover, Face	EIMCO scoop #585, battery	EIMCO scoop #592, diesel	Petitto "Mule"
Shields Move/Shift	17	16	16
Spare Equipment	1. All but shields 2. None	All but shields	Shearer, tail/head drives, AFC

Detailed accounts of the transfers under study were developed and distributed to the participating companies in a *Report of Case Studies* (see Appendix B).

3.4.1 Mine A

The mine is located in northern West Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted for steam power generation. The Pittsburgh No. 8 seam is being mined with a seam and cut height ranging from 60 to 70 inches and an average of 66 inches. The mine is a dedicated longwall operation with three to four active continuous mining development sections. Four development or gate entries are used on 200 foot average centers. The panel length ranges from 6000 to 7600 feet and width averages 600 feet.

Two production shifts and one maintenance shift are used on a five workday per week basis. The mine produces 4000 tons of run of mine (R.O.M.) coal per production shift with an average of 25% reject. The production crew consists of one supervisor, one shearer operator, three shield operators, two mechanics, and one electrician, for a total of eight workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, Eicotrak haulage system, approximate weight 50 tons;

Face Conveyor - Westfalia Lunen, 34 inch width, twin inboard chain;

Drives - Westfalia Lunen, 400 HP motor at head and tail, crossframe discharge system at head;

Stage Loader - Westfalia Lunen, 46 inch width;

Roof Support - 120 Westfalia Lunen shields, 2 leg, 580 ton yield pressure, approximate weight 18 tons each.

The mine utilizes an adjacent longwall panel system with an average overburden of 500 feet. Ground conditions are relatively good with approximately three feet of soapstone immediate roof and eight to ten feet of limestone main roof. The floor is predominately hard shale and competent.

3.4.2 Mine B

The mine is located in southwest Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted as metallurgical coal. The Pocahontas No. 3 seam is being mined with a seam and cut height ranging from 72 to 78 inches. The mine is a dedicated longwall operation with six active continuous mining development and two longwall sections. The two longwall sections do not operate at the same time due to power, haulage, and preparation plant capacity limitations. Four development or gate entries are used on 120 by 100 foot average centers. The panel length ranges from 4000 to 7000 feet and width averages 600 feet. Three production shifts per day are used on a five workday per week basis. The mine produces 8000 tons of run of mine (R.O.M.) coal per production day with an average of 40% reject. The production crew consists of one supervisor, one shearer operator, one shield operator, one mechanic, and one person in the gate area, for a total of five workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, Dynatrac haulage system, approximate weight 50 tons;

Face Conveyor - Halbach & Braun, 33.75 inch width, twin inboard chain;

Drives - Halbach & Braun, 350 HP motor at head and tail, crossframe discharge system at head;

Stage Loader - Halbach & Braun, 40.6 inch width;

Roof Support - 120 Meco International shields, 4 leg, 808 ton yield pressure, approximate weight 21 tons each.

The mine utilizes the adjacent longwall panel system with an overburden range of 1500 to 2400 feet. Ground conditions are relatively good with a sandy shale immediate roof and sandstone main roof. The floor is predominately clayey shale and competent, except when wet.

3.4.3 Mine C

The mine is located in southwest Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted for metallurgical coal. The Pocahontas No. 3 seam is being mined with a seam and cut height ranging from 65 to 70 inches. The mine is a dedicated longwall operation with four active continuous mining development sections. Four development or gate entries are used with a yield pillar design of 150-foot center stable pillars and 50-foot center yield pillars. The panel width and length average 730 and 6900 feet, respectively. Three production shifts and weekend maintenance are used on a five production workday per week basis. The mine produces 3700 tons of run of mine (R.O.M.) coal per production shift with an average of 32% reject. The production crew consists of one supervisor, two shearer operators, three shield operators, one mechanic, and two electricians, for a total of nine workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, 720 HP, Supertrac haulage system, approximate weight 50 tons;

Face Conveyor - American Longwall, 39-inch width, twin inboard chain;

Drives - American Longwall, 500 HP motor at head and tail, cross frame discharge system at head;

Stage Loader - American Longwall, 49 inch width;

Roof Support - 151 Hemscheidt shields, 2 leg, 750 ton yield pressure, approximate weight 16 tons each.

The mine utilizes the adjacent longwall panel system with overburden ranging from 1,050 to 2,700 feet. Ground conditions are relatively good with sandy shale immediate roof and sandstone main roof. The floor is predominately sandy shale and is problematic. Throughout the mine, five to six inches of floor are taken during the mining process to reach a more competent material.

3.5 Comparison of Longwall Transfer Procedures

The primary objective of any longwall transfer is to cease production in a mined-out panel and re-establish production in a new panel as quickly as possible while maintaining safety and controlling cost. The methods used by industry to accomplish this objective have many common elements and some distinct variations.

Similarities and differences in longwall transfer techniques are discussed for Mines A, B, and C.

3.5.1 Personnel Utilization

Personnel allocation on a per activity basis were collected from Mines B and C, with Mine B providing data on the recovery only. Mine A did not provide transfer personnel data due to the issue of confidentiality. Personnel requirements for the transfer activity sequence of each mine were determined and personnel utilization profiles were generated for Mine B (see Figure 3.2) and Mine C (see Figure 3.3).

The general shape of the two profiles are similar, although Mine B included data for the recovery only. For both profiles, the maximum number of workers are required in the first three or four shifts of the transfer. This is followed by a decline and leveling in the number of required workers. At the beginning of a transfer, several activities are occuring simultaneously in order to open the headgate area for equipment recovery and transport. This is the probable reason for similar peaks in the required worker profiles. In addition, the leveling profiles are a result of the serially executed recovery of face equipment, including the shearer, face conveyor, and shields.

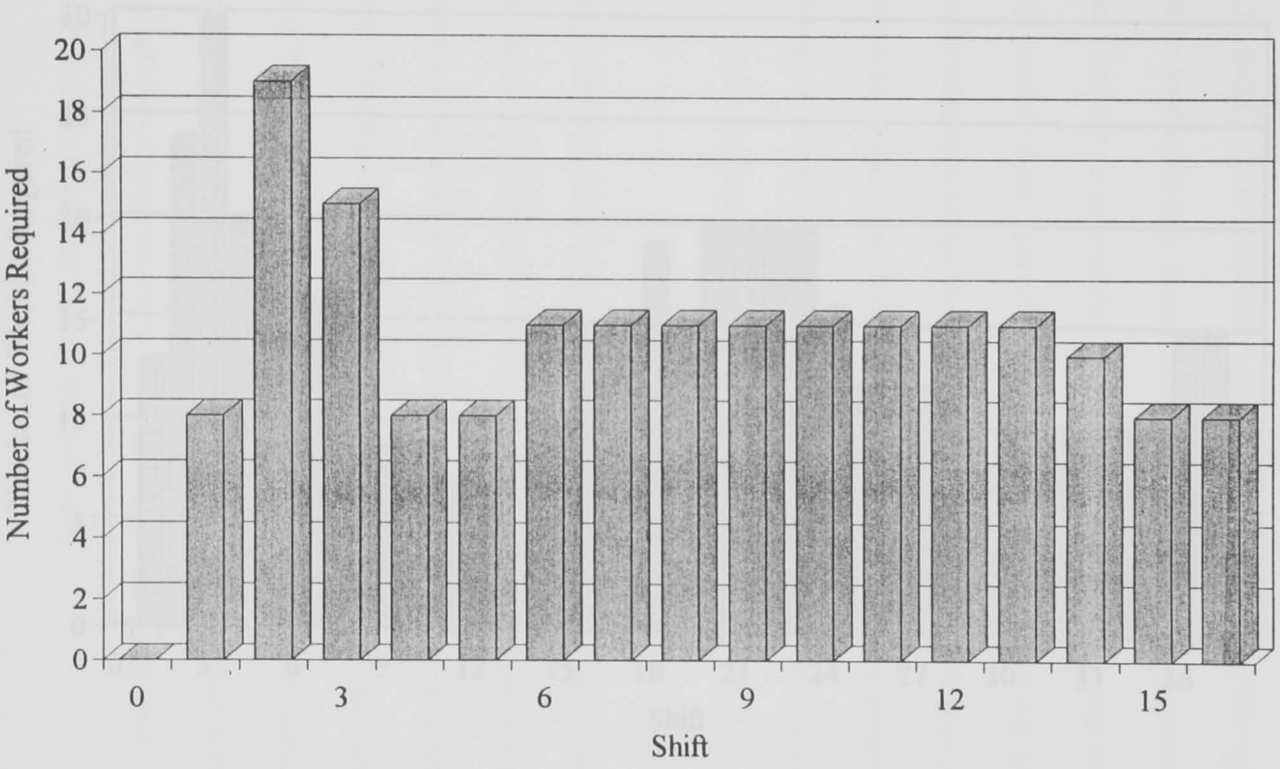


Figure 3.2 Mine B Personnel Utilization Profile

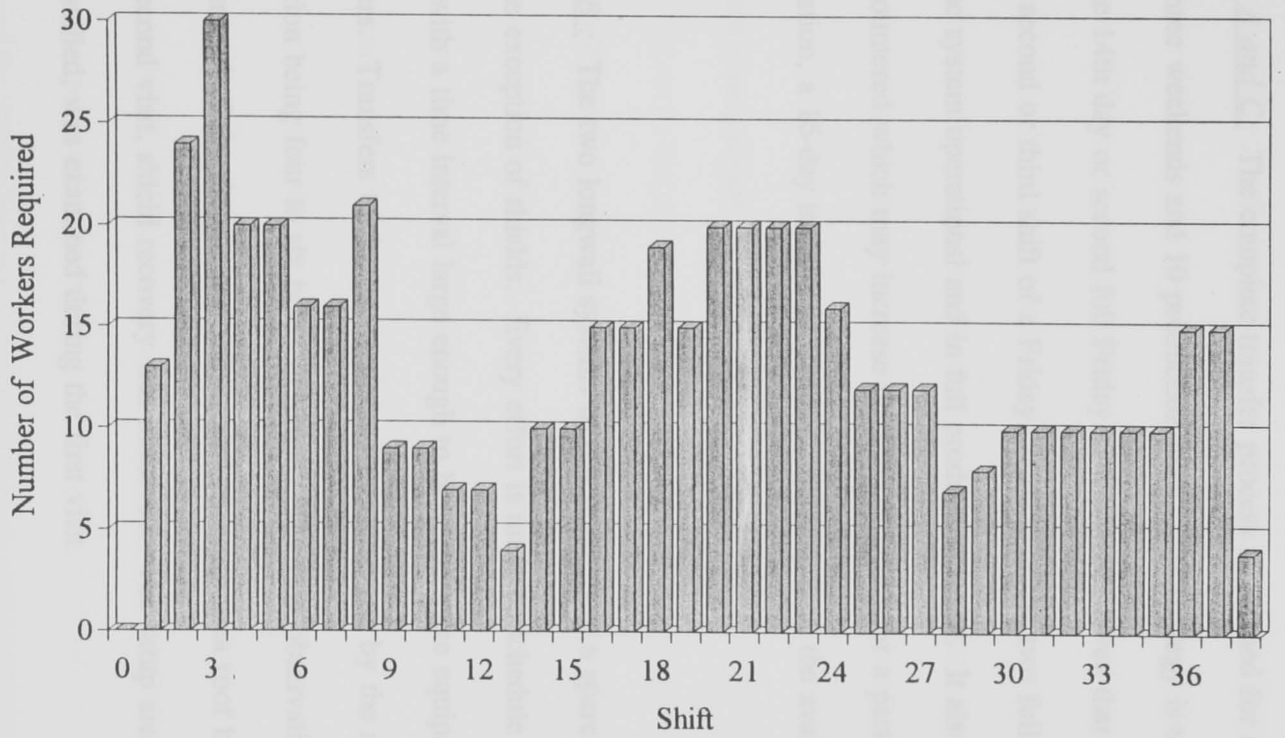


Figure 3.3 Mine C Personnel Utilization Profile

3.5.2 Transfer Duration Planning

Mines A and C: The complete transfer process is planned for approximately 16 days, or three weekends and 10 production days. The strategy is to finish the transfer by the 14th day or second full Friday of the move, given that transfer work began on the second or third shift of a Friday. This provides two full non-production days to get the system operational and in full production mode. It also allows for any problems encountered which may increase the time required for a particular move. For this operation, a 16-day transfer is standard, regardless of the availability of spare equipment.

Mine B : The two longwall systems in this mine share a spare set of equipment, with the exception of shields. Every effort is made to schedule transfers of the two systems with a time interval large enough to have the spare equipment available for all transfers. Transfers of the two systems were observed by the researcher, with each observation being four to six hours in length. The first observation occurred during the removal of the shearer and subsequent recovery area roof bolting. At the time of the second visit, shield recovery was observed. The setup area, with spare equipment installed, was examined during the first visit.

With the use of spare equipment, the complete transfer process is planned for approximately nine days, or two weekends and five production days. The strategy is to completely finish the transfer by the seventh day or first full Friday of the move. This provides two full non-production days to get the system operational and in full production mode. It also allows for any problems encountered which may increase the time required for a particular move. As indicated by management of Mine B, several longwall operations of their parent company complete nine-day transfers. It is apparent that this company has developed a very efficient transfer methodology.

3.5.3 Sequence Comparison

A longwall transfer can be generally divided into a series of major steps, which are common to all companies. These steps are as follows:

1. pre-move planning and training;
2. preparation of move supplies/tools/equipment;
3. setup area preparation and, if applicable, spare equipment installation;
4. face termination activities;
5. disassembly, transport, and reassembly of longwall equipment, and;
6. adjustments to full production.

A comparison of the similarities and differences in each major step of the transfer process for Mines A, B, and C is given.

Pre-Move Planning and Training

Detailed planning is paramount for economical, safe, and timely longwall face transfers. It is common for pre-move planning to actually begin when key personnel meet immediately after a particular move to recognize and discuss problems and make recommendations regarding the next move. Typically, these same personnel meet at least one month before an upcoming move to plan the transportation routes, major move events, equipment service requirements, and personnel allocation. Transportation routes must be checked for roof and floor conditions, entry size for equipment clearance, roadbed or grade conditions, and condition of the rail system. There must be sufficient track switching points between the recovery and setup areas so that a steady flow of components to the setup area is maintained. Each piece of face equipment must be checked for major service and this information recorded for planning and inventory purposes. All three mines in the research performed these tasks.

Every company has their own pre-move planning and training program. The extent of this program greatly depends on the requirements imparted by upper level management and worker move experience. The degree of complexity for a move-planning document is dependent on an individual company's perspective on the importance of written rules for the move execution. Most companies have developed some form of written planning documents for the execution of specific transfer activities.

Mine A utilizes the most comprehensive transfer procedure documentation of all mines in the research. Detailed recovery and installation manuals, developed by on-site management, was collected for the research (see excerpts in Appendix C-1). The manuals contain divisions of the recovery and installation process into major tasks, each of which with step-by-step instructions as to their execution. The recovery manual has 29 tasks with 164 individual steps and the installation has 33 tasks with 243 steps. A layout sketch or drawing exists for nearly every task.

Mine B uses a comprehensive transfer procedure document, including the only bar chart of all data collected. The recovery manual, developed by on-site management, and a time study of a previous transfer were collected for the research (see excerpts in Appendix C-2). The manual contains divisions of the recovery process into 29 major tasks, each with instructions, required materials, personnel, and shifts. Layout sketches for shield recovery are included in the manual. The installation process was divided into 27 major tasks by the longwall coordinator during an on-site interview.

Mine C utilizes a concise transfer manual assigning major tasks to longwall foremen. The manual, developed primarily for recovery by on-site management, was collected for the research (see excerpts in Appendix C-3). The manual contains divisions of the recovery process into approximately 45 activities, with a listing of each activity's planned execution shift. No layout sketches or drawings were available.

Mines B and C use stepwise procedural manuals which are relatively short (fifteen pages or less), with few drawings or sketches representing actual transfer plans. These mines depend greatly on the expertise of their personnel, especially management, to efficiently execute their transfers. The specificity of the planning document for Mine A was heavily influenced by the mine superintendent. Mine A is the only company in the research in which the mine superintendent is also the longwall coordinator. Mines B and C have both positions. A detailed planning document makes it easier for the superintendent to delegate authority and gives him more time to manage the total mine.

Mine B, the only company in the research to use a graphical planning diagram had developed a Gnatt chart for their particular move process. This chart provides a time sequence of activities and their estimated completion time, but no indication of activity relationships. None of the companies had performed or were planning to perform any type of critical path calculations on their transfers. Company management gave several reasons for this, primarily including: time constraints on the job (not enough time to do scheduling); lack of enthusiasm for the usefulness of scheduling; satisfactory transfer results without scheduling; and, lack of knowledge of computer software for scheduling.

Preparation of Move Supplies/Tools/Equipment

The type and amount of move supplies/tools varies based upon factors such as geologic conditions, length of equipment transport from the recovery to the setup area, and the degree of service/maintenance for the face equipment disassembly and reassembly. Detailed lists of these items were used by each mine being investigated. Transfer supervisors indicated that past move experience gave them an idea of the type and quantity of supplies and tools that must be provided for the next move. Additionally, these lists provide management an assessment of transfer items as well as a written order to inventory the required supplies and parts for the move.

All three companies used some type of specialized move equipment, including the following:

Mine A

(1) inby transport - Eimco 585 battery scoops, two in headgate, one in tailgate;

(2) outby transport - Westfalia Lunen lowboy rail car;

(3) walking shield advance - F-frame;

(4) recovery roof bolting - five stopers;

Mine B

(1) inby transport - Eimco 592 diesel scoops (two);

(2) outby transport - Tools Works Industry (TWI) lowboy rail car;

(3) walking shield advance - F-frame;

(4) recovery roof bolter - Fletcher Slimline (two) and Dynatrac bolters (two);

Mine C

(1) inby transport - Simmons Rand scoop (603 - recovery, 605 - setup),
Pettito mule in recovery;

(2) outby transport - Difco lowboy rail car, diesel locomotives;

(3) walking shield advance - F-frame;

(4) recovery roof bolting - Almenco stopers (four hydraulic, one pneumatic).

Equipment brands are dictated by factors such as geographic location of equipment suppliers and manufacturing facilities, economics, reliability, ruggedness, management and worker experience with certain brands, and company policy. The first three factors, especially economics, were recognized by mine management as the critical elements.

Many similarities can be observed in the type of transfer equipment used, especially in the first three categories. High-capacity scoops, or free-steered vehicles, are common for inby transportation because of their mobility and versatility. The Pettito mule is normally found in mines with poor floor conditions, as in Mine C, due to tractor mobilization. For mines located in the eastern U.S., outby transportation is primarily rail, with the lowboy rail car being the dominate transport vehicle for transfers. Since the three mines use recovery shields, or walkers, the F-frame is used as the device to connect and anchor the walkers. A further discussion of walking shields and other transfer equipment is given in later sections of this chapter.

A major difference in specialized equipment types is the use of stopers by Mines A and C and roof bolting machines by Mine B. The advantages of stopers include the ability to independently bolt in multiple locations within the recovery area, and relatively small size when compared to a bolting machine. Disadvantages include increased handling requirements for workers (stopers are very difficult to manuever) and ther requirement for additional power takeoffs (hydraulic and pneumatic) in the encumbered recovery area. Fewer roof bolting machines can access the face area, normally requiring more time for bolting. However, mechanized tramming and bolt installation is easier on the workers. In interviews with transfer coordinators, the choice of stopers or bolting machines for roof bolt installation was usually affected by the past experiences of the workers and company policy. The economics of stopers is less than bolting machines, but the increased handling requirements by workers often precludes this advantage.

Setup Area Preparation and Spare Equipment Installation

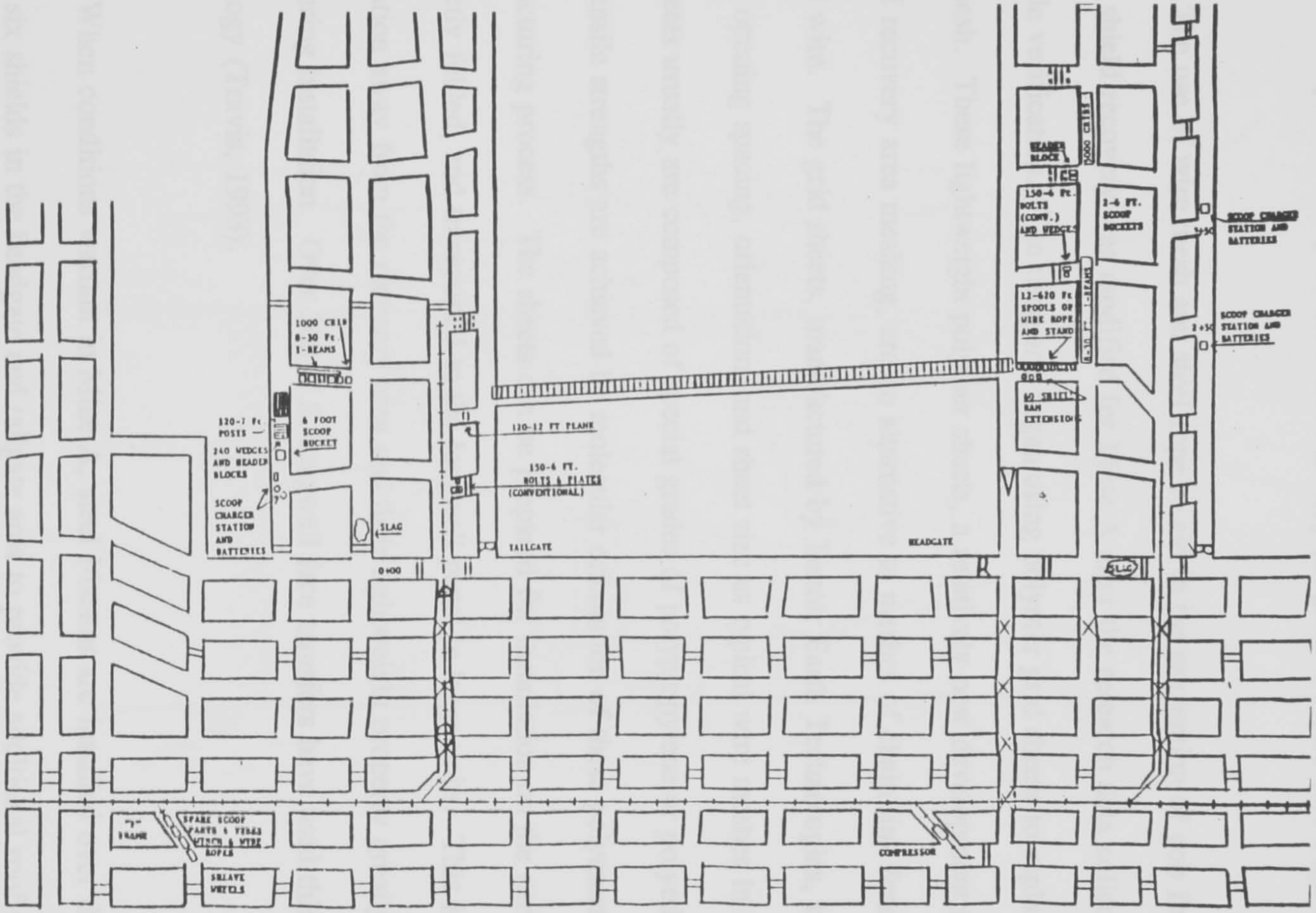
Setup area preparation involves converting the development entries into the new longwall panel. Three or four setup entries are driven parallel to the new longwall face and joined with crosscuts. For the mines being investigated, one entry is used for the setup area and the other entries as bleeders to provide ventilation for the gob, once mining begins. The setup entry, at least, 20 feet wide, dependent on the roof control plan, allowing sufficient room for equipment installation.

A rectangular cut, or stall, is made on the headgate side of the new face to provide an area to install the shearer. The dimensions of the stall are dependent on the size of the shearer with cutting drums installed. Initially, ventilation must be established for the setup area. Intake air is directed through the headgate entries, across the setup area, and returned through the tailgate entries. This process is complicated when adjacent panels are used, as is the case for the three mines in the research. With adjacent panels, the headgate entries on the old panel become tailgate entries for the new panel. To maintain bleeders, numerous, closely spaced cribs are erected in the bleeder area and tailgate entries. Roadbeds for rubber-tired vehicles and rail beds are checked in order to bring in the heavy equipment used on the longwall face.

Upon completion of panel ventilation and setup area preparation, spare equipment must be installed in the setup area. Mines A and B conduct transfers where all equipment except shields are spare. In Mine C, spare equipment availability fluctuates, since trading of one set of spare equipment occurs between several of the owner's operations. However, a relatively consistent group of spare equipment was available, including the shearer, parts of the face conveyor, and conveyor drives (headgate and tailgate). The transfer supervisors stressed the importance of completing setup area preparation and spare equipment installation prior to face termination of the old panel. In fact, each indicated a period of at least one week as optimal.

Face Termination Activities

Face termination involves the development of an area, or recovery room, large enough for the recovery of equipment, while maintaining safe ground conditions. Prior to the initial development of the recovery room, transfer supplies and equipment are strategically located around the face stop line in the headgate, tailgate, and main entries (see Figure 3.4). For Mine A, with a roof material which is relatively friable, this process starts eight to twelve cuts prior to the final stop point or line. At this

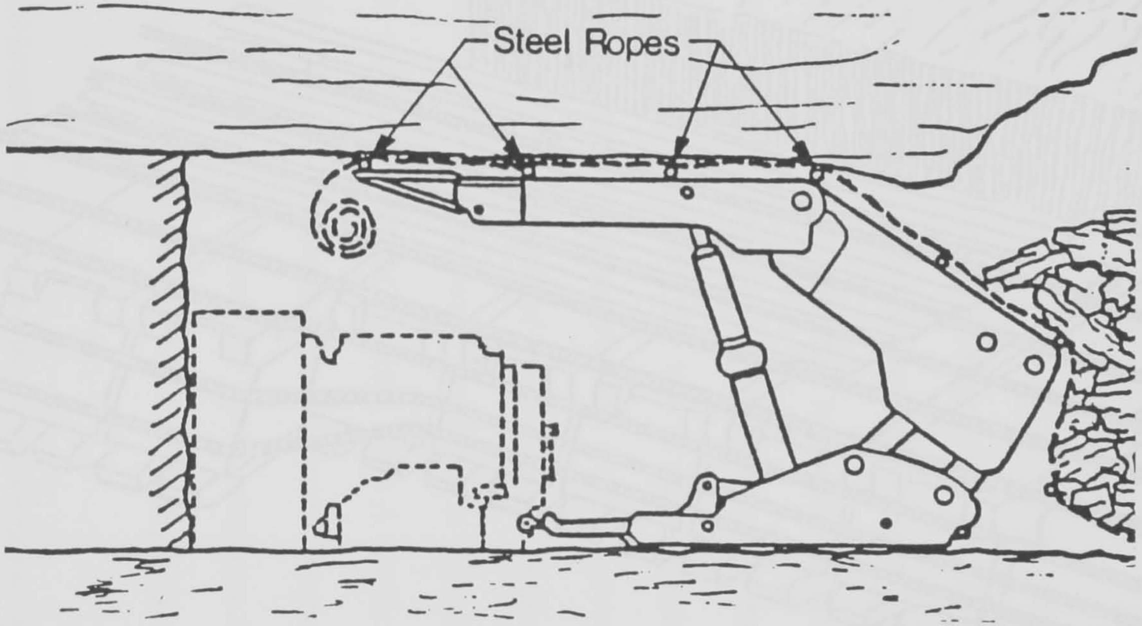


Source: Mine A Recovery Manual, 1991

Figure 3.4 Recovery Supplies and Equipment point, 0.5-in. steel ropes and wire mesh (or polymer grid sheets) are laid over shield canopies and pulled on top of the shields as they progress forward (see Figure 3.5).

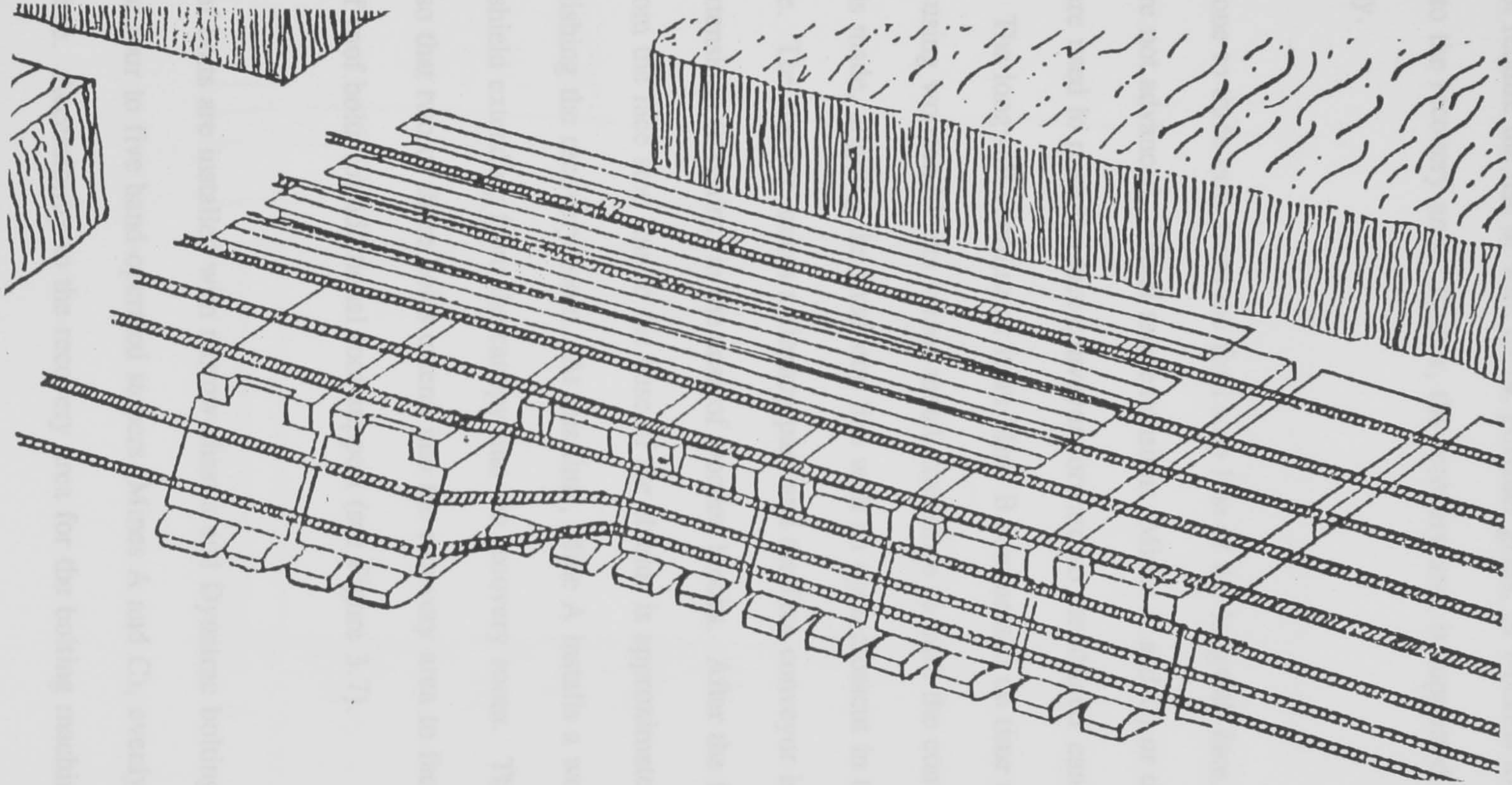
The use of wire mesh and steel rope to aid in the prevention of gob flushing during shield recovery was modified for Mine A after the research data collection and schedule verification. The company began using polymer grid sheets to replace the wire mesh. These lightweight polymer sheets, a relatively new development in the field of recovery area meshing, are an alternative to meshes of chain link fence or welded wire. The grid sheets, manufactured by Tensar Earth Technologies, have similar opening spacing, orientation, and sheet size as typical wire meshes in use. The sheets usually are composed of special grades of polypropylene or polyethylene. High tensile strengths are achieved by molecular orientation of these polymers in the manufacturing process. The sheets can be prepared for installation on the surface, compactly folded, and transported to the longwall panel in large units. This initial preparation away from the recovery area and their lightweight property greatly save time during installation. Over 200 U.S. longwall face transfers have used this technology (Travis, 1993).

When conditions warrant in Mine A, steel I-beams are installed over the first five or six shields in the headgate and tailgate area to provide additional roof support (see Figure 3.6). Management in Mines B and C has decided that their roof condi-



Source: Adam, et al., 1982

Figure 3.5 Overhanging Wire Mesh



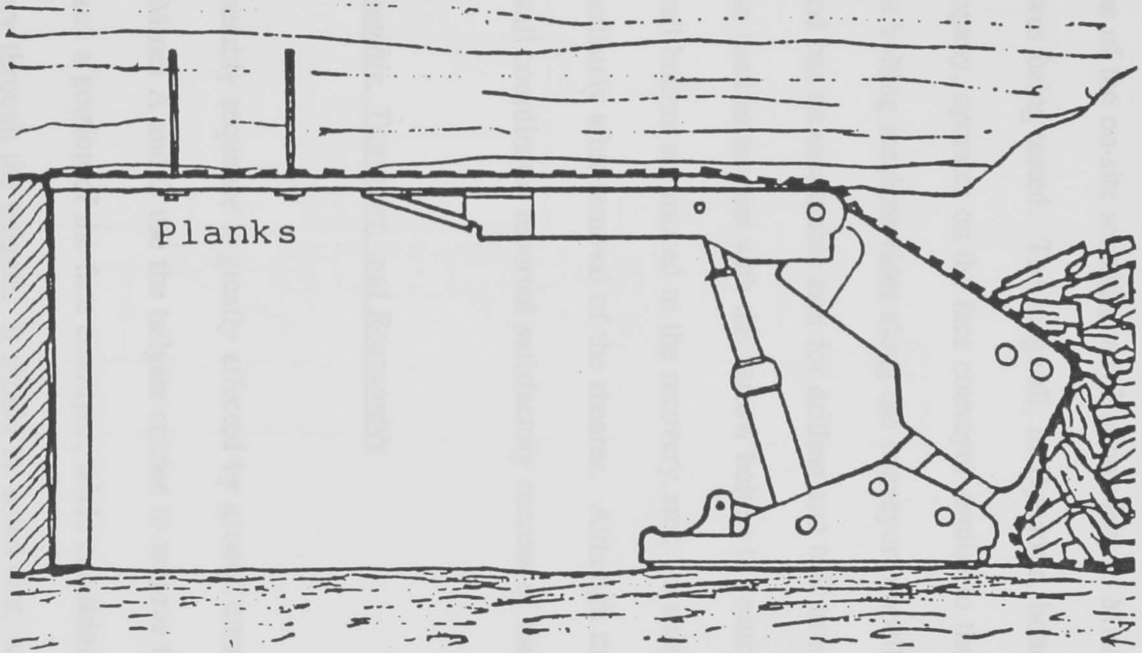
Source: Mine A Recovery Manual, 1991

Figure 3.6 I-Beam Installation

tions do not require the use of wire mesh, polymer grids, or I-beams to prevent gob flushing into the recovery area. Rather, the recovery area is supported with roof bolting only.

At one to three cuts from the final stop line of the longwall face, the shield supports are not advanced. Metal ram extensions (Mines A and C) or crib blocks (Mine B) are used to push the face conveyor forward so the shearer can make the final pass. The longwall coordinator from Mine B commented on time and cost savings of using wooden blocks versus metal extensions to push the conveyor. The final pass is made, aligning the final stop line with an open crosscut in the headgate and tailgate. The shearer makes a cleanup pass and the face conveyor is pulled back with the extensions or chains, in the case of wooden blocks. After the final cut, the distance from the face stop line to the base of the shields is approximately 10 to 11 feet, establishing the recovery room. At this time, Mine A installs a wooden plank over each shield extending from the canopy into the recovery room. These planks are predrilled so that two or three holes extend into the recovery area to facilitate the insertion of roof bolts for additional roof support (see Figure 3.7).

Roof bolts are installed with narrow-chassis and Dynatrac bolting machines (Mine B) or four to five hand-operated stopers (Mines A and C), evenly distributed along the face. Accessibility to the recovery area for the bolting machines is provided



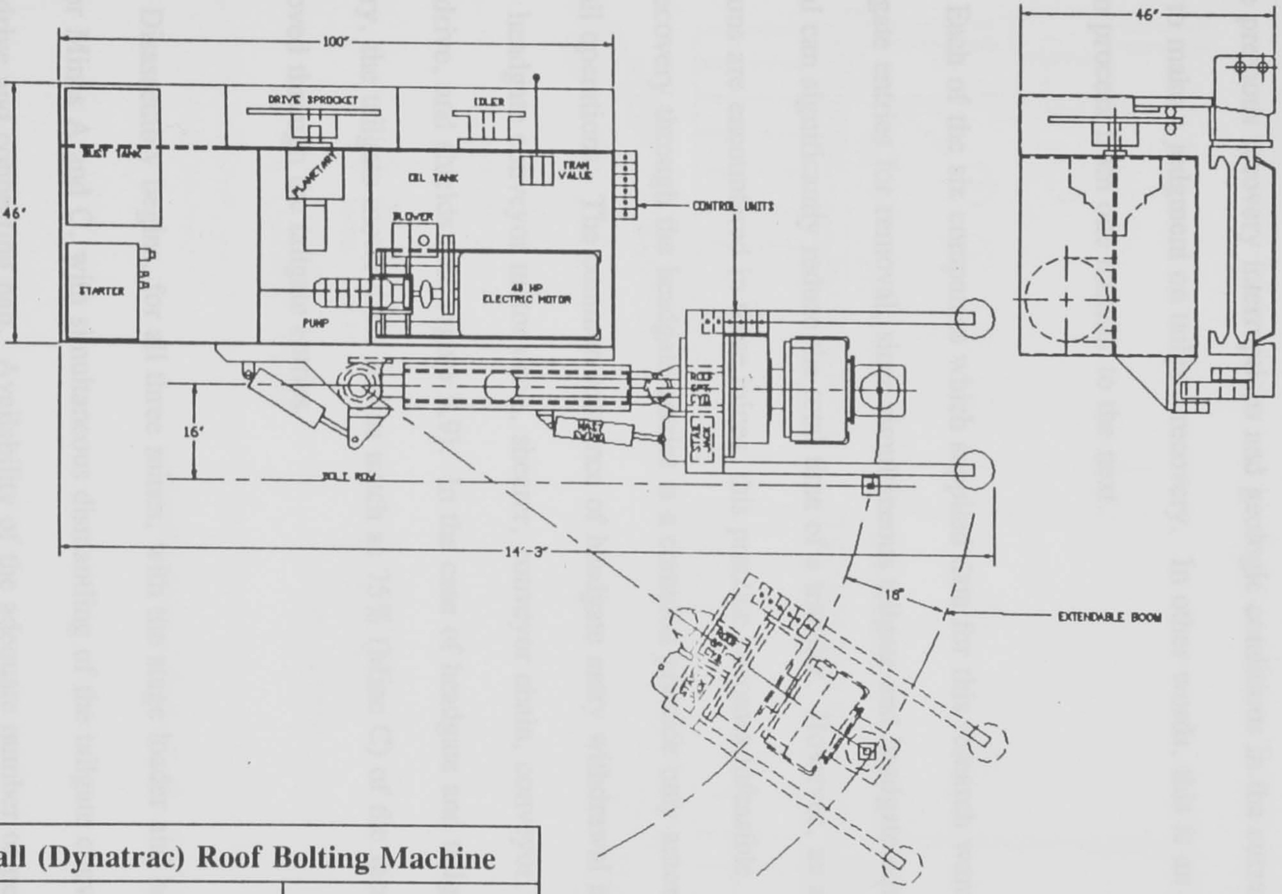
Source: Adam, et al., 1982

Figure 3.7 Additional Roof Support - Wooden Planks only after the removal of the conveyor head drive, connecting pan, and shearer. Accessibility for stopers is provided immediately after the final pass of the shearer.

At the time of the on-site schedule verification visits to Mine B, a new type of bolting machine was being tested. The longwall, or Dynatrac, bolter, made by J.H. Fletcher and Company, operates on the face conveyor similar to the shearer (see Figure 3.8). This bolting machine rides along the conveyor propelled through the Dynatrac chain and has an extendable arm for drilling and bolt insertion. Two of these machines are used in tandem with the narrow bolters to reduce the bolter cycle time. The longwall bolters are moved to the recovery area via shield transporters and are installed immediately after removal of the shearer. Although they are still in testing, the longwall coordinator reported satisfactory success of the new machines.

Equipment Disassembly, Transport, and Reassembly

The disassembly sequence is greatly affected by ground conditions in the tailgate entries. Mines A and C use the tailgate entries to remove the tailgate drive, connecting pan, and a portion of the face conveyor, while conditions in Mine B prohibited recovery through the tailgate. It should be noted that, while Mines A and C used the tailgate for partial equipment recovery, these mines had significantly longer transfer durations than Mine B, which did not use tailgate recovery.



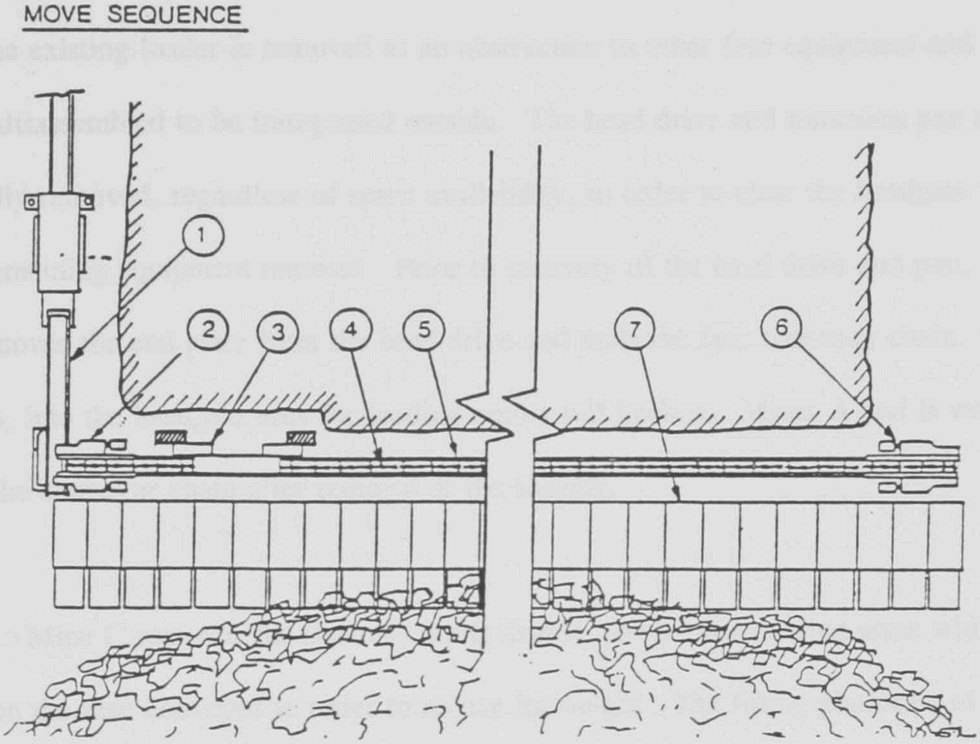
Longwall (Dynatrac) Roof Bolting Machine	
Drawn by Charles Patrick	September, 1993
Adapted from Fletcher, 1992	Not to Scale

Figure 3.8 Fletcher "Dynatrac" Roof Bolting Machine

The decision by management to utilize the tailgate for recovery is subjective, since ground conditions change from panel to panel. A company must closely observe previous recovery interruptions and geologic conditions in the current tailgate entries to make a judgment on tailgate recovery. In other words, this is an ongoing decision process from one transfer to the next.

Each of the six companies which supplied data for this research wanted to use the tailgate entries for removal, since simultaneous tailgate and headgate equipment removal can significantly reduce the total time of a transfer. However, as adverse conditions are encountered in these mines, this practice becomes infeasible. Equipment recovery through the headgate entries is a common practice only among U.S. longwall operations. The common sequence of headgate entry withdrawal is stage loader, headgate conveyor motor drive, shearer, conveyor chain, conveyor, tailgate motor drive, and shields (see Figure 3.9). In the case of headgate and tailgate recovery, the tailgate motor drive and as much as 75% (Mine C) of the face conveyor is removed through the tailgate entries.

Disassembly begins, for all three mines, with the stage loader and head drive and, for Mines A and C, with simultaneous dismantling of the tailgate conveyor motor drive and connecting pan. Availability of the adequate number of personnel is a key factor in the tailgate area work. Because the shields must come through the



1. Stage Loader
2. Head Drive
3. Shearer
4. Conveyor Chain
5. Conveyor
6. Tail Drive
7. Roof Shields

(Adapted from Adam, et al., 1982)

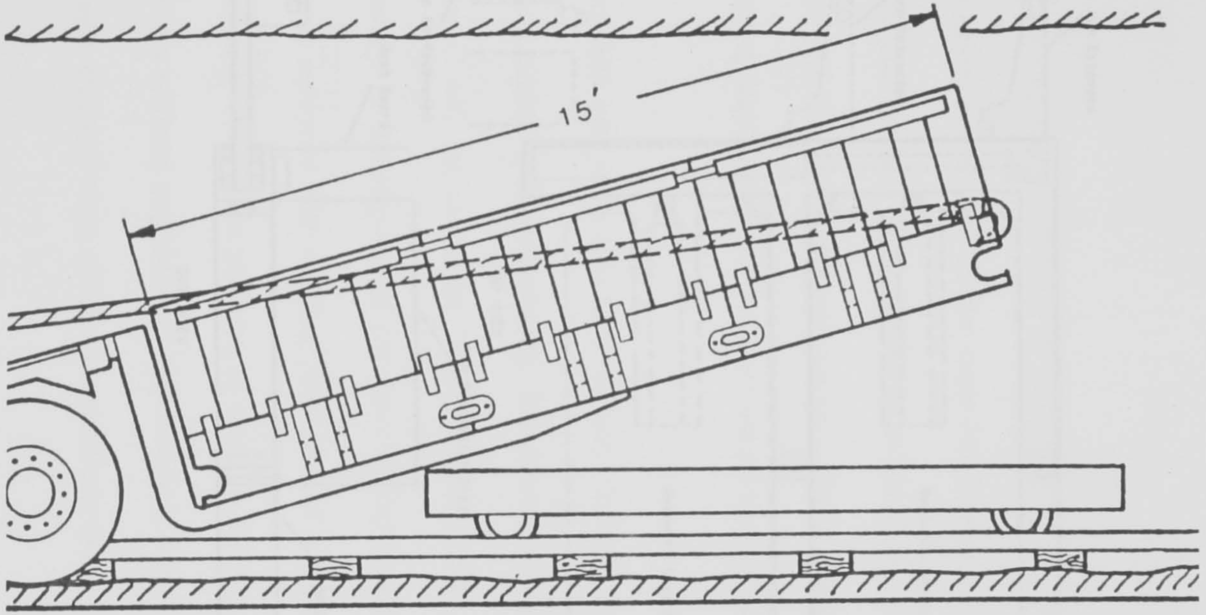
Figure 3.9 Equipment Withdrawal Sequence headgate area, equipment clearing in the headgate takes priority over tailgate work, if enough personnel are not available. In the case of a spare stage loader (Mines A and C), the existing loader is removed as an obstruction to other face equipment and later, fully disassembled to be transported outside. The head drive and transition pan must be fully removed, regardless of spare availability, in order to clear the headgate for the remaining equipment removal. Prior to recovery of the head drive and pan, Mine C removes the end plate from the head drive and pulls the face conveyor chain, via scoop, into the headgate area for loading onto a rail lowboy. Mines A and B wait to pull the conveyor chain after removal of the shearer.

Mine C removes the shearer cutting drums, cowls, and ranging arms while still on the face conveyor to order to reduce its weight. The lifting platforms of two scoops are then used to maneuver, lift, and transport the shearer to a rail lowboy in the #2 headgate entry. Mines A and B remove the shearer cutting drums and cowls while on the face conveyor. For Mines A and B, the ranging arms are not normally removed for transporting the shearer. As the shearer is being prepared, rails are installed flush with the face conveyor and a specialized rail lowboy car is attached to the conveyor's chainless haulage system. A chainless haulage section on the rail lowboy provides a track for the shearer to tram directly onto the transporter. The rail car is then pulled by locomotive or scoop to the track switch and taken off the section.

Upon removal of the shearer, Mines A and B pull the face conveyor chain, by scoop, into the headgate area and cut into equal length sections. The chain is then either boxed for removal from the section or stored in the headgate entries for later removal. Once the chain is clear, the face conveyor is removed in sections of two or three, dependent on clearance and company preference (see Figure 3.10). After removal of the face conveyor, all three mines use a scoop to clear the recovery area in preparation of shield removal.

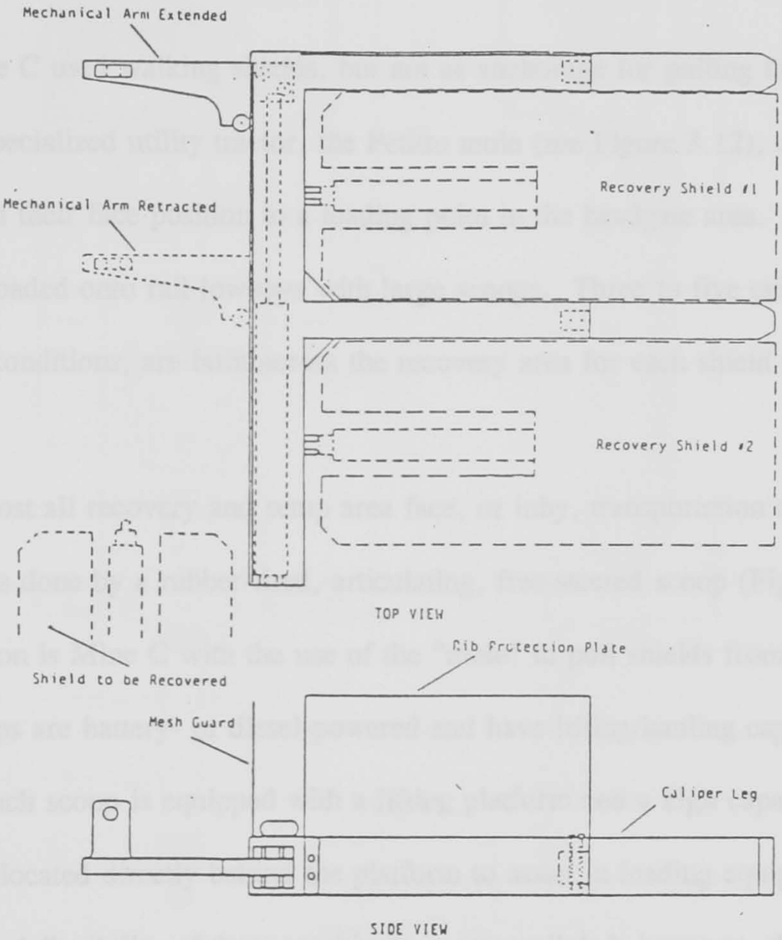
The recovery, transport, and installation of face shields are major components of a face transfer. This is especially true if spare equipment is utilized and/or poor ground conditions are encountered in the recovery area. Approximately 50% of the total move time was consumed by shield transfer for the mines evaluated in this research. According to key transfer personnel, this figure is average and can go much higher in bad roof and floor conditions.

All mines which provided data for this research pulled shields through the headgate entries. The tailgate shields are first to be recovered. Mine A and B used walking or recovery shields, where two shields are turned to move parallel to the face stop line. An anchorage beam or F-frame is attached to the walkers to provide a device to advance the walkers and an anchor to pull the face shields off line (see Figure 3.11). Large scoops are then used as carriers/pullers to transport shields off



Source: Adam, et al., 1982

Figure 3.10 Face Conveyor Section Removal



Source: Deems, 1990

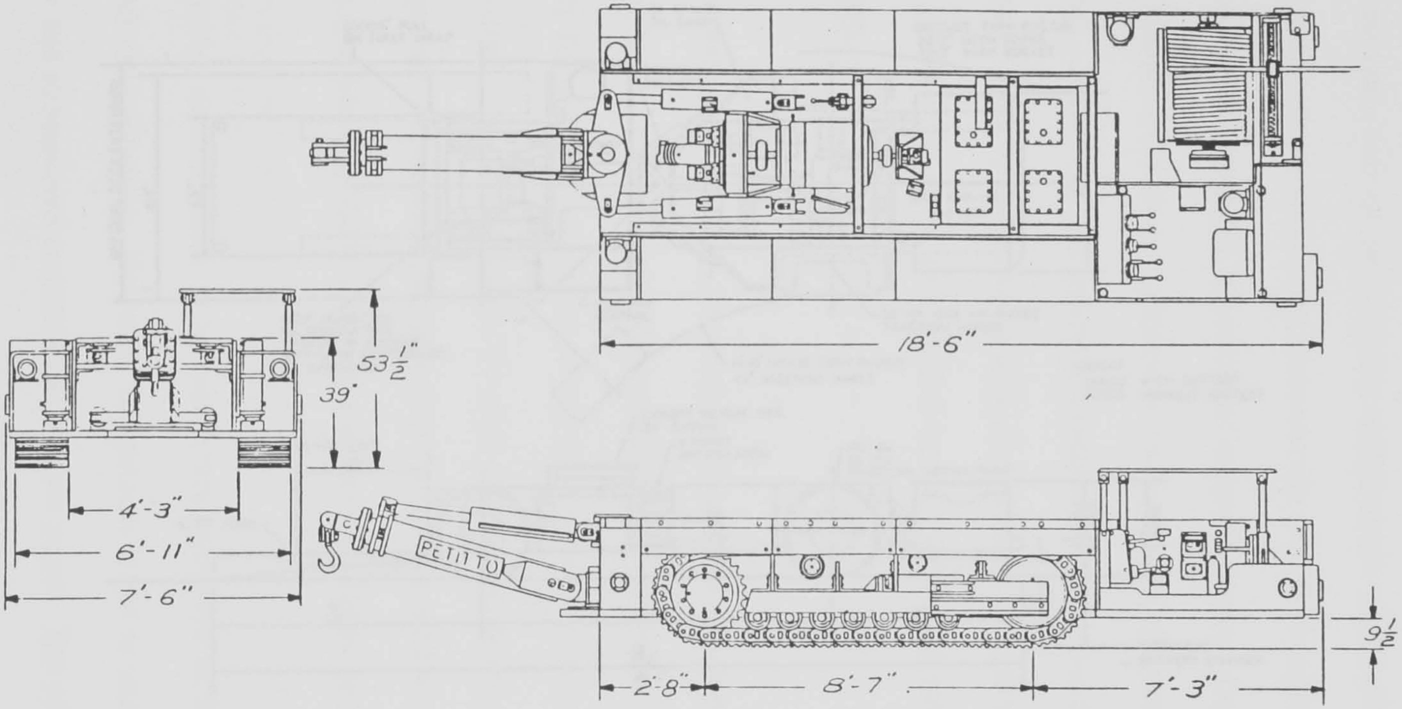
Figure 3.11 Anchorage Beam or F-Frame

the face to the #2 headgate entry at a rail transport point. Upon removal of a face shield, one to three crib blocks, based on ground conditions, are built in the empty space.

Mine C used walking shields, but not as anchorage for pulling face shields. Rather, a specialized utility tractor, the Petitto mule (see Figure 3.12), dragged the shields from their face position to a loading point in the headgate area. The shields were then loaded onto rail lowboys with large scoops. Three to five cribs, dependent on ground conditions, are built across the recovery area for each shield removed.

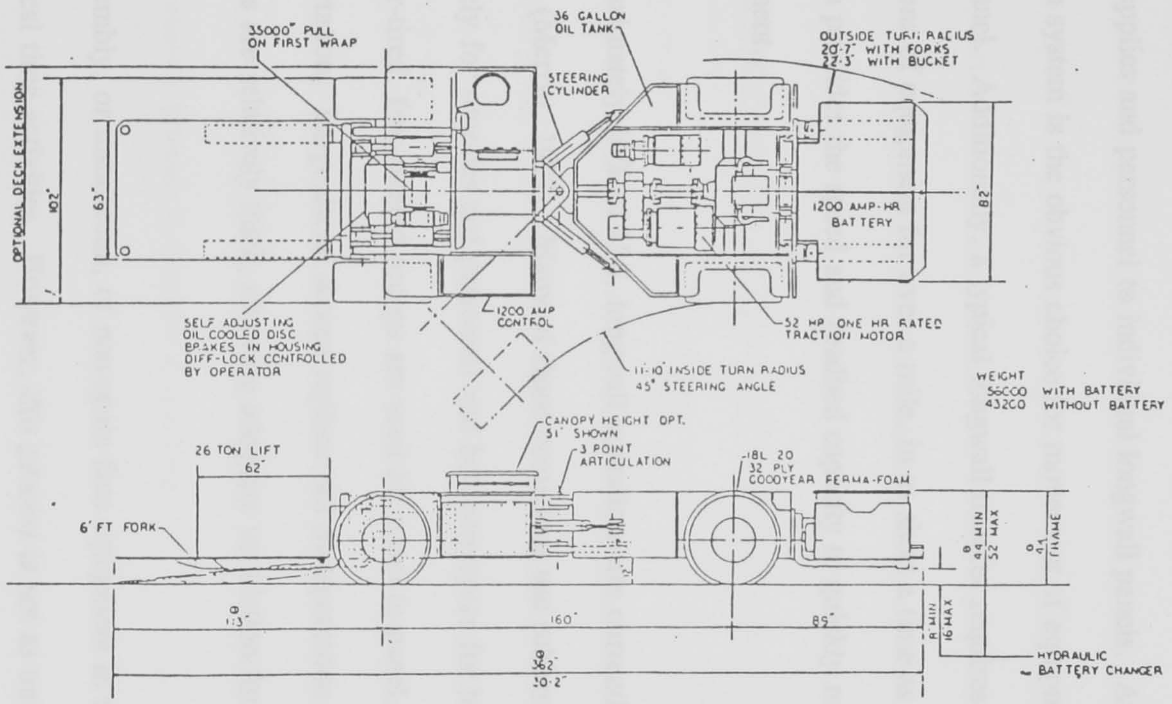
Almost all recovery and setup area face, or inby, transportation of longwall equipment is done by a rubber-tired, articulating, free-steered scoop (Figure 3.13). The exception is Mine C with the use of the "mule" to pull shields from the recovery area. Scoops are battery- or diesel-powered and have lifting/hauling capacities over 25 tons. Each scoop is equipped with a lifting platform and a high capacity, wire rope winch located directly behind the platform to assist in loading equipment. The versatility and flexibility of these machines are unparalleled; however, their performance can be adversely affected when soft floor conditions exist.

Panel to panel, or outby, transportation is dominated by rail, as with the mines in this research. Mines utilizing longwall systems cover a large area due to the



Source: Petitto Mine Equipment, 1991

Figure 3.12 Petitto Mule



Source: EIMCO Mining Machinery, 1991

Figure 3.13 Scoop/Shield Carrier

multiple panel layout for the longwall's economic justification. A longwall mine with a 15-year life can span over ten square miles underground. Generally, in this situation, rail transportation is the most economically justifiable system for providing production supplies and personnel to individual longwall panels. An in-place rail transportation system is the obvious choice for movement of equipment from the old to the new panel. Additionally, a typical longwall transfer requires the transport of about 3000 tons of equipment for over a mile, in as short a time as possible. Rail transportation provides the speed and roadbed capacity to quickly mobilize this much heavy equipment.

Approximately 10% of U.S. longwall operations are currently west of the Illinois Basin (Merritt, 1992). Many of these operations use rubber-tired transportation exclusively for supplies and personnel and belt conveyors for haulage. In these mines, rubber-tired, free-steered scoops are used for panel to panel, or outby, equipment transportation. Large diesel scoops replace rail transportation primarily because western seams are relatively thick, allowing adequate ventilation for diesel equipment.

Reassembly, or installation, of non-spare face equipment in the setup area is a series of critical time activities. However, this process is not as unwieldy as equipment recovery due to improved conditions at the new panel. The setup area was made ready well in advance of equipment installation. A relatively level, clean floor and secure roof/face were prepared. The setup area is significantly wider than the recovery area; therefore, the installation is not as encumbered.

Each piece of equipment arriving from the recovery area is cleaned, maintenance performed, moved into position along the new face, and connected to adjacent equipment. If major service is not necessary for an individual piece of equipment, minor service may be performed after the equipment is moved into its face position.

Adjustments to Full Production

Mines A, B, and C performed similar tasks to prepare for full production. Hydraulic pressure and electrical wiring checks are conducted, once all equipment has been installed on the face and connected. The face conveyor chain is adjusted to the proper tension and all equipment turned on to check for operating condition. Several non-cutting passes of the shearer is made. After key personnel are reasonably sure the system is in good working order, the first mining pass of the shearer is attempted. Shield and conveyor advance is checked at this time.

3.6 Summary

Current longwall face transfer field data were collected from three mining operations in the eastern United States. General operational characteristics of each mine were described, including geologic conditions, mine layout, production capabilities and labor requirements, and equipment types. Face transfer personnel utilization was compared for two operations from which the data were available and the general plan of transfer duration was given for each mine. Finally, a description of transfer activities, sequences, and equipment was detailed. The procedures of the three mines were compared to determine the standard and variant methods utilized to execute a transfer. This investigation essentially provided a definition of the state-of-the-art of longwall face transfers.

IV. TRANSFER MODELING

4.1 Introduction

A longwall face-to-face transfer is labor intensive, expensive, transitory, and a necessary non-production process of the total longwall mining operation. Facilitation is greatly aided by proper planning. Transfer planning through computer modeling can provide valuable information on the criticality of and relationships among activities in the transfer process. Modeling is attempted to gain insight into the relationships among the various components of a system and to predict performance under some new conditions being considered.

The sequential nature of the transfer process can be closely represented with project scheduling techniques. The breakdown of longwall transfers into sequenced activities with specific time estimates is described in Chapter 3. With user-defined activities, predecessors (or successors), and activity time estimates, an ordered occurrence, critical path, and total duration can be determined. However, the use of project scheduling is made difficult due to the number and complexity of transfer activity interactions. To efficiently apply scheduling techniques to longwall transfers, computerization is needed. Further, deterministic estimates of activity durations do not accurately represent the time variations that actually occur during the execution of activities. In this chapter, transfer models, developed using project scheduling and simulation software, are compared and contrasted with data from actual transfers.

4.2 Model Development Methodology

A model is a representation of a real system, an abstraction of reality (Balci, 1992). Modeling a real system is an extensive process in which a problem is well defined, abstractly represented, and tested, so that the results of which will be useful to the decision makers who originally initiated the study. A simulation model is a mathematical-logical representation of a system which can be exercised in an experimental fashion on a digital computer (Pritsker, 1984). Simulation models are ideally suited for carrying out the network scheduling replication of longwall transfer processes.

The process of executing a successful simulation study involves detailed examination of the problem, study of purposes and objectives, and type of results desired. In order to effect a successful study, a thorough approach of developing models is required. The modeling process in this research requires a comprehensive, iterative method. While the majority of authors in this area dwell primarily on simulation languages, few devote space to simulation development. Of these, one which provides broad coverage of the complete development process is Balci's (1992) simulation life cycle (see Figure 4.1). Ten life cycle phases are represented by the oval symbols. The dashed arrows describe the processes which relate the phases to each other, while the solid arrows refer to credibility assessment stages.

The life cycle is not sequential as represented by the dashed arrows. Rather, the arrows show the direction of development throughout the life cycle. The life cycle is iterative in nature and reverse transitions are expected (Balci, 1992). This process was used to develop the longwall transfer models described in this chapter.

4.2.1 Problem Formulation

Problem formulation is the process by which an initially communicated problem is translated into a formulated problem sufficiently well defined to enable specific research action (Woolley and Pidd, 1981). This process is necessary to insure a valid outcome of the model. The accuracy of problem formulation greatly affects the acceptability and credibility of model results (Balci and Nance, 1985).

The complexity and cost of the longwall transfer process require extensive planning by the company executing a transfer. The companies interviewed for this

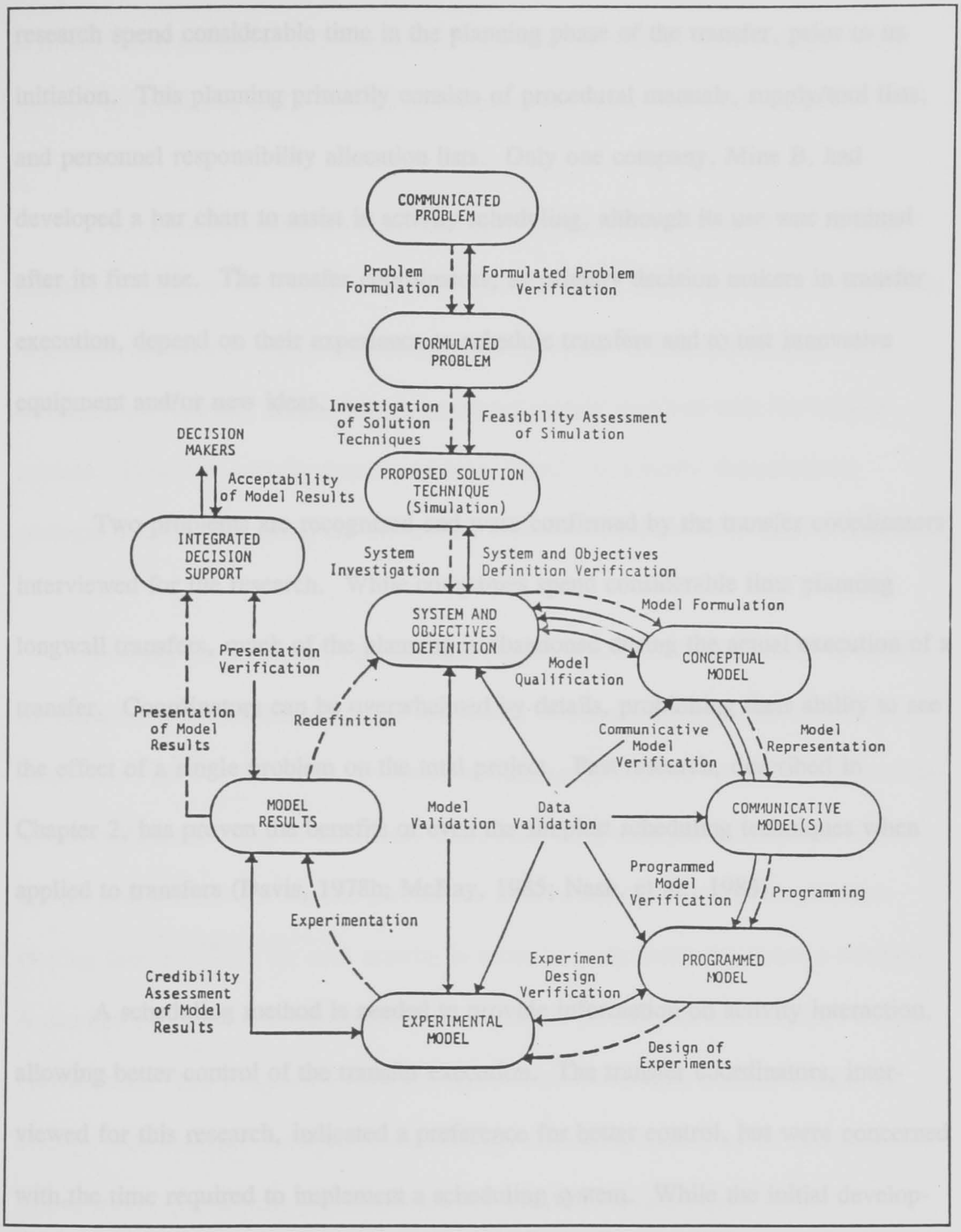


Figure 4.1 Simulation Life Cycle (Balci, 1991)

research spend considerable time in the planning phase of the transfer, prior to its initiation. This planning primarily consists of procedural manuals, supply/tool lists, and personnel responsibility allocation lists. Only one company, Mine B, had developed a bar chart to assist in activity scheduling, although its use was minimal after its first use. The transfer coordinators, as primary decision makers in transfer execution, depend on their experience to schedule transfers and to test innovative equipment and/or new ideas.

Two problems are recognized and were confirmed by the transfer coordinators interviewed for the research. While companies spend considerable time planning longwall transfers, much of the planning is abandoned during the actual execution of a transfer. Coordinators can be overwhelmed by details, prohibiting their ability to see the effect of a single problem on the total project. Past research, described in Chapter 2, has proven the benefits of even the simplest scheduling techniques when applied to transfers (Davis, 1978b; McKay, 1985; Nash, et al., 1983).

A scheduling method is needed to provide information on activity interaction, allowing better control of the transfer execution. The transfer coordinators, interviewed for this research, indicated a preference for better control, but were concerned with the time required to implement a scheduling system. While the initial development time of computer-based scheduling can be substantial, maintenance of the system is minor when compared to the benefits. The benefits include time savings, fewer number of problems, and increased information availability for coordinators.

The second problem involves the use of deterministic estimates for activity durations. Current scheduling software requires activity time estimates to analytically determine the critical path(s) and duration of a project. These deterministic time estimates are typically obtained from personnel closely involved with the transfer process. However, activity times vary from transfer to transfer dependent on geologic conditions, mining layout, worker experience, and other subjective factors.

For any particular activity, a single duration value is chosen when, in reality, the duration varies infinitely along a continuum within a minimum and maximum range (see Figure 4.2). Time estimates, as continuous random variables, are stochastic and difficult to apply to traditional scheduling computational techniques. The critical path method (CPM) and precedence networking (PN) require single, non-varying time estimates for each activity in order to analytically determine a solution. A detailed explanation of precedence networking is provided in section *4.2.4 Model Formulation*. The Program Evaluation and Review Technique (PERT) utilizes an average time estimate for a particular activity, calculated from a set of user-provided values which approximate a Beta probability distribution (see Figure 4.3).

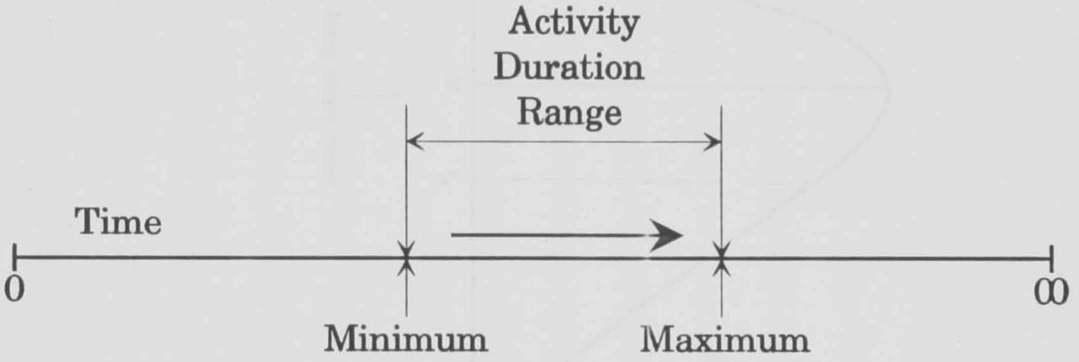
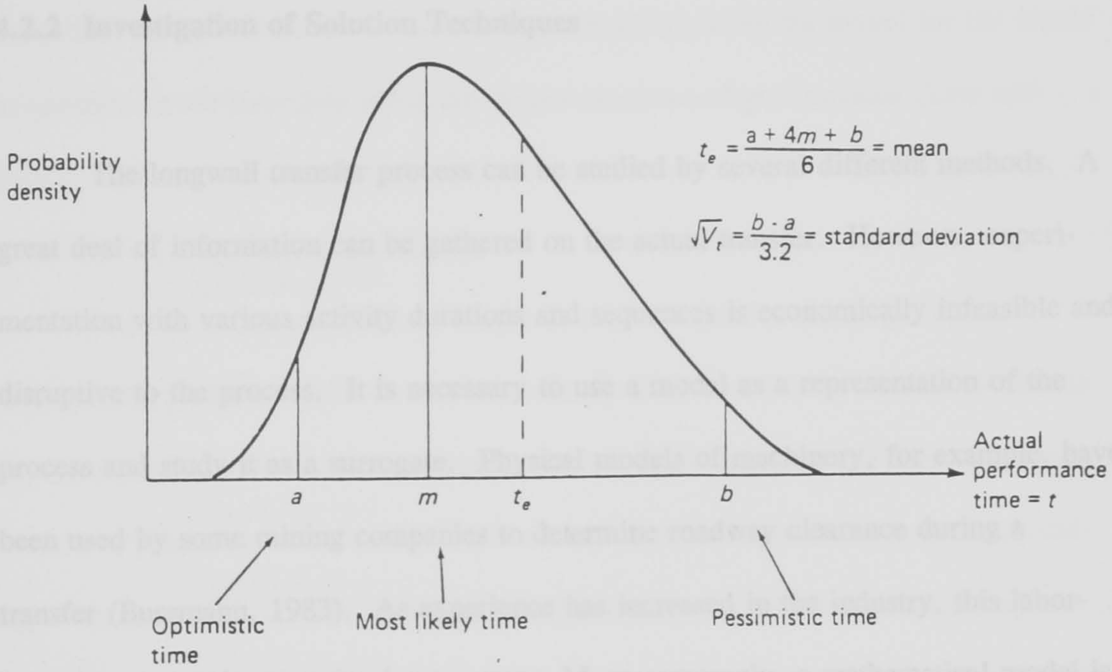


Figure 4.2 Time as Continuous Random Variable



Source: Moder, Phillips, Davis, 1983

Figure 4.3 PERT's Beta Distribution

CPM and PN scheduling techniques cannot address the varying nature of activity durations, and PERT is a quasi-statistical approach which allows only an approximation of one particular distribution. A transfer scheduling model is needed, which incorporates activity time variations into the PN scheduling method.

4.2.2 Investigation of Solution Techniques

The longwall transfer process can be studied by several different methods. A great deal of information can be gathered on the actual transfer. However, experimentation with various activity durations and sequences is economically infeasible and disruptive to the process. It is necessary to use a model as a representation of the process and study it as a surrogate. Physical models of machinery, for example, have been used by some mining companies to determine roadway clearance during a transfer (Bussmann, 1983). As experience has increased in the industry, this labor-intensive, expensive practice is very rare. More commonly, a mathematical model is developed to better represent the logical and quantitative relationships in a system or process. These relationships are manipulated and changed to see how the model reacts, and thus how the system would react, if the mathematical model is a valid representation of the system.

A mathematical model can be solved with either an analytical or numerical (simulation) approach. If the model is simple enough, it may be possible to obtain an exact, analytical solution. Simplicity of a mathematical model can be described in terms of rudimentary relationships among the deterministic entities of a system. As the complexity of a mathematical model increases, closed-form solutions become infeasible. Simulation must be used to numerically exercise the model for the inputs in question to see how they affect the output measures of performance (Law and Kelton, 1991).

Current techniques to study longwall transfers involve meetings of key management personnel prior to and immediately after a particular transfer to discuss expected problems or those encountered. Information gathering and control during a transfer is primarily based on memory and experience. Network or project scheduling is an analytical solution technique which provides the information necessary to effectively study longwall transfers. Further, the complex interaction and number of transfer activities are most efficiently analyzed by computer-based scheduling. Therefore, scheduling by computer software was chosen to analyze various longwall transfers for this research.

While the solution of a longwall transfer network schedule is based on specific mathematical equations, activity durations are estimates, at best. Moreover, stochastic activity durations combine with system complexity to create a highly complicated problem. This problem is too complex to allow realistic models to be evaluated analytically, but must be studied by simulation. Simulation is the process of designing and utilizing a model, which represents a real-world system, for the purpose of experimentation (Balci, 1992). Inputs from probability distributions are used for values of variables, such as activity durations, to determine a solution to the stated problem. Simulation of the longwall transfer is chosen for this research to provide a planning tool for existing transfer techniques and a predictor for any changes being considered.

4.2.3 System Investigation

A system is defined as any collection of interacting elements that operate to achieve some goal (Balci, 1992). This definition accurately represents a longwall face transfer, where interacting activities are executed to move equipment from a mined-out to a new panel. A longwall transfer is characterized as an interacting system of sequential tasks affected by management style and organizational structure, worker experience, geologic conditions, mining technique and layout, type of equipment to be moved, type of specialized move tools and equipment, and other factors. The transfer takes place in a dynamic environment, where the same location is never repeated, yet the sequence from one move to the next is very similar.

To properly develop models of longwall transfers, factors affecting a transfer were identified and those relevant to the formulated problem described. Factors were considered in terms of system parameters, input variables, and output variables. Parameters are constant values that affect the system's operation. Input variables are independent (exogenous) and are produced or result from causes external to the system. Output variables are dependent (endogenous) and are produced or result from causes internal to the system (Balci, 1992).

System parameters related to the formulated problem include the level of detail in which the transfer is divided or the number of activities identified, the various relationships among individual predecessor/successor activities, and the sequence of activities for particular transfers. Input variables are primarily related to activity durations, whether constant time estimates or time variations represented by probability distributions. Output variables are network scheduling values, including critical path(s), critical activities, and project duration.

The level of detail in which the transfer is divided defines the number of activities in the model. This and the resulting relationships among and sequence of activities were obtained through literature research, company procedural documents, and personnel interviews. Constant time estimates for each transfer activity in the model was obtained from the transfer coordinators, while probability distributions and accompanying parameters were estimated by the author. The system parameters and input and output variables were all confirmed by the transfer coordinators from each mine, with the exception of the data related to the probability distributions. A commitment on the reliability of the estimates made by the author could not be obtained from the coordinators.

4.2.4 Model Formulation

Two problems are described in the problem formulation: representation of the longwall transfer with a project scheduling model and incorporation of time variations for individual activities. The following sections describe formulation of models for the two problems.

Project Scheduling Model: The face transfer can be termed a *project* and the planned execution of a transfer, *project management*. Project management involves the coordination of a group activity wherein the manager plans and controls to achieve an objective with constraints on time, cost, and performance (Moder, et al., 1983). Planning commits resources in the most effective fashion. Controlling makes events conform to a specific schedule to attain the objective. Planning and controlling a longwall transfer is, at best, a difficult task. A method is needed to represent activities, their durations, and the relationships among activities. Network scheduling techniques, such as the critical path method (CPM), program evaluation and review technique (PERT), and precedence networking are ideal for managing complex projects with the following characteristics (Wiest and Levy, 1977).

1. The project consists of a well-defined collection of activities, which, when completed, marks the end of the project.
2. Within a given sequence, the activities may be started and stopped independently of each other.
3. The activities are ordered or must be performed in technological sequence.

A longwall face transfer is well described by these characteristics, providing justification for the use of network scheduling techniques for studying moves. The advantages of using these techniques are as follows (Moder, et al., 1983).

1. Planning - Network scheduling requires the establishment of project objectives and specifications, and then provides the realistic methodology for determining how to attain these objectives.
2. Communication - Network scheduling provides a clear, concise, and unambiguous method of documenting and communicating project plans.

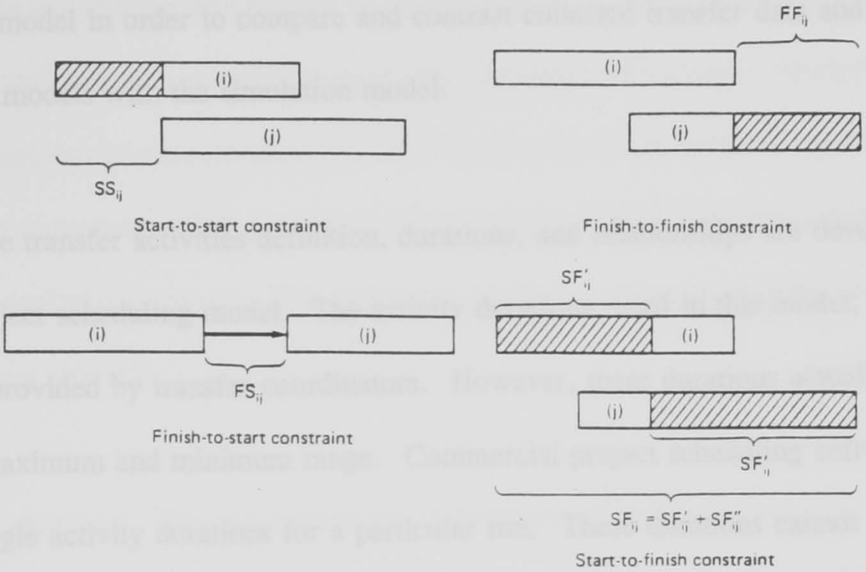
3. Psychological - Network scheduling provides project milestones to operating personnel and a clear delineation of responsibilities, encouraging a team feeling.
4. Control - Network scheduling facilitates the application of management by exception, concentrating management efforts on critical activities. It allows continual updating for defining new schedules as the project progresses.
5. Training - Network scheduling can be used to train new managers and other personnel on the overall execution of a project.

The most sophisticated type of scheduling technique available is precedence networking (PN). PN uses activity-on-node (AON) nomenclature to represent a project. The activity-on-node diagram represents activities by nodes (boxes or circles) and the predecessor/successor activity relationships between any two activities are shown by a connecting arrow. The arrow's point is at the successor node.

Precedence networking differs from CPM and PERT in that activity relationships can be represented in a more complex form than the basic finish-to-start relationship. A finish to start relationship, where one activity must finish before the start of its successor, is traditional for CPM and PERT. However, in complex projects, such as longwall transfers, more complex relationships exist and must be represented. PN was developed to enact additional types of relationships. Three of the most common PN constraints include: finish-to-finish (FF), start-to-start (SS), and start-to-finish (SF) (see Figure 4.4). Not only does PN permit these alternative relationships, but it allows for lead/lag quantities to be associated with any of them. Lead/lag quantities are minimum time periods that separate start and/or finish points specified in the relationship. Further explanation of the PN computational methodologies is given in the *Model Representation* section.

Precedence scheduling provides a realistic method for detailed project planning, including coordination at all levels of management and reduces the risk of overlooking tasks necessary to complete a project. The application of scheduling techniques to face transfer is most effectively done by computers due to the complexity of the problems. Several microcomputer-based, commercial software scheduling packages with precedence networking facilities are available. A package, available from Primavera Systems, was chosen for this research to perform modeling on transfer schedules. The capabilities of this software, especially in the areas of input ease of complex data and graphical output, is well suited for a comprehensive modeling study of longwall transfers.

Simulation Model: The scheduling model was formulated to realistically represent longwall transfers as a project with sequentially executed activities. Analysis by project management was chosen to provide a methodology of effectively



The nomenclature and assumptions to be used are as follows:

SS_{ij} denotes a start-to-start constraint, and is equal to the minimum number of time units that must be complete on the preceding activity (i) prior to the start of the successor (j).

FF_{ij} denotes a finish-to-finish constraint, and is equal to the minimum number of time units that must remain to be completed on the successor (j) after the completion of the predecessor (i).

FS_{ij} denotes a finish-to-start constraint, and is equal to the minimum number of time units that must transpire from the completion of the predecessor (i) prior to the start of the successor (j). (Note: This is the sole logic constraint used in PERT/CPM, with $FS_{ij} = 0$).

SF_{ij} denotes a start-to-finish constraint, and is equal to the minimum number of time units that must transpire from the start of the predecessor (i) to the completion of the successor (j).

Source: Moder, Phillips, Davis, 1983

Figure 4.4 Precedence Networking Relationships studying longwall transfers. This methodology is maintained for formulation of the simulation model in order to compare and contrast collected transfer data and project scheduling models with the simulation model.

Face transfer activities definition, durations, and relationships are developed for the project scheduling model. The activity durations, used in this model, are estimates provided by transfer coordinators. However, these durations actually vary within a maximum and minimum range. Commercial project scheduling software utilizes single activity durations for a particular run. These durations cannot vary, except by manual modification. Manually iterating through a time range for each of as many as 70 activities in a longwall transfer is infeasible due to time constraints. For this reason, an analysis technique is needed to provide two operations: (1) project scheduling capability, as in the first model; and (2) iterative variation of activity durations. This combination of operations is not available in commercial project scheduling software. Rather, a simulation or high-level programming language must be used.

The combination of a project scheduling analytical solution with stochastic activity duration inputs is well represented by Monte Carlo simulation. Monte Carlo simulation is defined as a scheme employing random numbers which is used for solving certain stochastic or deterministic problems where the passage of time plays no substantive role (Law and Kelton, 1991). A simulation which describes relationships that do not change with respect to time is said to be static versus dynamic. While longwall transfers occur over time, the calculations for project scheduling are analytical and can be considered static. Activity durations are obtained by randomly selecting from user-specified parameters of probability distributions and a single solution is analytically found. This process is iterated to generate realistic variations in the project schedule.

Assumptions: The two models are abstractions of reality for longwall transfers. During formulation of the models, assumptions regarding the bridge between reality and the models were made. It is necessary to explicitly state these assumptions, as follows.

1. Longwall face transfers can be well represented by project scheduling techniques using precedence networking.
2. The level of detail or number of activities in which the longwall transfer has been divided is acceptable for the study, both for the researcher and mine management.
3. The sequence of and relationships among activities are assumed to be constant. It was assumed that environmental factors (e.g. poor geologic conditions, high levels of water), deteriorating equipment, inexperienced personnel, varying

organizational structure, and other factors had no effect on activity sequences and relationships.

4. Transfer activities relate only to those activities which are exclusively specified in the project scheduling scheme.
5. External factors, such as a company's inability to prepare the transfer setup area in a new panel for occupancy, does not affect the sequence or timing of transfer activities.
6. Activity duration estimates by transfer coordinators are considered average for any activity and those estimates vary, to some degree, around that average.

4.2.5 Model Representation

The method used to represent and communicate the formulated models is greatly dependent on the background of the people to whom the models are being communicated. Written descriptions of the scheduling computations, common to both models, combined with flowcharts of the individual models, have been generated for this purpose.

Precedence networking is an analytical project scheduling method which is used in both of the developed models. The computational approach used for precedence networking is similar to CPM and PERT, with the exception of more complex activity relationships. A sequential forward and backward pass through the network is required to calculate the early start/finish and late start/finish times for each activity. From these values, slack/float time, the critical path(s), and project duration can be determined. The forward and backward pass are each a two-step procedure, which are applied to individual project activities, in topological sequence. Activities are indexed as activity i with successor activity j. A topological sequence is one where predecessor and successor activities, i and j, are arranged in ascending order. The following nomenclature is used for formulas and discussion of precedence network computations:

D_j = duration time for activity j

ES_j = earliest start time for activity j

EF_j = earliest finish time for activity j

LS_j = latest start time for activity j

LF_j = latest finish time for activity j

FS_{ij} = finish-to-start constraint

SS_{ij} = start-to-start constraint

FF_{ij} = finish-to-finish constraint

SF_{ij} = start-to-finish constraint

Forward pass

Step 1. Compute the early start time, ES_j, of the activity (j) in question.

$$ES_j = \underset{all\ i}{MAX} \begin{bmatrix} Initial\ Time,\ 0 \\ EF_i + FS_{ij} \\ ES_i + SS_{ij} \\ EF_i + FF_{ij} - D_j \\ ES_i + SF_{ij} - D_j \end{bmatrix} \qquad (4.1)$$

Step 2. Compute the early finish time, EF_j.

$$EF_j = ES_j + D_j \qquad (4.2)$$

Backward pass

Step 1. Compute the late finish time, LF_i of the activity (i) in question.

$$LF_i = \underset{all\ j}{MIN} \begin{bmatrix} Terminal\ Time \\ LS_j - FS_{ij} \\ LF_j - FF_{ij} \\ LS_j - SS_{ij} + D_j \\ LF_j - SF_{ij} + D_i \end{bmatrix} \qquad (4.3)$$

Step 2. Compute the late start time, LS_i.

$$LS_i = LF_i - D_i \qquad (4.4)$$

The initial time is the project start time, normally set at zero (0), and the terminal time is the project finish time, normally equal to the early finish time of the last activity in the topological sequence. Once the early and late times have been determined, utilizing the forward and backward procedures, the activity slack times and project duration can be determined, as follows:

$$Activity\ float = \begin{bmatrix} LF_j - EF_j \\ or \\ LS_j - ES_j \end{bmatrix} \tag{4.5}$$

$$Project\ duration = \begin{bmatrix} Terminal\ Time \\ or \\ EF_{last\ activity} = LF_{last\ activity} \end{bmatrix} \tag{4.6}$$

The critical path is determined, as in the CPM and PERT methods, by the activity sequence with the minimum float. In the case where the project duration is equal to the early or late finish of the last activity, the float along the critical path is equal to zero (0).

Project Scheduling Model: To efficiently manage and study longwall face transfers, computerized scheduling is needed. This provides the ability to: (1) maintain complex schedules with multiple activities and interrelationships; (2) easily modify existing schedules; and, (3) support high resolution output. Several project management software packages with these characteristics are commercially available and were reviewed for use in this research. Of these, "Finest Hour" by Primavera Systems, Inc. was chosen because of its vast capabilities. This software runs on a microcomputer with an 80286 or higher processor, hard disk with 8 MB of minimum space available, DOS 3.1 or higher, and an EGA or VGA color monitor. Finest Hour sells for $5,000 commercially, but was donated by Primavera for this research.

The project scheduling model, applied through the Finest Hour software, is represented by a flowchart (see Figure 4.5). Finest Hour requires a list of activities, their relationships to each other (predecessor/successor), and activity durations. This information can be input via text-based data entry screens or graphical node diagrams, similar to scheduling diagrams (see Figure 4.6). The schedule is processed and the results, in text or graphical form, can be viewed on screen, printed, or plotted. Subsequent modifications or adjustments in the input data can be made at this time. The program user interface is sophisticated due to the many options offered. These extensive capabilities is an advantage, but the time to learn and productively use the software is protracted.

Simulation Model: Monte Carlo simulation was chosen for this research to combine project scheduling analytical computations with stochastic activity durations. No commercial scheduling software has the stochastic activity duration feature. Further, simulation programming languages (e.g. GPSS/H, SLAM) do not easily allow variations in the project schedule. Therefore, a simulation program was developed in a structured programming language. The program follows the flowchart in Figure 4.7. As with Finest Hour, the simulation program requires a list of

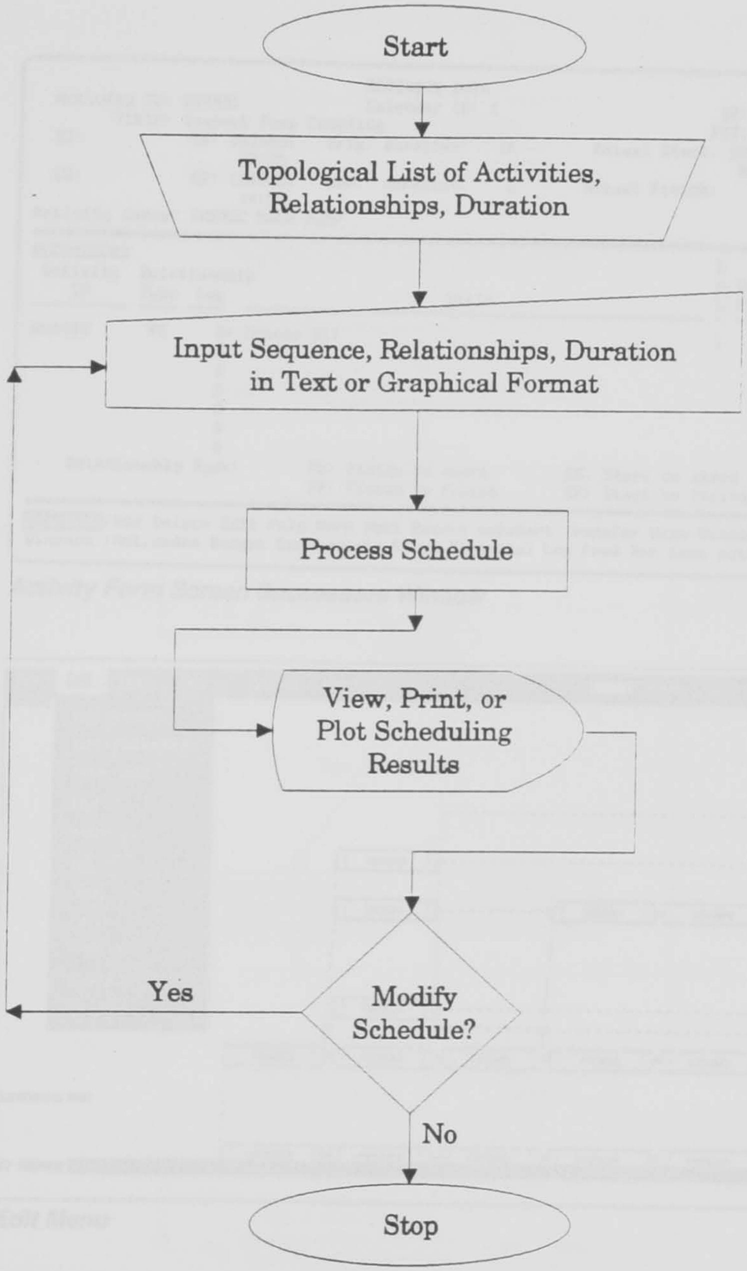
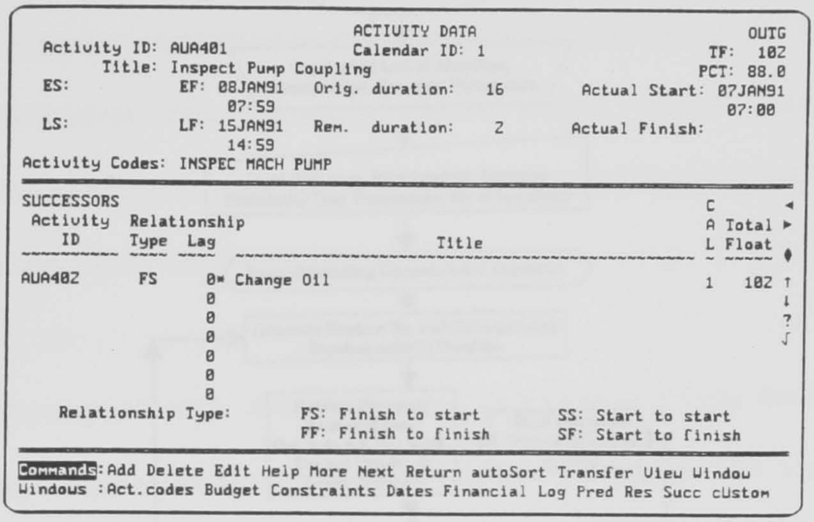
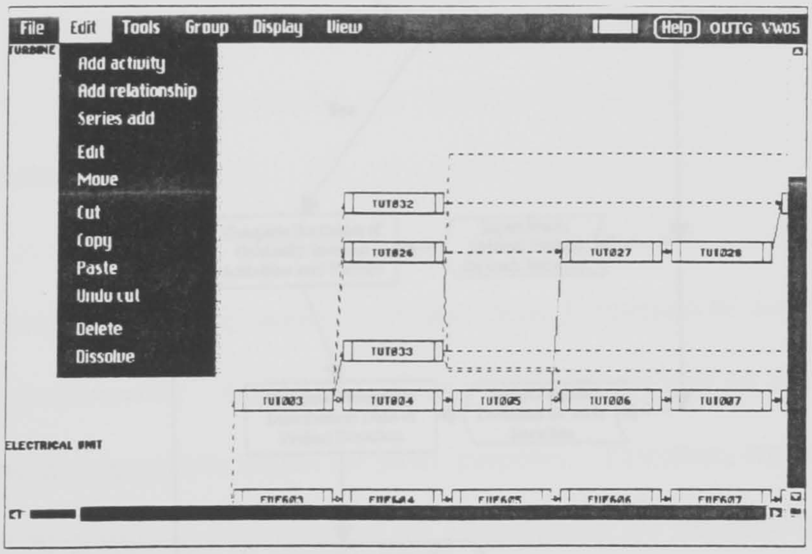


Figure 4.5 Project Scheduling Model Flowchart



```
                              ACTIVITY DATA                              OUTG
  Activity ID: AUA401         Calendar ID: 1                          TF:  102
       Title: Inspect Pump Coupling                                 PCT: 88.0
  ES:         EF: 08JAN91   Orig. duration:   16        Actual Start: 07JAN91
                  07:59                                                07:00
  LS:         LF: 15JAN91   Rem.  duration:    2       Actual Finish:
                  14:59
Activity Codes: INSPEC MACH PUMP
SUCCESSORS                                                          C        ◄
 Activity  Relationship                                             A Total  ►
    ID     Type  Lag                  Title                         L Float
~~~~~~~~~~ ~~~~  ~~~~ ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ~ ~~~~~  ♦
AUA402      FS      0* Change Oil                                   1   102  ↑
                    0                                                        ↓
                    0                                                        ?
                    0                                                        √
                    0
                    0
                    0
   Relationship Type:        FS: Finish to start        SS: Start to start
                             FF: Finish to finish       SF: Start to finish
Commands:Add Delete Edit Help More Next Return autoSort Transfer View Window
Windows :Act.codes Budget Constraints Dates Financial Log Pred Res Succ cUstom
```

Activity Form Screen Successors Window



Edit Menu

Source: Primavera Systems, 1993

Figure 4.6 Finest Hour's Data Input Screens

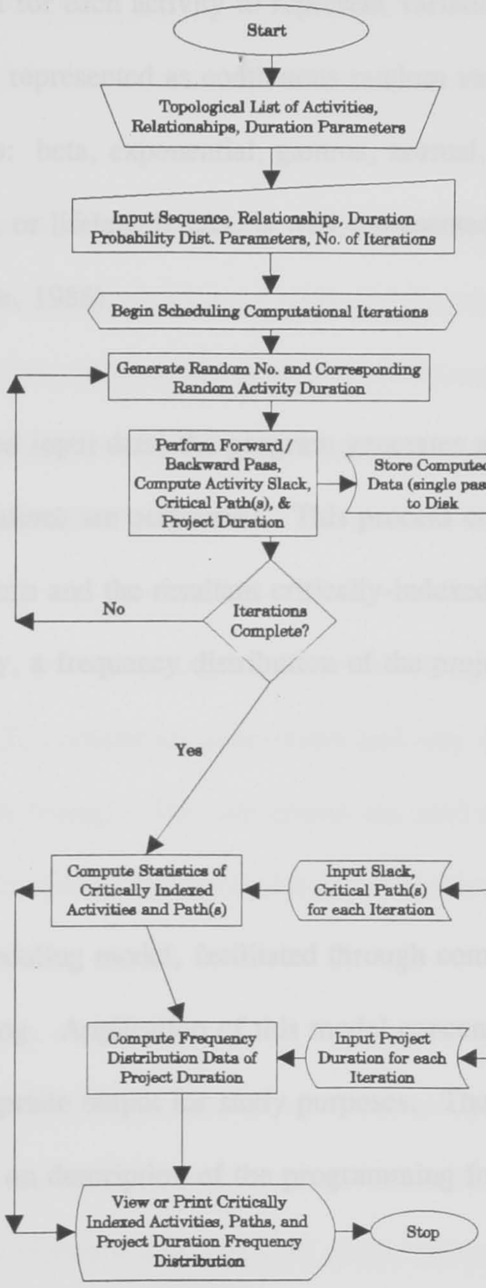


Figure 4.7 Simulation Program Flowchart

activities and relationships. Additionally, a probability distribution and related parameters are required for each activity to represent variations in activity durations. Durations, or time, are represented as continuous random variables in the following probability distributions: beta, exponential, gamma, normal, triangular, uniform, and weibull. Activity time, or lifelength data, is well represented by these distributions (Scheaffer and McClave, 1986).

With the required input data, the program generates an activity duration array and scheduling computations are performed. This process continues for a user-designated number of iterations and the resultant critically-indexed activities and paths are generated. Additionally, a frequency distribution of the project durations is produced.

4.2.6 Programming

The project scheduling model, facilitated through commercial software, required no programming. Application of this model concentrated on data input and generation of the appropriate output for study purposes. Therefore, the following discussion concentrates on description of the programming for the simulation model.

Language: A structured programming language (FORTRAN, C, BASIC, etc.) was needed for the development of the simulation model. BASIC, or more specifically, Microsoft QuickBasic (or QBasic), was chosen primarily because of its capabilities and the researcher's knowledge of the language. QBasic, Version 4.5, provides a structured programming environment for MS-DOS microcomputers.

QBasic is a programming environment which includes tools to write, edit, run, and debug programs. Instant feedback is provided by the compiler by checking the validity of each line of code entered. Sophisticated data handling, iterative functions, and mathematical operations are accessible through the language. QBasic is well-suited for the simulation programming task in this research project.

Main Programs: Two main programs were developed for the simulation. The first program, ACT.EXE, contains six subroutines and nine function definitions (see Appendix C for program listing). The subroutines are used to load, process, and output data, while the functions define probability distributions and a random number generator.

When executed, ACT.EXE reads the input file, generates a duration for each activity, according to the specified probability distribution parameters, performs the scheduling computations (forward and backward pass), and outputs the early start/finish and late start/finish times for each activity, critical path(s), and project duration. The program repeats these functions for the specified iterations, writing the outputs to disk after each pass. Written in this manner, practically any size project can be managed within the 640K memory limitation for the DOS operating environment.

The second program, STATS.EXE, reads the data generated by ACT.EXE, determines the critically indexed activities and paths, sorts the project durations into frequency ranges, and outputs this data to disk. This program contains three subroutines and one function definition (see Appendix C for program listing).

Program Execution - ACT.EXE: The program manages data input through an ASCII file, generated by any text editor which leaves no leading or trailing characters with the data string. Once the topological list of activities, activity relationships, and duration parameters have been gathered for the project to be simulated, this data is entered into the data file in the following format.

Section #1: Number of project activities, number of iterations.

Section #2: Topological list of activities, probability distributions and related parameters for each activity.

Section #3: Topological list of activities, their immediate successors, and relationship type.

The input file is read and data are assigned to variables by the subroutine LOADDATA. After initializing the main loop for the specified number of iterations, the subroutine CALCULATEDURATIONS generates a duration array for the project activities. The FORWARDPASS subroutine moves through each path within the project, computing the early start and finish for each activity. The backward pass is then performed by the REVERSEPASS subroutine, where the late start and finish times and the project duration are determined. These data are then written to a file on disk. The critical path is found, in the FINDCRITPATH subroutine, by moving along each path in the project checking for minimum activity slack. Once found, this is written to file and all critical activities are then written to file by the subroutine WRITECRITACTIVITIES. This process is then repeated for the specified number of iterations with all output data written to the same file to be processed by the STATS.EXE program.

Program Execution - STATS.EXE: The STATS.EXE program reads the ACT.EXE output data. Two subroutines, SORTCRITPATHS and SORTCRITACTS are called to determine the number of occurrences of each critical path and activity. Once found, indexed lists of critical paths and activities are written to an output file. The subroutine, SORTDURATIONS, is used to find the minimum and maximum project durations. This range is equally divided and the frequency of project duration occurrences in each division is determined and written to file. This is used to develop a frequency distribution of project durations for a particular simulation run.

4.2.7 Experimental Design

A primary goal of experimentation is to produce a thorough, yet concise replication of the communicated problem, enabling valid inferences from the model output. The experiment must be designed to accurately represent the relationship between the controllable variables and the models' response. Further, experimental design must be made to glean the most information from the data (Pritsker, 1984).

The experiment was designed to address the previously formulated problems: determination of transfer system behavior and incorporation of time variations in activity durations. The experimental process involved accurate recognition and estimation of the system's controllable variables, including activity identification, sequencing, relationships, and durations. Through literature and mining personnel interviews, the system parameters and input variables were obtained and verified.

System data were collected on a preliminary visit to each mine site. A project scheduling model was utilized to replicate and study the behavior of each transfer.

Project scheduling techniques have been used as the primary analysis tool of previous research studying longwall transfers (Davis, 1978b; Nash, et al., 1983; Peng and Chiang, 1984; Pimental, et al., 1982). In addition, the basic activity-sequencing characteristics of a transfer and interviews with mine personnel confirmed the project-oriented nature of longwall transfers. The models were verified by the transfer coordinators during a second visit to each mine site.

A project scheduling simulation was developed to incorporate time variations for activity durations. System parameters, including activity sequencing and relationships, were maintained as in the study of transfer behavior. The simulation represents activity durations through continuous probability distributions. Collection of estimates of probability distribution parameters for individual activities from transfer coordinators was prevented due to time limitations. The coordinators could not obligate the time required to review and make estimates for each activity in their model.

In the absence of activity duration data required for the simulation, a heuristic procedure must be used (Balci, 1992; Law and Kelton, 1991). With little or no data, a time estimate is assumed to be a continuous random variable, varying infinitely within a maximum and minimum range. Estimates of the activity durations by transfer coordinators are assumed to be averages which actually occur between practical maximum and minimum values. By identifying a maximum (pessimistic) and minimum (optimistic) time value, the random variable, activity duration, can be considered to have a triangular distribution.

The transfer coordinator time estimates were used as the average, or most likely, value for each activity and the pessimistic and optimistic values were estimated by the author. For nearly every activity, the interval between the pessimistic and average value was larger than the interval between the optimistic and average value. This skews the triangular distribution to the left and provides a realistic reflection of the true nature of activity durations. The most likely, or average, estimates assume that activities are being executed in an efficient manner, making it difficult to collapse these times significantly. Adversely, the likelihood of unanticipated problems can greatly increase the time for any particular activity.

Experimental Verification: Identical experimental conditions were maintained for both models. The project scheduling model, applied through reliable commercial software, uses an analytical procedure which provides accurate results for various input conditions. The analytical procedure in the simulation model was tested for accuracy using constant activity durations. When accessing the probability distributions for activity duration variations, identical experimental conditions were preserved for multiple runs of the simulation by using a verified pseudo-random number generator (Balci, 1992). The multiplicative congruential generator, used in the function routine of the ACT.EXE program and given in equation 4.7, produces an identical stream of random numbers when an integer seed (starting number) is provided by the user. This repetitive process assures that alterations in the input variables or system parameters, rather than changes in the random number stream, are affecting the results for multiple runs of the simulation.

$$Z_i = (7^5)\ Z_{i-1}\ (\mathrm{mod}\ 2^{31}-1) \tag{4.7}$$

Field data for this research, including transfer activity identification, sequences, relationships, and durations, were collected between the period of June 1991 to June 1992. Later field contacts with each mine transfer coordinator revealed that only minor modifications in the transfer process and accompanying schedule have been made or are being planned. While it is recognized that some of the collected data are over two years old, the reliability of the experimental results using those data, therefore, remains high.

Program Verification: Desk checking, model instrumentation, functional testing, and graph-based analysis were used to verify the accuracy and logic of the simulation program (Balci, 1992). Desk checking, a thorough review of each element of the program by hand, was used in combination with model instrumentation to check the logic of the main programs and subroutines. Model instrumentation is the insertion of additional code into the simulation program for the purpose of collecting information about the model behavior during execution. This verification process occurred primarily during the programming phase to assist in debugging the logic of the program.

Upon completion of the scheduling section of the program, model instrumentation and functional testing were conducted to determine the accuracy of the program's input-output behavior. A series of eight schedules, ranging from ten to 40 activities with various activity relationships, was first solved by hand and used as input for the simulation. The program's output was verified by a comparison to the hand-calculated solutions.

Desk checking was performed on the probability distribution and random number generator functions. Output data from each probability distribution were graphically analyzed and visually assessed to verify the reliability of the randomly generated activity durations. In addition, all distributions, with the exception of the triangular, were verified with a commercial software package called UNIFIT II. This microcomputer-based package consists of comprehensive set of data analysis tools which performs statistical tests to best fit data to one or more distributions. Data were generated from each function, analyzed, and the function verified with the UNIFIT software.

4.2.8 Experimentation and Results

These phases involve exercising the project scheduling and simulation models and interpreting the results. The experimentation process is conducted for two specific purposes. Both models are used to evaluate longwall transfer system behavior. The simulation model is further used for forecasting or predicting the reaction of the model, and hence the system, to alterations to the schedule. These alterations reflect the incorporation of new or innovative ideas and/or equipment into the transfer. Modeling transfer system behavior is discussed in this chapter, while Chapter 5, Time-Cost Tradeoff Analyses, deals with forecasting of system reactions.

Project Scheduling Model: Literature research, transfer documentation, and interviews with longwall personnel provided the data to develop the transfer activity sequences and relationships. For the identified activities, the transfer coordinators gave estimates of activity durations.

For Mine A, data for transfers, with and without spare equipment, were collected. Spare equipment was not always available for Mine A, due to the parent company sharing spares between two separately located operations. The transfer coordinator (the mine superintendent in this case) requested two schedules be developed for comparison purposes. For Mines B and C, data for transfers with spare equipment were collected due to relatively reliable sources of spares. In total, four schedules were developed.

Utilizing Finest Hour, schedules were developed with the given sequences and activity durations. Graphical descriptions of the schedules (bar charts and sequence diagrams) are shown for Mines A, B, and C in Appendices D-1, D-2, and D-3, respectively. The start time for all schedules was arbitrarily set at 4:00 p.m. on Friday, August 6, 1993. The second (4:00 p.m.) or third (midnight) shift is a common start time for U.S. transfers, since many companies utilize a five-day work week. Beginning the transfer on a non-production shift and working through the weekend reduces non-production time. This was the case for the three companies analyzed in the research. Since all transfers take place on a schedule of 24 hours per day, seven days per week, the start time is somewhat irrelevant. No breaks occur in a transfer, so total time can be estimated with any start time.

For Mine A, the finish times were computed to be 6:00 p.m., Saturday, August 14, 1993 and 5:00 p.m., Tuesday, August, 17, 1993 for the spare equipment and non-spare equipment transfers, respectively. The total elapsed modeled time for the spare equipment transfer was eight days, two hours (194 hours, or 24.25 shifts). For the transfer with no spare equipment, the total elapsed modeled time was eleven days, one hour (265 hours, or 33.125 shifts). As discussed in Chapter 3, the planned transfer duration for Mine A is sixteen days (384 hours, or 48 shifts). The models differed from the planned transfer time by 190 hours (-49.5%) for a spare equipment transfer and 119 hours (-31.0%) for no spare equipment (see Table 4.1).

In Mine B, transfers are planned for a nine-day duration and the modeled finish time was 6:00 a.m., Sunday, August 15, 1993. The total elapsed time for the modeled transfer was eight days, fourteen hours (206 hours, or 25.75 shifts). A ten-hour (-4.6%) difference exists between the modeled (206 hours) and planned nine-day (216 hours) schedule. Mine C's modeled finish time was computed to be 9:00 p.m., Wednesday, August 18, 1993. The total elapsed modeled time for the transfer was twelve days, five hours (293 hours, or 36.6 shifts). This differed from the planned transfer time of sixteen days (384 hours) by 91 hours (-23.7%).

The results of each model were reviewed and verified by the associated transfer coordinators from the three mines. Large discrepancies are noted between the planned and modeled times for Mines A and C. These differences are attributed to the sixteen day (384 hour) planned transfer durations by these mines. While sixteen days is allowed and expected by mine management, the modeled durations

Table 4.1 Planned Versus Modeled Transfer Durations

Mine	Transfer Time, Hours		Difference of Plan and Model	
	Planned	Modeled	Time, Hrs.	Percent
Mine A - Spare Equipment	384	194	190	44.5
Mine A - No Spare Equip.	384	265	119	31.0
Mine B	216	206	10	4.6
Mine C	384	293	91	23.7

were considered realistic by both transfer coordinators. As an explanation, both coordinators indicated that a more relaxed time frame was purposely planned toward the end of each transfer. This provides time for any unexpected problems which may be encountered during the transfer. The model reflects the possibility of Mines A and C executing significantly shorter transfer times. By attempting to execute a transfer with the estimated activity durations and sequence, the two mines may realize a substantial reduction in transfer duration. The overall monetary savings of reducing transfer time is dependent upon the individual mine; however, estimates of lost production potential for longwall mining systems range from $45 to $100 per minute (Hedges, 1984; Tucker, 1985).

Of the three mines, Mine B's transfer process is the most accurately represented by the project scheduling model. The ten-hour (4.6%) difference between the planned and modeled transfer duration for Mine B is relatively small, almost negligible. The transfer for Mine B is executed on an "as-soon-as-possible" schedule. The estimated activity durations and sequence are strictly adhered to, as in the development and execution of the project scheduling model. It can be concluded that the activity duration estimates and sequences provided by the transfer coordinator are accurate, resulting in a good representation of the transfer process by the model. Thus, any changes to the model could provide valuable information as to how the longwall transfer system may behave.

Simulation Model: Input data from the project scheduling models were modified for input into the simulation models. As previously noted, probability distribution parameters were not available for the simulation. These data were obtained by a heuristic procedure used to estimate triangular distribution parameters in the absence of data (see section *4.2.7 Experimental Design*). The estimated activity durations, used in the project scheduling models, were designated as the most likely values. Optimistic and pessimistic times were estimated for each activity by the author and used as the lower and upper limits, respectively, of the triangular distributions.

With the activity duration data and relationships defined, simulation models were developed for each transfer. The output file, ACTIVITY.DAT, from the ACT.EXE program contains data on each activity for each iteration. This file is manipulated by the STATS.EXE program to produce the model results. The size of the output file increases as the number of activities and iterations increase. The largest model contained over 60 activities with as many as five relationships from one activity to another. The output file for this model, at 1000 iterations, is approximately seven megabytes, written to the microcomputer's hard disk. The size of this file limits the total number of iterations which can be executed by the simulation model.

For each transfer, the simulation model was iterated 100, 500, and 1000 times to examine differences in the results. No significant changes occurred, especially between the output of 500 and 1000 iterations. Therefore, the output of each model is a result of the simulation going through 1000 iterations. This output contains critically indexed paths and activities, the transfer duration for each iteration, and histogram data. A sample of this output is shown in Appendix C with the simulation program listing.

Statistics were computed, from the output files, for each set of transfer duration data. Confidence intervals (95%) were established for the duration data by taking the lower and upper 25th (2.5%) tail values of the sorted durations. The median values were also obtained from these sorts and the average duration was calculated for each transfer. These data are contained in Table 4.2. Frequency distributions were generated for Mine A with and without spare equipment, Mine B, and Mine C as shown in Figures 4.8, 4.9, 4.10, and 4.11, respectively.

In Table 4.2, the median and average values for individual models are approximately equal. Further, these values are only slightly higher than the transfer durations from the project scheduling models, with a minimum difference of 0.58 hours and maximum of 12.7 hours. These differences can be attributed to the estimated duration parameters, which are skewed further toward the pessimistic time.

Table 4.2 Transfer Simulation Model Results

Confidence Interval	Project Duration, Hours			
	Mine A		Mine B	Mine C
	No Spare Equipment	Spare Equipment		
Lower 2.5%	253.62	192.29	196.02	272.95
Median	271.44	206.71	208.17	292.42
Upper 2.5%	289.66	222.08	228.69	312.82
Average	271.83	206.59	209.34	292.54

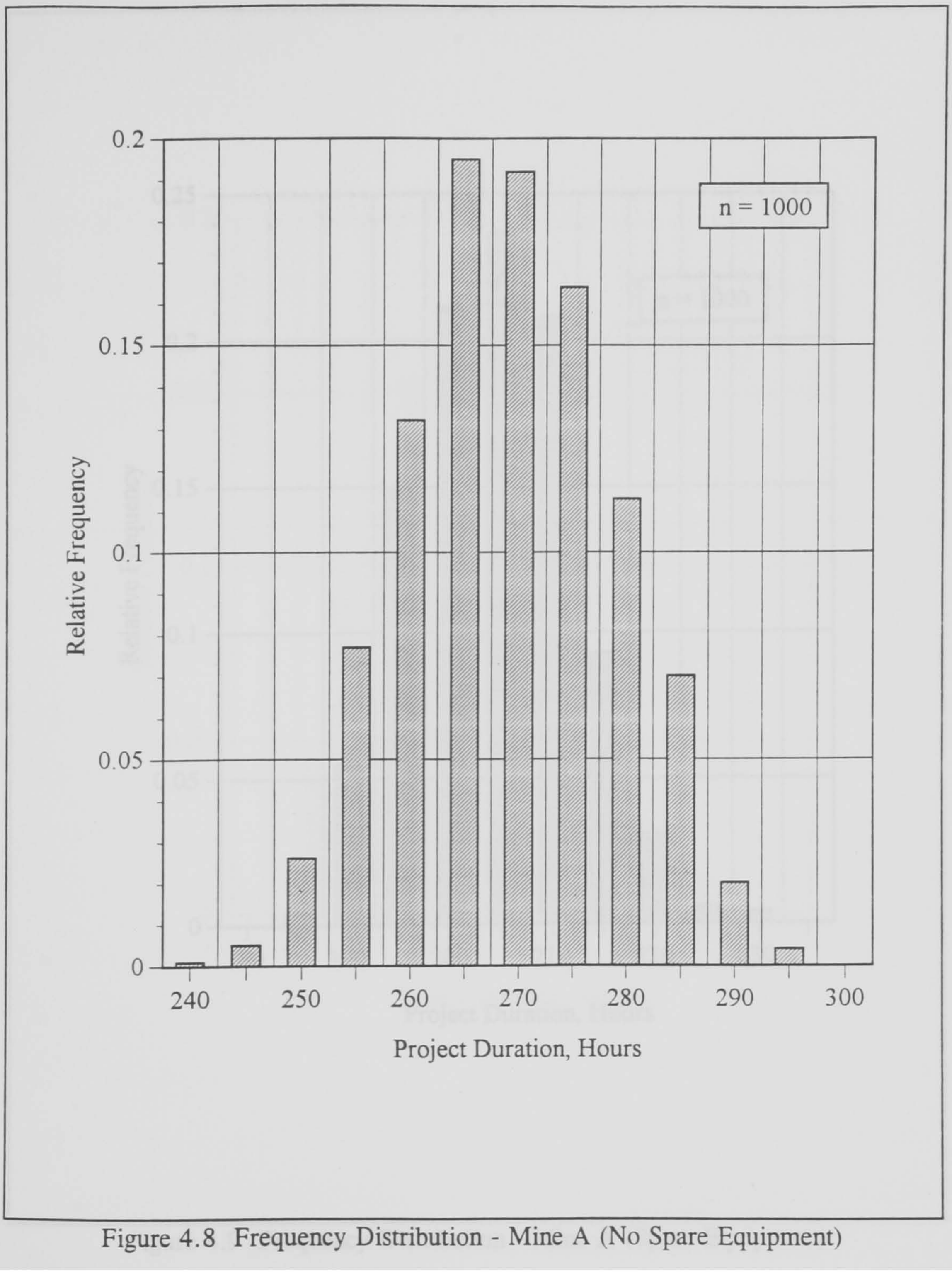


Figure 4.8 Frequency Distribution - Mine A (No Spare Equipment)

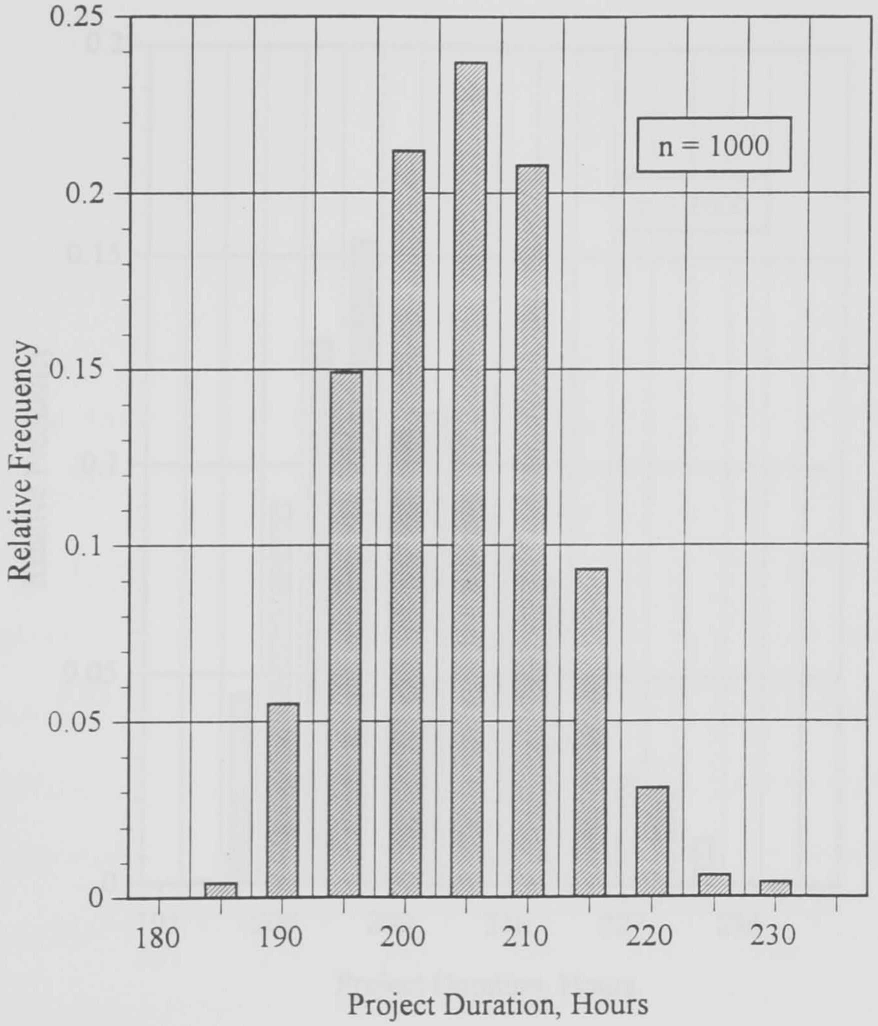


Figure 4.9 Frequency Distribution - Mine A (Spare Equipment)

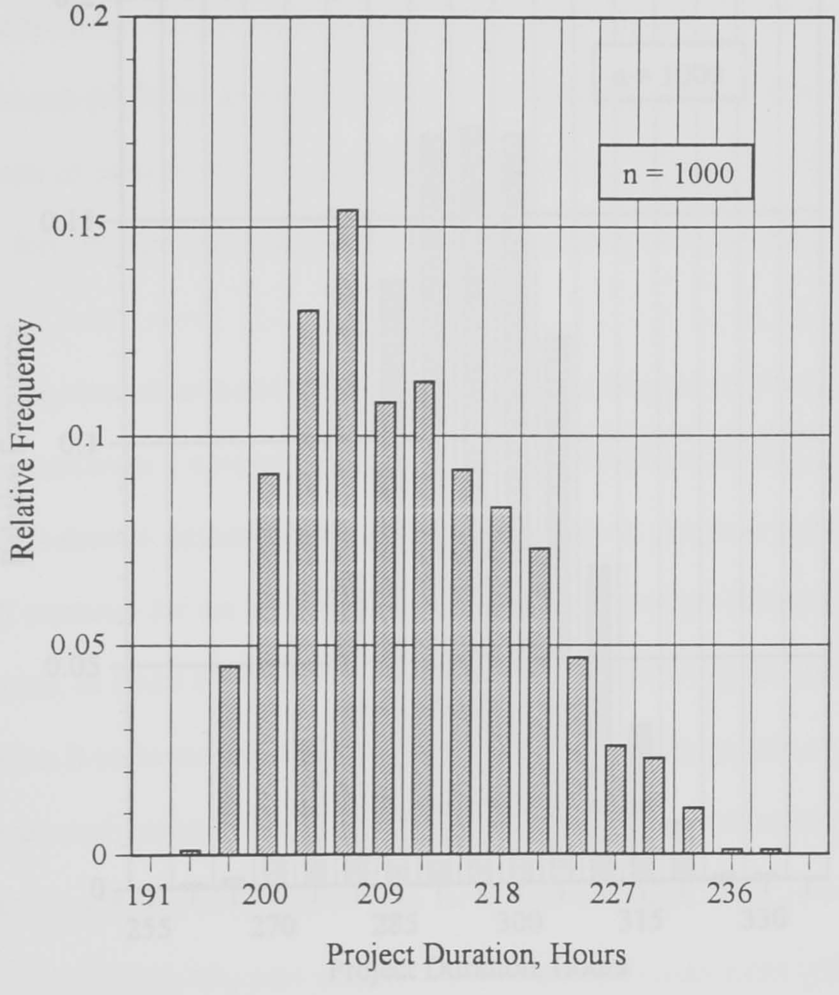


Figure 4.10 Frequency Distribution - Mine B

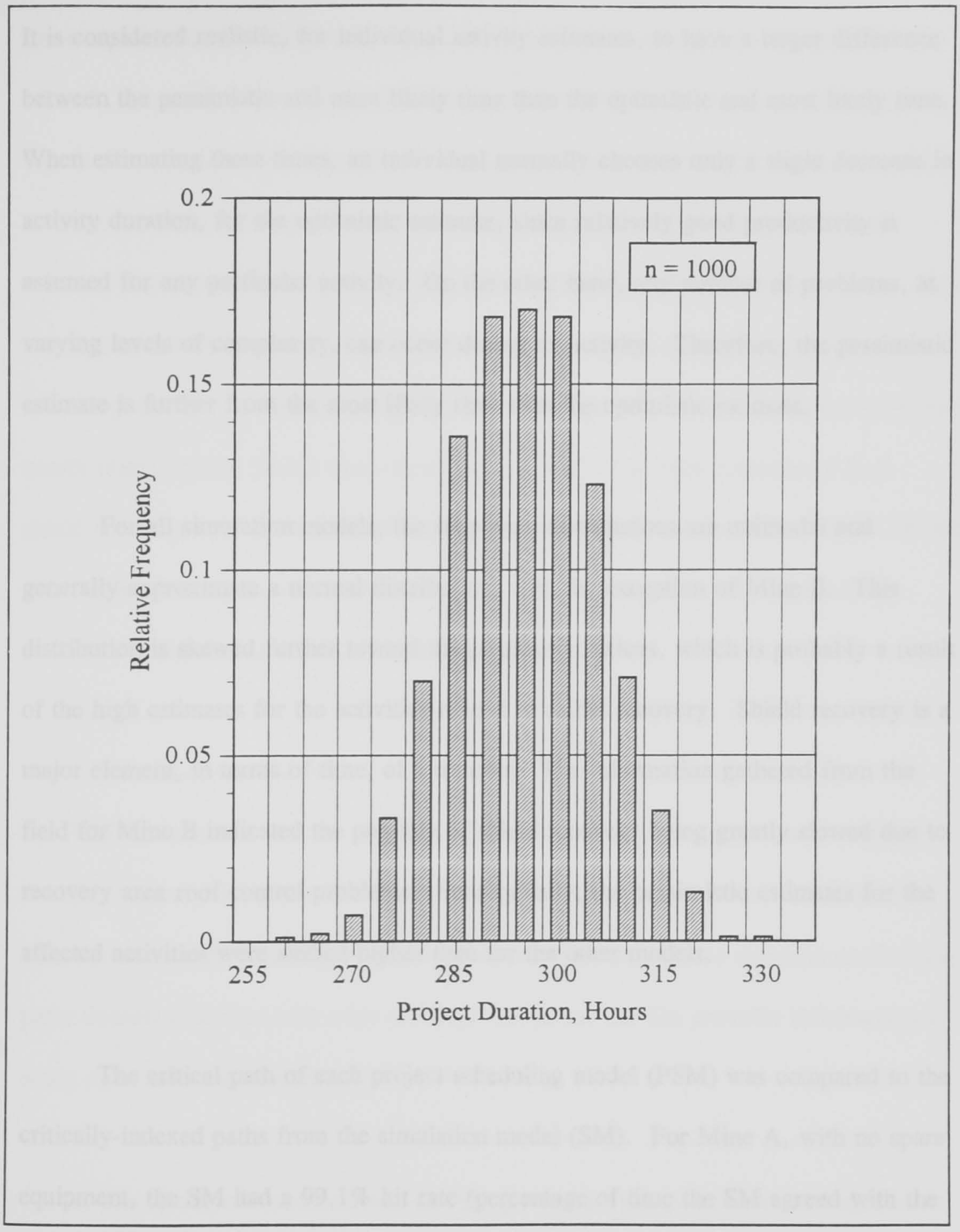


Figure 4.11 Frequency Distribution - Mine C

It is considered realistic, for individual activity estimates, to have a larger difference between the pessimistic and most likely time than the optimistic and most likely time. When estimating these times, an individual normally chooses only a slight decrease in activity duration, for the optimistic estimate, since relatively good productivity is assumed for any particular activity. On the other hand, any number of problems, at varying levels of complexity, can occur during an activity. Therefore, the pessimistic estimate is further from the most likely time than the optimistic estimate.

For all simulation models, the frequency distributions are unimodal and generally approximate a normal distribution, with the exception of Mine B. This distribution is skewed further toward the pessimistic values, which is probably a result of the high estimates for the activities related to shield recovery. Shield recovery is a major element, in terms of time, of a transfer. The information gathered from the field for Mine B indicated the possibly of shield recovery being greatly slowed due to recovery area roof control problems. Subsequently, the pessimistic estimates for the affected activities were shifted higher than for the other models.

The critical path of each project scheduling model (PSM) was compared to the critically-indexed paths from the simulation model (SM). For Mine A, with no spare equipment, the SM had a 99.1% hit rate (percentage of time the SM agreed with the PSM critical path). Otherwise, one other path was recognized. For Mine A, with spare equipment, the SM hit rate was 93.3% with three other paths recognized. For Mine B, the SM hit rate was 80.1%, with another 17.6% (97.7% total) occurring on a path directly adjacent to the PSM critical path. The adjacent path had a one-hour slack in the PSM. Six other paths were recognized in the SM, primarily due to minimal slack on several adjacent paths. For Mine C, the SM hit rate was 0%. This was due to the PSM critical path containing one particular critical activity which was not recognized by the SM as being critical. This critical activity is adjacent to several nearly critical paths, which were chosen by the SM. The wide variation of face shield recovery time shifted the SM critical path to the related activities. A 99.7% hit rate occurred along the shield recovery path. Two other paths were recognized, neither of which being the PSM critical path.

Results of the SM critical path indexing indicate very similar outcomes with the PSM for Mines A and B. The results of Mine C show the importance of using the SM, where activity duration variations can be represented. The PSM alone can, in most cases, represent longwall transfers well. However, when adjacent non-critical paths contain activities with wide duration variations, the SM provides information to make more informed decisions.

The results of the simulation model, given the input parameters and agreement with the project scheduling models, are considered realistic and accurate representations of the transfers being investigated. The longwall mining companies can obtain valuable information from the transfer simulation model, as can be seen in Table 4.2 and Figures 4.8 to 4.11. Instead of a single estimate of transfer duration, as provided by the project scheduling model, an average and likely range is given by the simulation model. Additionally, the value of the variation can be determined from the confidence intervals. For example, in Mine B, there is a 95% confidence that the transfer duration will be between 196 and 229 hours, with an average of 209 hours.

4.3 Summary

Using the life cycle development process (Balci, 1992), a project scheduling and simulation model of the longwall transfer process were developed. Using field data from existing longwall transfers, schedules were generated by the models. These schedules closely matched the field data, verifying the accuracy of the models. Valuable information can be obtained from these models, in the form of objective measures of transfer durations.

V. TIME-COST TRADE-OFF ANALYSES

5.1 Introduction

Results of the planning and scheduling stages of a longwall face transfer provide a network plan for the activities making up the project and a set of earliest and latest start and finish times for each activity. In particular, the occurrence time for the network terminal task in the project scheduling model is the estimated project duration, based on activity time estimates. In the simulation model, the project duration is represented by a frequency distribution based on the likely range of values for activity durations. For both models, the project duration time is considered a result of "normal" or average time estimates.

Similarities exist among operations executing longwall transfers. However, between operations and within a particular operation, a number of sets of resources and sequences can combine to complete a transfer and each set is an alternative plan method. The introduction of innovative ideas and/or equipment to reduce transfer time further complicates this process. Ultimately, the chosen plan has an estimated project duration and cost.

A non-producing longwall costs the mining company $45 to over $100 per minute in lost production potential (Hedges, 1984; Tucker, 1985). The magnitude of this indirect transfer cost makes consideration of the relationship between project duration and total project cost essential. Direct transfer costs are a result of quantities and prices of materials, time spent by workers, and duration of use and cost of equipment to perform the selected operations. Indirect costs, directly related to the project duration, are added for a total project cost.

Indirect costs will decrease as project duration decreases, but this may be at the expense of increased direct costs of a faster but less efficient set of resources and sequence of operations. A preference may be given to a plan that has higher estimated direct costs if it reduces project duration and related indirect costs, such that the total project cost is decreased. There can, therefore, be a trade-off between alternative plans. A plan may be chosen whose estimated direct costs are significantly higher than the others, but whose estimated duration and indirect costs are significantly lower, resulting in a lower total project cost. Evaluating alternatives in this fashion is called a *time-cost trade-off* comparison. In this chapter, analytical methods to reduce transfer durations in the most cost efficient manner are developed and reviewed.

Key factors affecting the choice to reduce transfer duration include: (1) lost production potential, (2) mine production estimates and requirements, (3) rebuild time of non-spare longwall system components, (4) mine company policy, (5) worker experience, and (6) development of the setup area. The use of the following procedures assumes a need for transfer duration reduction based primarily on lost production potential. The influence of other relevant factors must be made by individual companies applying the procedures.

5.2 Time-Cost Trade-Off Methodology

Reduction in longwall transfer duration is normally accomplished by adding more resources, typically workers, and/or introducing new and different procedural techniques or equipment. Few companies utilize an analytical approach to determine the economic feasibility of reduction techniques. Most rely primarily on judgement and task cost comparisons versus an overall economic effect of an alternative technique on the total project.

If a change in transfer procedure or equipment is proposed, management must depend on past knowledge and foresight to determine the feasibility of the new idea. A more objective approach would allow analysis of the probability of an innovation's positive or negative affect on the overall move process. Network scheduling can be used here; however, a reliance on single estimates of activity durations is highly subjective when applied to sequences affected by new equipment or ideas. More appropriately, scheduling simulation can be applied to represent the effects of changes to the model, and thus, to the system.

The following time-cost trade-off procedures are investigated.

1. Transfer time is reduced by "buying" time on the most critical activities, where time can be obtained at the least cost. The simulation model provides a list of critically indexed activities from which the most critical can be identified and analyzed for time reduction by applying more resources.

2. Alternative roof control methods are compared. The simulation is used to determine the effect of a recovery area roof control method. The method increases transfer duration, but decreases duration variation by providing better roof control conditions for the recovery area. In order to make a rational decision, overall project costs are compared for a transfer with and without this method.

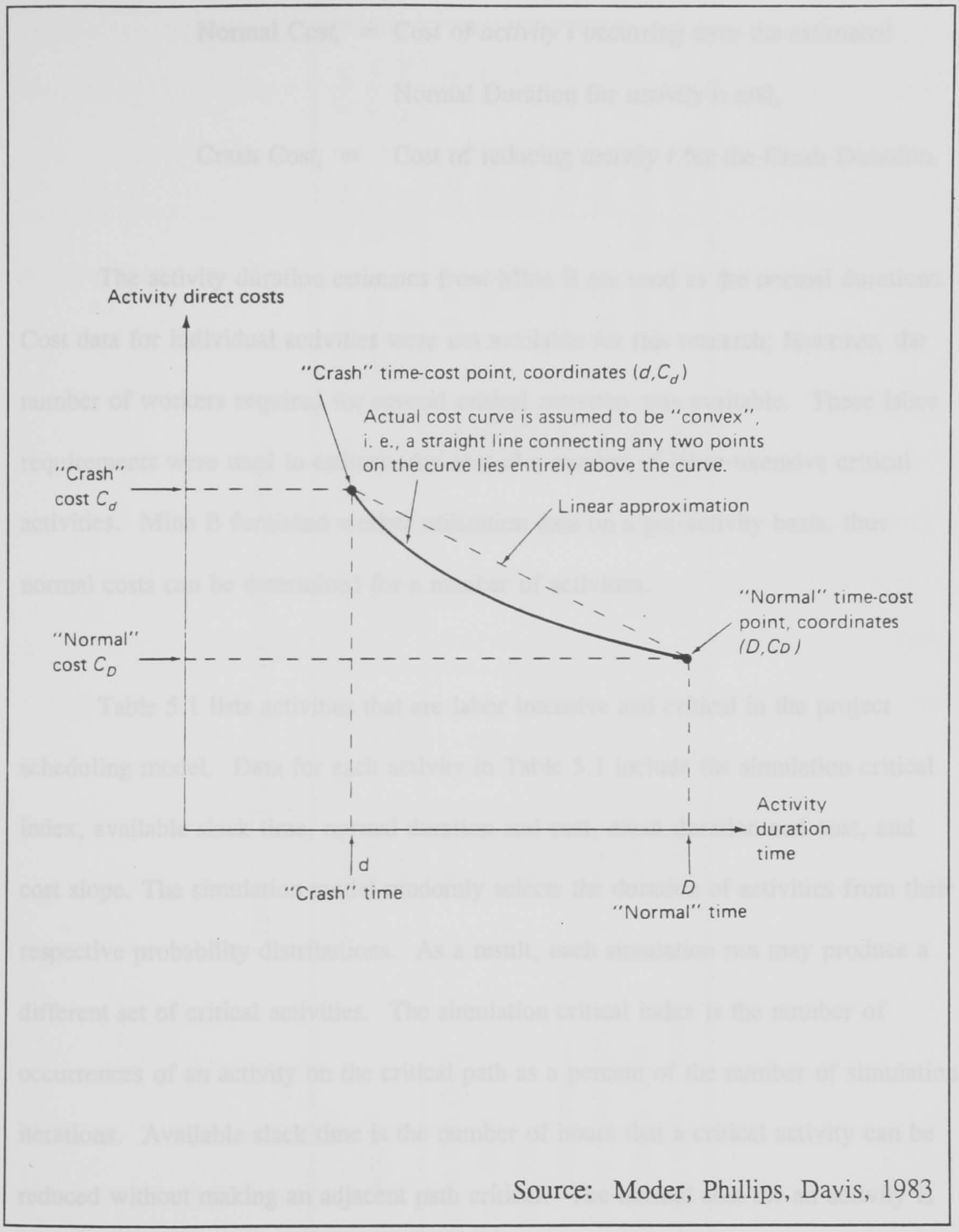
These techniques are tested on the most accurately represented field transfer, Mine B. The project scheduling model yielded only a 4.6% difference in the planned and modeled transfer durations. The simulation model closely corresponded to the project scheduling model. By choosing a transfer system which is accurately modeled, a more realistic foundation to test the analyses techniques is provided.

5.2.1 Buying Critical Activity Time

This procedure effectively reduces project time by providing more resources to those critical activities that can be obtained at the least cost. Determination of the least cost activities requires careful examination of the critical and nearly critical paths. Tight scheduling of a longwall transfer creates several adjacent, or nearly critical, paths which have minimal slack time. The key element of this procedure is identifying activities where time can be bought at least cost. A time-cost comparison factor, the activity *cost slope*, can be used for this purpose. It is defined in equation 5.1 and graphically shown in Figure 5.1.

$$\mathit{Cost\ Slope}_i = \left[\frac{\mathit{Normal\ Cost}_i - \mathit{Crash\ Cost}_i}{\mathit{Normal\ Duration}_i - \mathit{Crash\ Duration}_i}\right] \tag{5.1}$$

where: Cost Slope_i = Cost per unit time reduction for *activity i*;



Source: Moder, Phillips, Davis, 1983

Figure 5.1 Cost Slope for Time-Cost Trade-off

Normal Cost_i = Cost of *activity i* occurring over the estimated Normal Duration for *activity i*; and,

Crash Cost_i = Cost of reducing *activity i* for the Crash Duration.

The activity duration estimates from Mine B are used as the normal durations. Cost data for individual activities were not available for this research; however, the number of workers required for several critical activities was available. These labor requirements were used to estimate the cost of a number of labor-intensive critical activities. Mine B furnished worker utilization data on a per-activity basis, thus normal costs can be determined for a number of activities.

Table 5.1 lists activities that are labor intensive and critical in the project scheduling model. Data for each activity in Table 5.1 include the simulation critical index, available slack time, normal duration and cost, crash duration and cost, and cost slope. The simulation model randomly selects the duration of activities from their respective probability distributions. As a result, each simulation run may produce a different set of critical activities. The simulation critical index is the number of occurrences of an activity on the critical path as a percent of the number of simulation iterations. Available slack time is the number of hours that a critical activity can be reduced without making an adjacent path critical. The normal cost for an activity is computed from the number of workers as specified by the transfer coordinator. The

Table 5.1 Time-Cost Trade-Off Comparisons

Activity	Simulation Critical Index	Available Slack, Hours	Normal Duration, Hours	Normal Labor Cost	Crash Duration Hours	Crash Labor Cost	Cost Slope, $/Hour
Extend Track to Pan (305)	98.8%	1	3	$324	2.5	$486	324
Remove Track (315)	100%	5	2	$216	1.75	$324	432
Remove Pans (515)	100%	1	6	$486	5	$648	162
Prepare for Shield Removal (810)	82%	1	3	$486	2.75	$567	324
Remove Tailgate Shields (815)	100%	6	3	$486	2.5	$648	324
Remove Face Shields (830)	100%	6	60	$11,340	56	$14,580	810
Install Lights & CIU's (1710)	100%	6	30	$2,430	26	$3,240	203

crash cost is a result of an estimated number of additional workers required to reduce the activity to an estimated crash duration. It is assumed the additional workers are readily available to be assigned to the critical activities. Both the normal and crash costs are based on an industry-standard worker salary of $18.00 per hour plus a 50% fringe increase, for a total of $27.00 per worker-hour.

The crash cost and duration of each activity are estimates used to demonstrate this particular time-cost trade-off procedure. While these estimates were not confirmed by longwall "experts," the estimates are considered realistic and are used primarily to demonstrate the procedure. For Mine B, the project scheduling model yielded nineteen activities along the critical path. Of these, eighteen were identified by the simulation model as having a critical index greater than 80%. In fact, the next closest activity occurs in only 18% of the iterations. While it is reasonable to investigate all of the most critical activities, seven are chosen for analysis. These seven activities have sufficient available slack time and ample data are available or can be estimated to determine a cost slope for each.

The resulting activity cost slopes in Table 5.1 range from $162/hour to $810/hour with an average of approximately $368/hour. These time-reduction cost rates are much less than the cost of lost production potential for longwall mining systems. As previously stated, the cost of lost production ranges from $45 to $100 per minute, or $2,700 to $6,000 per hour. These figures were confirmed during data collection at Mine C by the Vice President of Engineering.

A comparison of the estimated cost slopes and lost production costs indicates viable reductions in the critical path time, thus reducing the total transfer duration. The activities to be reduced can be prioritized by the cost slope, with the minimum values given highest priority. Of the seven activities being analyzed, only six can be reduced (activity #830 is not free, due to reduction of activity #815). This is due to two critical activities being in series where they were competing for the available slack time. Thus, the activity with the lower cost slope was reduced. The resulting total available reduction is 10.25 hours at a cost of $4,644. When compared to a lost production cost, for 10.25 hours, ranging from $27,675 to $61,500, at $45 to $100 per minute, respectively, the reduction is economically feasible.

5.2.2 Comparison of Alternative Roof Control Methods

This procedure determines the effect of introducing an alternative recovery area roof control method into the transfer sequence. Mine B uses roof bolting machines to secure the recovery area for equipment disassembly and removal. This method is well suited for relatively competent roof strata above the longwall panel.

As the roof conditions deteriorate, bolting becomes less effective and equipment recovery is slowed.

A partial transfer shield recovery was observed at Mine B during one of the two data collection site visits. During the visit, shield removal was hampered by roof control problems. The roof material was more friable than expected, greatly reducing the effectiveness of roof bolting. Gob flushing onto the shields and into the recovery area impeded shield removal and crib construction. The transfer coordinator stated that one shield had been recovered in the previous shift and only four were expected in the current shift. While the average time for shield removal is 30 minutes (sixteen per shift), this time varies widely in poor conditions.

Recovery area screening (meshing) along the roof line above the shields has proven to be effective in reducing gob flushing. This method increases average transfer duration but tends to decrease duration variation due to better recovery roof conditions. In the past, chain link or welded wire served as the primary screening material. The weight, installation time, and expense of this material inhibited its use by many mines. In the last several years, many companies have replaced wire mesh with polymer grid sheets (described in Chapter 3). More than 200 longwall transfers have used this replacement screening material with much less cost and installation time (Travis, 1993).

The time-cost trade-off procedure applied here examined the effect of reducing the variation of transfer duration on overall project cost. By introducing screening into Mine B's transfer sequence, the project scheduling model reflects an increase in average transfer duration. This increase is equal to the time required to install the screening material, approximately twelve to sixteen hours (Travis, 1993). With the increased costs for screening materials and installation plus an increase in average transfer duration, this alternative roof control method seems infeasible. However, the project scheduling model uses average activity estimates and does not provide information on the variation of those estimates.

The simulation model can represent this problem more accurately. With this model, the reduction in variation of shield recovery time can be obtained. A time variation reduction is required to fully examine the feasibility of a time-cost trade-off for the screening method. The simulation model was applied to a transfer in Mine B with and without screening materials. Differences in input included screening time and reduction of time variation for shield recovery activities. Through the use of the pseudo-random number generator, the simulation model maintains exact repetition of the random number stream. This assures that all variables in the simulation, other than those reflecting changes for screening, were held constant.

Frequency distributions of the project durations, generated by 1000 runs of the simulation, are shown in Figure 5.2. It can be seen that the average transfer duration with screening is greater than without screening. Yet, the variation in the transfer duration with screening is significantly less than the one with no screening. A 95% confidence interval was established for the project durations by taking 2.5% of the lower and upper tail values of the two data sets (see Table 5.2).

An average U.S. longwall face is 218 meters (715 feet) wide. In order to screen the recovery area for this width, the cost includes materials at approximately $11,000, fabrication at $4,000, and installation labor at $2,600, for a total cost of $17,600 (Travis, 1993). An economically feasible time-cost trade-off would offset the screening cost by saving enough time at $45 to $100 per minute in lost production potential.

The lower confidence interval can be interpreted as an optimistic estimate of the project duration since it corresponds to the shortest duration of critical activities. Adversely, the upper confidence interval is interpreted as the pessimistic estimate since it corresponds to the longest duration of critical activities. For the lower interval, the non-screened transfer should be utilized, due to the increase in cost and transfer duration from screening. The net cost of screening, seen in Figure 5.3, is determined by duration differences in the screened and non-screened transfer. For the

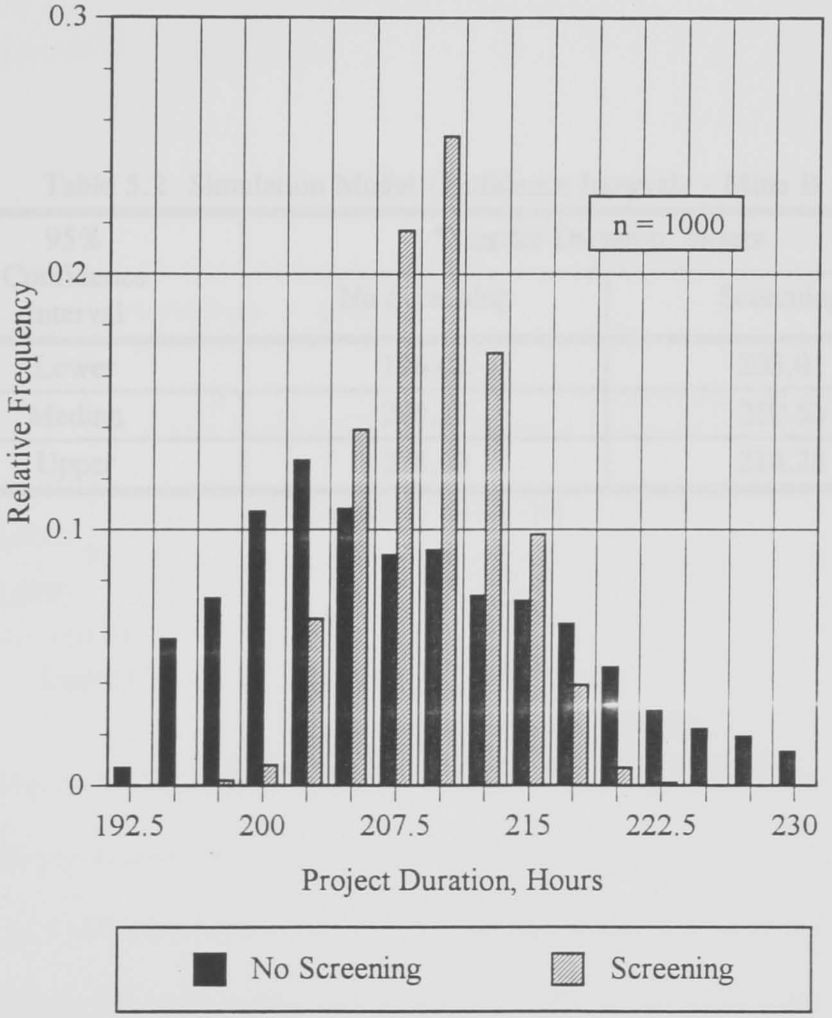


Figure 5.2 Frequency Distributions - Screened and Non-Screened Transfers

Table 5.2 Simulation Model Confidence Intervals - Mine B

95% Confidence Interval	Transfer Duration, Hours	
	No Screening	Screening
Lower	196.02	203.01
Median	208.17	210.63
Upper	228.69	218.28

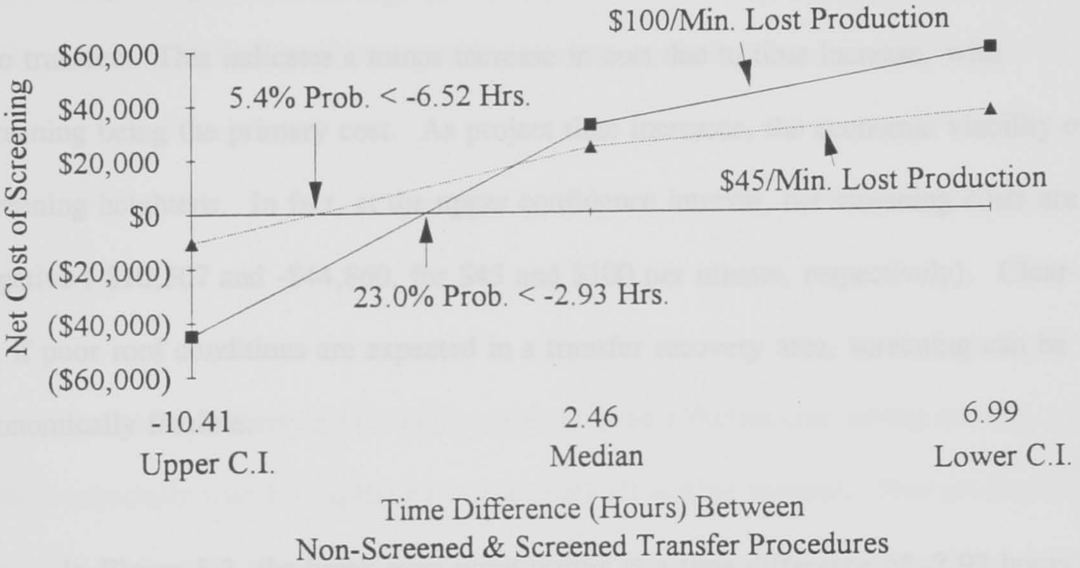


Figure 5.3 Time-Cost Trade-Off of Alternative Roof Control Methods

lower confidence interval, the difference is 6.99 hours (203.01 - 196.02). This value is multiplied by the lost production potential and is then added to the total cost of screening, or $17,600. The resulting net screening cost is $36,473 and $59,540 ($45 and $100 per minute, respectively).

Only a slight increase in project duration is seen for the average times of the two transfers. This indicates a minor increase in cost due to time increase, with screening being the primary cost. As project time increases, the economic viability of screening heightens. In fact, at the upper confidence interval, net screening costs are negative (-$10,507 and -$44,860, for $45 and $100 per minute, respectively). Clearly, if poor roof conditions are expected in a transfer recovery area, screening can be economically feasible.

In Figure 5.3, the break-even point occurs at a time difference of -2.93 hours, for the $100 per minute lost production cost. This break even point corresponds to zero ($0) net cost of screening, meaning the choices of screening and non-screening will result in the same cost. The time difference value, at the break even point, is computed by dividing the lost production cost into the screening installation cost [$17,600/($100*60) = 2.93]. A similar argument applies at a lost production cost of $45 per minute.

When the time differences are added to the screened transfer median time, the simulation project durations are greater during 5.4% and 23% of the time for $45 and $100, respectively. These percentages correspond to the probability, for this particular scenario, of the net cost of screening being zero or less. If the transfer time savings, as a result of screening, are larger than the break even time differences, screening becomes economically feasible. An individual company, with this data, can make a more informed decision regarding transfer screening.

5.3 Summary

Reduction of time in the mining process is an effective cost saving method. This is especially true for capital-intensive longwall mining systems. Non-productive activities, such as face transfers, require careful examination to determine time saving alternatives which are cost effective. The current procedures to analyze time reduction methods are primarily based on judgement and intuition. A more objective approach was developed to perform informed risk assessment. This approach uses time-cost trade-off techniques to compare the cost of reducing the duration of various critical activities and to examine the introduction of a new time-saving method into the transfer process.

The project scheduling and simulation models of the transfer process were used to test two time-cost trade-off procedures. The project scheduling model provided information on critical activities which could be reduced. Cost estimates to reduce those activities were compared with the cost of lost production, resulting in prioritized activity reduction potential. The simulation model was used to compare an alternative roof control method for the transfer recovery area. By applying time variations to the effected activities, the model provided information to determine the probability of the alternative roof control being cost effective. For both procedures, the time-cost trade-off analyses provided analytical feasibility assessment of transfer duration reduction.

VI. CONCLUSIONS

In this chapter, conclusions of the research conducted for this dissertation is presented. Contributions, based upon the findings of the research, are discussed. Finally, recommendations for future work are given.

6.1 Conclusions

Longwall mining is an essential component of U.S. underground production systems, providing over 25% of the total coal produced. This productivity has greatly increased since the introduction of longwall mining systems in the U.S. in the early 1950's and continues to increase annually. Of all underground coal mining methods, this technique offers the highest productivity potential. In addition, the ongoing trend towards concentration of mining activities into fewer sections of a coal mine, as well as application of automation and remote control technologies, favor utilization of the longwall mining method. These trends are expected to continue, resulting in a very large portion of the future U.S. underground coal production being mined by longwall systems.

Longwall mining systems are very capital intensive, approximately $14 million for the U.S. average panel width of 700 feet (Merrit, 1993). As a result, activities related to production are carefully monitored. One of those activities is the longwall face transfer. In fact, face transfers, for many companies, are the largest single source of non-productive time. The execution of a longwall face transfer is a complex process with many activity interactions. Several critical factors contribute to safe and timely transfers, including worker training and experience, careful mine layout, anticipation of varying geologic conditions, utilization of specialized equipment, and extensive organization, planning, and control. While each of these factors warrant study, this dissertation suggests a methodology for better planning and control of the transfer process.

The study was undertaken to provide the potential to reduce overall transfer time for and the variation of transfer execution time among U.S. longwall operations. The first objective of the study was to investigate existing face transfers. The comprehensive nature of the study requires a sound understanding of transfer techniques currently in practice. To develop this understanding, transfer data were collected from five companies representing over 35% of the total operating longwalls, with detailed data from three eastern U.S. operations. From these data, a comparison of general operational characteristics, production equipment, labor requirements, and transfers procedures was conducted. In addition to the comparison of the three operations, a case studies report was generated. This report includes a detailed transfer procedure description for each mine and recommendations to reduce overall transfer time.

The comparison and input from the mining transfer coordinators provided information to divide the transfer process into discrete activities. Six major steps, with various numbers of related activities, were identified for each operation. In each step, transfer methods used by each operation were described, with similarities and differences identified. Special emphasis was given to those transfer activities deemed critical to the reduction of transfer time.

The study found, for the three operations, many similar transfer techniques and a few distinct differences. Personnel utilization was common for each operation, with an average of approximately twelve to fifteen workers, varying according to shift-by-shift needs. Two mines planned their transfers during sixteen-day periods, while the third estimated nine days. Each mine used very extensive pre-transfer planning to organize the process and all were interested in enhancing their planning capabilities. The three operations used similar specialized transfer equipment, including heavy-duty scoops and lowboy rail cars for longwall equipment transport. The equipment withdrawal, transport, and setup sequence was similar for the three mines with differences caused primarily by availability of spare equipment. This availability varied from no spare equipment to all but roof shields.

Several factors were identified as crucial to transfer duration reduction, including: (1) transfer organization and control; (2) spare equipment availability; (3) roof screening to prevent gob flushing in the recovery area; (4) roof shield withdrawal sequencing; (5) worker experience; and, (6) setup area readiness. This investigation is, by far, the most comprehensive study undertaken in a decade, with step-by-step descriptions of the transfer process. It provides an updated report on the state-of-the-art in U.S. longwall transfers.

The second objective of the study was to model the transfer process in order to enhance the efficiency of transfer execution. For the investigation of current practices, the transfer processes were divided, for comparison purposes, into six major steps and 60 to 70 sequenced activities. Activity sequences, such as these, can be well described by project scheduling techniques and the efficient use of these techniques requires computerization on complex projects, such as longwall transfers.

Project scheduling models were developed to analytically determine the critical path and project duration of longwall transfer processes originating from collected field data. The project scheduling models were applied through a commercial software package which yielded output on critical activities, paths, and project durations. The results of the models accurately represented the collected transfer data and were verified by the transfer coordinator from each operation. For the two operations with planned sixteen-day transfer durations, the model results were as much as 40% less than field estimates. The inference was the allotted time for transfer execution was too high and could actually be done in significantly less time. The transfer coordinators confirmed this and, while somewhat reluctant, were hopeful to implement time reduction changes. The remaining operation, which planned a nine-day transfer, was closely modeled with a 4.6% difference between the field data and model results. The transfer coordinator was very satisfied with these results and hoped to use the model output as a planning tool for future transfers. For the three operations, the project scheduling models provide better communication, monitoring, and control of the transfer process.

A simulation model was developed to predict the effect of alternative or innovative techniques or equipment on the transfer process. The model incorporates stochastic activity durations into the project scheduling analytical solution technique, providing a realistic representation of the time variation characteristics of transfer activities. Data, from the project scheduling models, were coupled with estimates by the author to develop probability distribution parameters for transfer activity durations. These data were then used as input for the simulation models, resulting in critically-indexed paths and activities and frequency distribution data for the transfer durations. The project scheduling critical path and activities closely matched those of the simulation models, with one exception. In one case, a single activity did not occur on the critical path for any runs of the simulation, but was critical for the project scheduling model. This activity was adjacent to several paths with minimum slack and was not chosen by the simulation. Due to corresponding results of the two models and the project scheduling model's match to the field transfer data, the simulation model was assumed to provide an accurate representation of the field data.

The project scheduling and simulation models provide the capabilities for information management required to effectively plan and control longwall transfers. The research demonstrates the use of the models to accurately represent and better manage existing transfer processes and the ability to conduct these analyses on a microcomputer. This provides incentive for longwall mining personnel to utilize this technology on a daily basis in order to greatly increase their ability to manage the execution of transfers.

The third objective of the study was to conduct an economic analysis of the time-cost trade-offs in the transfer process. The purpose was to determine the economic feasibility of alternative or innovative techniques applied in order to reduce transfer execution time. An economic evaluation of innovative techniques was developed with two time-cost trade-off procedures. In the first procedure, the direct costs of an collapsing critical activities were compared to the indirect cost savings of reducing overall project time. Critical activities from one operation were chosen from the project scheduling and simulation model results. The operation chosen to test the time-cost trade-off procedures was the one most closely modeled (4.6% time difference between planned and modeled transfer). It was assumed that planned changes in the model would accurately represent real changes to the system.

Seven labor-intensive critical activities were chosen in order to estimate their direct costs, since cost data were not available from the operations. The cost of collapsing and feasible time reduction were estimated for each activity. A cost slope, cost per unit time reduction, was determined from normal and collapsed time and cost. This was compared to the cost of lost production potential, up to $100 per minute, for longwall systems. For all activities examined, reduction was feasible.

The second time-cost trade-off procedure involved the addition of an alternative roof control method, screening the recovery area, to the transfer process. For the operation being investigated, screening could reduce the roof shield recovery time. A reduction of time variations for activities related to shield recovery was estimated and the simulation model used to represent these changes. When compared to the original simulation results for this operation, these results had a higher average transfer duration, but a lower dispersion. The median, and lower and upper confidence intervals for the two models were combined with real cost data for screening the recovery area. Subsequent costs of screened and non-screened transfers at the three intervals were compared with the lost production cost of longwall systems, $45 to $100 per minute. At the lower confidence interval and median for the two models, the net cost of screening was positive, indicating an infeasible alternative. However, at the between the median and upper confidence interval, the net cost of screening became negative, indicating a feasible time-cost trade-off. In other words, if poor roof conditions were expected, screening is economically feasible.

Decisions to incorporate innovative ideas and/or equipment for the reduction of transfer durations are based on judgement and subjective criteria. The time-cost trade-off procedures applied to the transfer process provide an objective technique to perform risk assessment and informed decision-making.

This research contributes to the improvement of longwall face transfer methodology through a systems engineering examination. The research may enable mine operators to evaluate, more objectively, the methods and equipment currently used in longwall face-to-face transfers, and may thus contribute to improvements in both the productivity and economic viability of this high productivity mining method.

The significance of this dissertation is a potential for substantial improvement in time and money in the design and operation of longwall mining systems.

6.2 Recommendations

This dissertation is an innovative investigation of methods to increase the efficiency of longwall face transfer execution. The research has concentrated on improving the implementation of better planning and control. While a thorough study has been conducted, several areas of research and technology transfer will be the subject of future work in this field. The suggestions for further research from this dissertation are as follows.

An enhancement of the simulation computer model would be beneficial. The simulation computer model performed well for this investigation by accurately representing the existing transfer data and project scheduling model. Two areas of improvement are identified. The user interface for input and output could be enhanced by providing more assistance to the user in the form of easier data input and on-line help information. Overcoming the 640K memory barrier could allow more simulation iterations, further verifying the randomness of activity duration selection from the probability distributions. The memory barrier limitation could be overcome by providing more memory to the program. This could be accomplished by developing the simulation program in the Windows environment, perhaps through Visual Basic. Another option is to switch to the C programming language, which is more capable of accessing upper level memory.

The accuracy of the simulation could be increased by the development of field-based probability distributions for transfer activity durations. The time estimates used to develop the triangular distributions for activity durations are considered realistic. However, field-based data collection of transfer activity durations could provide information required to develop probability distributions representative of the actual time variations. While gathering these data is feasible, it would require a large amount of time for repetitive observation of transfers in various mining and geologic conditions to obtain realistic estimates.

The application of time-cost trade-offs could be more thoroughly tested with actual cost data from in the mining industry. The time-cost trade-off procedures provide valid risk assessment of transfer time reduction techniques. The next logical step is to apply the procedures with actual industry cost data. While the cost estimates used for the dissertation are considered realistic, they are available for only labor-intensive transfer activities. With industry cost data, the time-cost trade-off procedures could be applied throughout the transfer process, identifying those activities with economically feasible time reduction.

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Appendix A

Mine Data Sheet

Date ____________________

Longwall Move Data Sheet

Company :

Location:

Contacts:

Seam Thickness: Cut Height:

Coal use: _____Contract _____Spot _____Steam _____Metallurgical

Mining Characteristics

Type of mining: _____ Longwall with CM development only
_____ Longwall, CM development, CM production

Number of longwalls:

Development entries on longwall:
Number: Centers:

Panel dimensions
Face width: Face length:

Geologic conditions
Immediate roof type:

Main roof type:

Floor type:

Number and type of production workers:

Shifts/Day: _____ Production _____ Maintenance Days/Week:

Production: __________ Shift __________ Month __________ Year

Equipment Type

Shearer:

AFC:

Stage Loader:

Drives:

Supports:

Move Equipment Type

Outbye equipment transport type (rail, rubber tire, etc...):

Outbye support transporters:

Face support movers:

Face bolter type:

Shearer mover:

Other:

Spare Equipment on Installation

_____ Shearer

_____ AFC - Number of pans ______________________

_____ Headgate drive

_____ Tailgate drive

_____ Power package

_____ Supports - Number ______________________

Move Procedure

Move frequency:

Order of equipment removal: Removed through
headgate tailgate

_____ Stage loader
_____ Headgate drive
_____ Tailgate drive
_____ Shearer
_____ Face conveyor
_____ Roof supports

Order of equipment installation:

_____ Tailgate drive
_____ Face conveyor
_____ Roof supports
_____ Shearer
_____ Headgate drive
_____ Stage loader

Duration and Manpower Use

Move shifts/day: Days/week:
Total move duration:
Shifts: Days:

Type of Equipment	Number of Shifts Required		
	Removal	Installation	Total
Stage Loader			
Tailgate drive			
Headgate drive			
Shearer			
Face conveyor			
Supports			
Total			

Appendix B

Report of Case Studies

REPORT OF CASE STUDIES

LONGWALL FACE-TO-FACE TRANSFERS

September, 1993

Abstract

Longwall Face-to-Face Transfers

Face-to-face equipment transfers, which involve disassembling longwall equipment in a panel, transporting, and then reassembling it in a new panel, are the largest source of longwall non-productive time for many companies. This, in addition to transfer costs of over $100,000, makes reduction and control of face transfer times essential. This report was conducted to optimize the execution of longwall face transfers by examining current techniques and identifying standard and variant practices. Detailed data were collected from three eastern U.S. mining companies, who represent over 30% of the total U.S. longwall faces. The report includes an overview of general transfer procedures, a detailed account of transfers at each of the three mines, and recommendations as to the reduction of transfer time for each mine.

Introduction

Longwall mining systems offer the potential for improved safety and productivity, better ground control, higher levels of coal recovery and lower unit production cost. In addition, the ongoing trend towards concentration of mining activities into fewer sections of a coal mine, as well as application of automation and remote control technologies, favor utilization of the longwall mining method.

The driving factor for increased interest in longwall mining is high productivity potential. From 1985 to 1990, the average productivity of U.S. longwall systems increased substantially from about 1,000 to more than 2,370 tons per shift (Combs, 1992). The utilization of more powerful equipment, higher equipment availabilities, larger longwall panels, better planning and organization, and the experience gained in longwall mining were the major contributing factors to productivity improvements (Dunlap, 1990; Duan, 1990).

High productivity of a longwall system comes at the expense of about two million dollars per 100 linear feet of face installed. An investment of this magnitude requires careful optimization of time and resources to maintain economic feasibility. Non-productive activities must be held to a minimum. A major source of non-productive time is the transfer of longwall equipment from a worked-out to a new panel. Minimizing face-to-face transfer time, therefore, is a critical concern of coal mining companies.

Statement of the Problem

A non-producing longwall costs the mine owner from $45 to over $100 per minute in lost production time (Hedges, 1984; Tucker, 1985). Face-to-face equipment transfers, which involve disassembling longwall equipment in a panel, transporting, and then reassembling it in a new longwall panel, are the largest source of longwall non-productive time for many companies. This, in addition to a move cost of over $100,000, makes reduction and control of face transfer times essential.

Longwall panel size has increased steadily over the years. Increasing panel width directly affects transfer time, since more equipment must be moved. During this same time, the average transfer time has held relatively constant. Since average transfer time has changed little while equipment size and quantity has increased, the inference is that the ability to execute a transfer has improved. However, large variations in transfer times exist from company to company. In 1991, reported transfer times ranged from 240 to 3128 worker-shifts (Combs, 1993). While some of this variation can be attributed to differing move crew size and whether spare equipment is used, such a large variation indicates notable distinctions in how companies perform transfers.

In an effort to identify factors affecting the variations in transfer durations, an investigation of existing longwall transfers was initiated. The intent was to examine transfer techniques, identify similarities and differences, and determine catalysts for optimum performance.

Data Collection

Face-to-face transfer data was collected from companies who operate over 42% of the total U.S. longwall faces. Six companies, operating 38 of the 90 active longwall systems (Merritt, 1993), were involved, with detailed information coming from three operations. These three operations were chosen for detailed analysis, and hereafter, will be referred to as Mines A, B, and C for confidentiality purposes. The sources of data were two moves observed by the researcher, company procedural manuals, move time studies, supervisor shift and move reports, and, most importantly, extensive interviews with personnel responsible for moves, including longwall coordinators and mine superintendents.

Contact with longwall mining companies began at the corporate level in order to determine their willingness to participate in such an extensive study. Participating companies were making a considerable commitment, since a number of hours were required of the mine personnel for on-site interviews as well as detailed information on transfer techniques, equipment, supplies, and personnel. Each company was granted confidentiality in the study and were provided the results of the research.

The determination of collected data type was primarily influenced by the intent to analyze individual company transfer procedures, compare and contrast transfer procedures among companies from which data were collected, and determine transfer practices which are common throughout the U.S. longwall industry. It was resolved that the following data were required:

- Mining conditions and environment,
- Transfer planning and training methods,
- Transfer activity sequence and timing details,

- Transfer equipment type and utilization, and
- Transfer personnel and supply requirements.

At least two visits to each mine were made, one for data collection and the second for network schedule verification. Existing company transfer documents were gathered and on-site interviews with key management personnel were conducted. At one site, underground visits to observe two separate moves were made. Both visits were made during the recovery portion of the moves, the first during equipment disassembly and the second during shield removal. This gave the researcher a feel for the transfers' comprehensive nature, hectic execution, and equipment and personnel utilization. A comparison of operational characteristics are given in Table I.

Upon completion of the data collection process, precedence networking techniques were utilized to generate transfer sequence diagrams and bar charts of each mine's general transfer procedure. A second visit was then made to each mine to verify the diagrams/charts, activity durations, and personnel/supply requirements. After processing the results of the second visit, sequence diagrams and bar charts were sent to each mine for future use.

Table I. Mine Operational Characteristic Comparison

Parameter	*Mine A*	*Mine B*	*Mine C*
Location	Northern WV	Southwest VA	Southwest VA
Seam	Pittsburgh #8	Pocahontas #3	Pocahontas #3
Cut Height	66 inches	72 - 78 inches	70 inches
Gate Entries	4	4	4
Panel Width	600 feet	585 feet	730 feet
Panel Length	6000 - 7600 feet	4000 - 5000 feet	6900 feet
Overburden	500 feet average	1500 - 2400 feet	1800 feet average
Immediate Roof	Soapstone, 3 feet	Sandy shale	Sandy shale
Immediate Floor	Hard shale	Clayey shale	Sandy shale
Prod. Crew Size	8	5	9
Prod. Shifts/Day	2	3	3
Prod. Days/Week	5	5	5
R.O.M. Prod./Shift	4000 tons	3000 tons	3700 tons
Move Supervisor	Superintendent	LW Coordinator	LW Coordinator
Avg. Moves/Year	2	2	2
Shifts to Move	48	15	48
Worker-Hours to Move	Not Available	1500 (not including spares)	2380 total
Avg. # Workers on Recovery	12 (17 for wire mesh)	12	12
Shield Mover, Face	Eimco scoop #585, battery	Eimco scoop #592, diesel	Petito "Mule"
Shields Move/Shift	17	16	16
Spare Equipment	1. All but shields 2. None	All but shields	Shearer, tail/head drives, AFC

Case Study - Mine A

The mine is located in northern West Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted for steam power generation. The Pittsburgh No. 8 seam is being mined with a seam and cut height ranging from 60 to 70 inches and an average of 66 inches. The mine is a dedicated longwall operation with three to four active continuous mining development sections. Four development or gate entries are used on 200 foot average centers. The panel length ranges from 6000 to 7600 feet and width averages 600 feet. Two production shifts and one maintenance shift are used on a five work-day per week basis. The mine produces 4000 tons of run of mine (R.O.M.) coal per production shift with an average of 25% reject. The production crew consists of one supervisor, one shearer operator, three shield operators, two mechanics, and one electrician, for a total of eight workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, Eicotrak haulage system, approximate weight 50 tons;
Face Conveyor - Westfalia Lunen, 34 inch width, twin inboard chain;
Drives - Westfalia Lunen, 400 HP motor at head and tail, crossframe discharge system at head;
Stage Loader - Westfalia Lunen, 46 inch width;
Roof Support - 120 Westfalia Lunen shields, 2 leg, 580 ton yield pressure, approximate weight 18 tons each.

The mine utilizes the adjacent longwall panel system with an average overburden of 500 feet. Ground conditions are relatively good with about three feet of soapstone immediate roof and eight to ten feet of limestone main roof. The floor is predominately hard shale and competent.

Transfer - General

The complete transfer process is planned for approximately 16 days, or three weekends and 10 production days. The strategy is to completely finish the transfer by the 14th day or second full Friday of the move, given that wire meshing began on the second or third shift of a Friday. This provides two full non-production days to get the system operational and in full production mode. It also allows for any problems encountered which may increase the time required for a particular move. For this operation, a 16-day transfer is standard, regardless of the availability of spare equipment.

A headgate and tailgate recovery system is used for the face transfer. The tailgate face conveyor drive, tailgate drive connecting pan, and approximately 75% of the face conveyor is removed through the tailgate entries. Specialized transfer equipment used at this mine includes:

(1) Inby transport - EIMCO 585 battery scoops, 2 in headgate, 1 in tailgate;
(2) Outby transport - Westfalia Lunen lowboy rail car;
(3) Walking shield advance - F-frame.

This operation utilizes the most comprehensive transfer procedure documentation of all mines in the research. Detailed recovery and installation manuals, developed by on-site management, was collected for the research. The manuals contain divisions of the recovery and installation process into major tasks, each of which with step-by-step instructions as to their execution. The recovery manual has 29 tasks with 164 individual steps and the installation has 33 tasks with 243 steps. A layout sketch or drawing exists for nearly every task.

Spare equipment availability fluctuates, since trading of one set of spare equipment occurs between several of the owner's operations. Therefore, two analyses of transfer procedures were performed, one with a complete set of spare equipment and one with no spares.

Transfer Description - Spare Equipment

The following transfer is typical for Mine A when spare equipment is used. All major pieces of equipment except shields were spare and available for installation prior to the beginning of the recovery process.

Recovery Room: Prior to the initial development of the recovery room, transfer supplies and equipment are strategically located around the face stop line in the headgate, tailgate, and main entries. To facilitate the installation of wire rope and mesh for recovery room development, a row of six-foot roof bolts are installed in the headgate and tailgate entries. To secure the recovery room wire ropes, 12 roof bolts are angle bolted where the roof meets the rib of the first pillar from the gob.

The mine schedules the start of the wire mesh process for a Friday second or third shift by altering, if necessary, the production rate of the longwall system as it approaches the point at which wire meshing must begin. If production must be increased, as is usually the case, the third or maintenance shift becomes a production shift. If needed, the rate is decreased by simply taking more time to effect production. A late Friday finish allows the weekend to complete the wire mesh process and begin equipment disassembly.

Recovery room development begins approximately 14 shearer cuts prior to the final face stop line. Wire rope and wire mesh are installed above the canopies of the shields. A spool-mounted, 9/16-inch steel wire rope is hooked to the shearer at the headgate, the shearer is trammed to the tailgate placing the rope on the toes of the shields, one full cutting pass of the shearer is made from the tailgate to headgate without advancing the shields, and the wire rope is cut, secured to the first angled bolt, and tightened against the roof with come-a-longs. Once the first rope is secure, one 12-foot roll and five 125-foot rolls of wire mesh are placed along the face conveyor from the tailgate. The conveyor is moved forward slowly during loading so that each subsequent wire mesh roll can be overlapped. The ends of each wire mesh roll was previously painted yellow for a distance of 18 inches in order to facilitate accurate overlapping. From both the headgate and tailgate, workers start "dinging" or binding the wire mesh to the first wire rope and the seams of the mesh together. Once completed, every fifth shield is lowered and advanced 30 inches under the wire rope and mesh. The remaining shields are then lowered and advanced. The overhanging wire mesh is hung on pre-installed hooks on the shield canopies.

The process of installing wire rope and wire mesh continues until the ninth rope is hung and attached to the wire mesh, prior to shield advancement. Two 30-foot I-beams are placed between the eight and ninth rope at both the headgate and tailgate and extend to the middle of the sixth shield from the ends of the shield line. The beams are laid on the drives and face conveyor and lifted onto the top of the second and fifth shields, which have been lowered and advanced. With the beams in place, the second and fifth shields are raised together. The remaining shield line is then lowered and advanced and a full cutting shearer pass is made.

The process of installing two 30-foot I-beams at the headgate and tailgate between the wire ropes continues until four sets of beams are between the 8th and

9th, 9th and 10th, 10th and 11th, and 11th and 12th wire ropes. One full cutting pass is made by the shearer for each wire rope installed. Once the 12th rope is installed, the shields are advanced for the last time and one more cutting pass is made. Installation of wire ropes and mesh and I-beam installation were deemed as two separate but interrelated activities. Specifically, the process of installing the I-beams must finish about one hour prior to the finish of hanging the 12th and final wire rope. The lag of one hour is chosen because this is the time it will take to finish hanging the final rope.

The use of wire mesh and steel rope to aid in the prevention of gob flushing during shield recovery was modified for this mine after the research data collection and schedule verification. The company began using polymer grid sheets to replace the wire mesh. These lightweight polymer sheets, a relatively new development in the field of recovery area meshing, are an alternative to meshes of chain link fence or welded wire. The grid sheets, manufactured by Tensar Earth Technologies, have similar opening spacing, orientation, and sheet size as typical wire meshes in use. The sheets utilize a strong, lightweight polymer, usually special grades of polypropylene or polyethylene. High tensile strengths are achieved by molecular orientation of these polymers in the manufacturing process. The sheets can be prepared for installation on the surface, compactly folded, and transported to the longwall panel in large units. This initial preparation away from the recovery area and their lightweight property greatly save time during installation. Over 200 U.S. longwall face transfers have used this technology (Travis, 1993).

A hydraulic cylinder built into the base of a shield connects the shield to the face conveyor and provides both a means to push the conveyor forward and to advance the shield. The hydraulic cylinders or rams can be extended to advance the face line one full cut (30 to 36 inches). Establishment of the recovery room requires the shearer to make two to four cuts beyond the last advancement of the shields. Ram extensions must be used to push the face conveyor forward for these cuts. In this mine, three foot long, metal ram extensions are connected between the ram and face conveyor. The conveyor is pushed forward without advancing the shields and one full cutting pass and another clean-up pass is made. The shearer is parked at the headgate and the face conveyor is pulled back. The ram extensions are removed and placed on the toes of the shields to be recovered with the face conveyor.

The recovery room has been established and the roof must be supported. At the tailgate, 12-foot planks are loaded onto the conveyor and distributed along the face, one per shield, except the shields over which the I-beams are installed. These planks are pre-drilled with two holes spaced at four to five feet to allow the insertion of roof bolts. Each shield is lowered, a plank inserted over the canopy, and the shield reset against the roof. The planks are perpendicular to the face and the holes are located toward face. Planks are installed in the headgate and tailgate area toward the center of the panel simultaneously, but never over adjacent shields. Upon completion of the plank installation, the face conveyor sections are disconnected at every other section, creating 10-foot sections for scoop removal. At the same time, the chainless haulage system or Eicotrak is disconnected. These steps are necessary for removal of the face conveyor.

Recovery area roof bolting starts after an approximate one hour lag from the start of plank installation. At four different locations, evenly spaced along the face, hydraulic stopers or large, hand operated drills are used to install six-foot roof bolts through the holes in the planks. All four stopers work toward the center of the face. Wooden header blocks are used in the case of shields with I-beams on the canopies, since no planks were installed over these particular shields.

Equipment Removal: Several ventilation stoppings are made in the headgate entries around the face stop line to improve the maneuverability of equipment transport. The headgate drive, stage loader, and tailgate drive are disassembled simultaneously. These three activities can start after a one hour lag from the start of the recovery area bolting. Rail lowboys are positioned for both the headgate and tailgate drives in their respective areas. The drives are loaded onto transfer scoops, which transport and load the drives onto the rail lowboys. The lowboys are temporarily stored on the rail straightaway beyond the face stop line until they can be transported between shifts. This is a requirement of the mining laws in West Virginia. Only those parts of the stage loader, which are necessary to clear the headgate area for removal of other face equipment, are disassembled and removed.

The headgate transition or connecting face conveyor section or pan is removed by scoop and rail track is extended from the headgate entry to meet the panline. During this procedure, the shearer is being prepared for removal. Preparation of the shearer can begin after a two hour lag from the start of the recovery area bolting in order to clear the roof bolters from the headgate area. A specialized shearer lowboy with a chainless haulage (Eicotrak) attachment is pushed to the panline and the lowboy Eicotrak is connected to the panline. The shearer is trammed onto the lowboy and pulled into the next or #2 entry to remove the cowls and drums. The shearer is then moved and coupled to the headgate drive lowboy in order to remove it between shifts. The rail track from the panline to the headgate track is removed, loaded onto a rail car, and transported off the section.

Upon removal of the track and tailgate drive, the face conveyor chain is cut and pulled with a scoop into the headgate area, where it is pieced, loaded on rail lowboys, and either stored or transported off the section. Cables and hoses along the face are gathered, bundled, and removed from the face area. When the conveyor chain is clear of the tail section, 10-foot sections of the face conveyor are removed through the tailgate. These sections are stored in the tailgate entries for later transport outside the mine. Approximately 75% of the face conveyor is removed through the tailgate. In the headgate, the shearer cowls and drums are transported by scoop to rail lowboys and taken off the section. Once the headgate is clear, face conveyor sections are removed by scoop. Removal of the conveyor sections through the headgate and tailgate continue until all sections are withdrawn.

Crib blocks are built under the four sets of overhanging I-beams in the tailgate entry to prepare for tailgate shield recovery. The three tailgate shields are removed by loading onto a scoop, transporting, and unloading onto a rail lowboy in the tailgate entry. This mine loads shields onto the end of the rail lowboys rather than the side. Immediately after the removal of each tailgate shield, crib blocks are built under the exposed I-beams. A scoop and winch ropes are used to turn the next two shields to travel parallel to the face stop line. These walking shields, or simply walkers, are positioned adjacent to each other and an attachment bar or F-frame is connected. This provides anchorage to recover the remaining face shields and to advance the walking shields. Crib blocks are built immediately under the exposed I-beams.

A scoop is located on the headgate side of the walkers. The walkers are positioned flush with the first face shield to be recovered through the headgate. The walker immediately adjacent to the face is advanced and the first face shield is lowered to provide clearance for the second walker to advance and set. The second walker is now set against the roof directly above lowered face shield. The face shield is lowered completely, all hoses, cables, and power is unhooked, and the F-frame and winch from the scoop are used to pull the shield into the recovery room. The scoop winch is used to pull the collapsed shield onto the scoop bucket. The scoop then transports the shield along the face to a rail lowboy in the headgate entry for transport to the new panel. Two shield lowboys are transported per trip. Once the face shield is clear of the walkers, two to three crib blocks are built in the space left unsupported by the shield. Cribs are transported to the recovery area from the headgate entries by the same scoops transporting the shields. The cribs are stored on the toes of the walkers and shields adjacent to the one being currently recovered. After the crib blocks are erected, the walkers are advanced to the tip of the next shield to be recovered. This cycle continues until all face shields are recovered from the face area. The F-frame is then removed from the walkers and they are removed by scoop to rail lowboys for transport to the setup area.

The face area of the old panel is now empty. Support equipment, used during the recovery, is loaded and removed from the section. Permanent ventilation stoppings are erected in strategic locations to develop airways for the adjacent panel, since the current headgate becomes the tailgate for the adjacent panel. Available personnel disassemble the stage loader and section belt conveyor tailpiece at a convenient time. This equipment will be rebuilt and used as spare equipment on another panel.

Spare Equipment Installation: A transfer which utilizes spare equipment, except shields, during the installation is described. The installation must begin with enough lead time to insure that the process is finished, except for shield installation, prior to the transport of the first shields from the old panel.

Longwall panel ventilation is established and several stoppings in the headgate and tailgate are removed to allow for roadways during setup. Crib blocks are set in the tailgate and bleeders to provide long-term roof support in these areas. Temporary scoop battery charging stations are established in the headgate entries beyond the headgate track. The longwall transformer and pump car are installed in the headgate entries and the section belt tailpiece is properly positioned. The headgate track is extended toward the setup area until flush with the #1 headgate entry. The following hoses and cables are transported to the longwall setup switch:

(1) Four 4/0 electric, 2.31-inch diameter;
(2) Electric control, 2.0-inch diameter;
(3) Hydraulic return, 2.8-inch diameter;
(4) Two hydraulic pressure, 1.98-inch diameter;
(5) Water supply, 1.95-inch diameter;
(6) Emulsion hose; and,
(7) 30 Victaulic couplers.

Cables and hoses are pulled separately down the section belt entry from the transformer location. The cables and hoses are bound with the Victaulic couplers every 20 feet. The couplers are then hung on the first row of roof bolts down the belt entry and across the entry to the transformer. All cables for longwall face equipment is hung separately on the face. Some cables extend the full face width, including the tailgate power cable, hydraulic return hose, methane monitor cable, water hose, communication cable, welder cable, temporary emulsion hose, and temporary phone line. The shearer power cable and shearer water hose extend only half the face width. Each cable/hose is pulled five to ten feet beyond their desired length and hung on the face with spads and insulated wire.

The boxed face conveyor chain and flights are spotted at the tailgate end of the longwall in direct line of the face conveyor installation area. The tailgate drive is spotted in the #1 tailgate entry flush with the face start line. Spotting the conveyor chain, flights, and drive facilitates the efficient installation of the face conveyor. The face conveyor is transported to the setup area on rail lowboys in 10-foot sections. A conveyor section is winched into a scoop bucket and transported to the desired location on the tailgate end of the setup area. The scoop unloads and positions each section in a pre-marked location. Once positioned, a 10-foot roof bolt is used to push a wire rope, connected to the conveyor chain in the tailgate intersection, through the bottom of the section. The scoop then pulls, via the wire rope, the chain through the opening of the bottom deck with the flights upside down. The scoop then pushes the pan section against the sections already in place and returns to transport the next conveyor section. The sections of face conveyor are connected together.

The conveyor installation process continues until 100 to 300 feet of conveyor and bottom chain have been installed. The top conveyor chain is then installed along the existing conveyor sections. A wire rope, the length of the installed conveyor, is laid on top of the conveyor and attached to a scoop and conveyor chain. The scoop is trammed toward the headgate pulling the chain the length of the conveyor. The process of alternately installing conveyor sections and chain continues until all conveyor sections, except the head transition pan, has been installed. The top conveyor chains are pulled 20 feet past the last pan section to allow slack for the transition pan and connection of top to bottom chain.

At this point, work is conducted in both the tailgate and headgate areas. In the longwall tail, the tailgate transition pan is transported from rail lowboy by scoop and placed two feet from the first panline section. A 10-foot roof bolt is used to thread a wire rope attached to the conveyor chain through the transition pan. The bottom chain is then pulled through the pan by the scoop and the pan is pushed against the first section and connected. The previously placed tailgate drive is now moved in line with the transition pan and the 10-foot roof bolt is threaded through the drive. The scoop pushes the drive against the transition pan and pulls the conveyor chain slack through the drive. The drive is bolted to the transition pan and the gob plate is transported by the scoop to the drive and pinned. The tailgate area is now prepared to receive face shields.

In the headgate area, the shearer cowls and cutting drums were transported to the setup by rail lowboy during the conveyor and chain installation. The cowls and drums are placed by scoop in the #1 headgate entry next to the shearer stall. While this occurs, the rail track is extended from the headgate entry to meet the panline. The shearer, transported to the setup area on a shearer lowboy, is now aligned with the cowls and drums in the #1 headgate entry. Temporary power is connected to the shearer and the tailgate side cowls and drums are installed. The chainless haulage (Eicotrak) attachment on the lowboy is connected to the panline and the shearer is partly trammed onto the panline. The headgate ranging arm is aligned with the remaining cowl and drum and they are installed. The shearer is trammed completely off the rail lowboy onto the panline, the Eicotrak is disconnected, and the lowboy removed from the area. The rail track is recovered to the rib line of the #2 headgate entry. A scoop pushes the panline toward the face until the shearer is fully in the stall area and temporary power to the shearer is disconnected.

The headgate transition pan is brought from a rail lowboy by scoop and spotted two feet from the last conveyor section. A 10-foot roof bolt is used to thread wire rope connected to the conveyor chain through the transition pan. The chain is then pulled through the pan by the scoop and the pan is pushed against the first section and connected. The headgate drive is now moved in line with the transition pan and the 10-foot roof bolt is threaded through the drive. The scoop pushes the drive against the transition pan, pulls the conveyor chain slack through the drive, and the drive is bolted to the transition pan. The slack from the top conveyor chain is placed over the drive and the top and bottom chains are connected. This connection procedure is repeated at the tailgate drive.

Cables and hoses, which were previously hung on the setup face, are installed onto the face conveyor. The hydraulic hose, communication cable, and methane cable are removed from the face and placed, one at a time, in the lower of the three compartment trays on the conveyor. The medium voltage electrical cables are placed in similar fashion in the middle compartment and keeper pins on the lower and middle trays are installed. The shearer cable and waterline are removed from the face and laid on the conveyor. The nylon cable holder, or bretby chain, is attached to the cable and waterline in sections. This configuration is placed in the conveyor cable trough, or upper open compartment of the conveyor. The tailgate and headgate drive cables are wired to the drives and the shearer cable is wired to the midface box and the shearer itself. The safety pull cord and phone line are installed along the face.

The stage loader installation can actually begin immediately after the setup area has been prepared, but prior to any equipment installation. However, since the stage loader is somewhat removed from the face equipment, it is installed when workers are available. The sequence of installation for the stage loader sections is as follows:

1. transition section from headgate drive to stage loader,
2. three flex pans,
3. crusher,
4. crusher discharge section,
5. electrical power boxes,
6. transition pan for gooseneck off of crusher discharge,
7. inspection door section of gooseneck,
8. boom section of gooseneck,
9. transition pan to the stage loader drive frame,
10. stage loader drive frame,
11. section belt conveyor tailpiece.

The stage loader electrical power boxes are wired to the appropriate sections of the stage loader and the stage loader is aligned and connected to the headgate drive, once installed. Final cleanup and checks are made in preparation of the face shields arriving from the recovery area. A lag time of one week is desirable between the finish of the setup area preparation and the arrival of the first shields.

Shield Installation: The three tailgate shields are the first to arrive in the setup area on rail lowboys. The first shield is removed from the lowboy by scoop with the long axis of the shield oriented perpendicular to the long axis of the scoop. The scoop trams to the tailgate end of the longwall face to set the first shield in place and then returns for the next available shield. The shields are placed so that the front base is 2.5-feet from the panline and each ram arm is in line with the conveyor attachment device, or clevis. As the shields are being installed, workers connect the hydraulics and electricals. A temporary emulsion hose is used to open the collapsed shield for clearance. This process continues until all face shields have been installed.

As face shields are removed from the recovery area, they are loaded for transport, two shields are transported per trip, and they are installed in the setup area in the shortest feasible time. The average time to remove a shield from the recovery area and prepare for transport to the setup area is 30 minutes. Therefore, from the start of shield recovery to the start of shield transport at two shields per trip, a lag of one hour occurs. The average transport time from the recovery to the setup area is one hour, resulting in a start-to-start lag of one hour from the beginning of transport to the beginning of installation.

Adjustments and Checks: Final hydraulic and electrical wiring and connections are performed and checked for operation. All electrical equipment are checked for proper grounding and the face conveyor chain is tightened to its operating tension.

Temporary cables and hoses are removed from the setup area and transported off the section. Several non-cutting passes are made to check the simultaneous operation of the complete system for interaction problems. Finally, two or three cutting passes are made while the system is monitored for operational effectiveness. If no problems are encountered, the longwall system goes back into full production mode.

As the final checks are performed on the longwall system in the setup area, a number of support operations are occurring in the gate entries. Included are:

1. Build cribs in bleeders,
2. Build cribs in tailgate to regulator,
3. Move and setup battery charging station and regulate to return,
4. Recover rail track approximately 500 feet in headgate,
5. Move transformer and pump cars to track entry,
6. Rebuild belt and fresh air walls temporarily removed for setup,
7. Hang double check curtains inby last open break in #2 & #3 headgate entry,
8. Spot parts car outby face one break between #3 and #4 entry.
9. Move longwall winch approximately 1000 feet from face in #2 entry intersection,
10. Build double cribs in #1 entry crosscuts aligned with face and outby face one break,
11. Spot longwall supply and belt cars at end of track.

Transfer Description - No Spare Equipment

The following transfer is typical for Mine A when no spare equipment (NSE) is available. The description of the transfer will highlight only those activities which differ from the spare equipment (SE) transfer. All major pieces of equipment except shields had to be transported and rebuilt or serviced during the recovery process. The general sequence of the NSE transfer is the same as the SE transfer with the exception of aligning the timing of the installation process with the arrival of equipment from rebuild or from the recovery area.

Recovery Room: Development of the recovery room is the same for transfers with or without spare equipment for this mine.

Equipment Removal: Disassembly of the stage loader begins immediately after the final pass versus after the beginning of recovery area bolting as in the SE transfer. Work continues on the stage loader until sections can be removed and transported to the setup area for service and installation. This work occurs as personnel are available, since the float or slack time for this activity, prior to its installation, is approximately five days.

The tail drive, head drive, and head drive connecting pan are recovered and installed in the same sequence as the SE transfer. After removal, the tail drive is transported to the setup area and spotted in the #1 tailgate entry for installation, after the face conveyor sections are in place. The head drive and connecting pan are disassembled at the same time as the tail drive, transported to the setup area to be installed after service and the shearer installation. The shearer is now recovered, taken outside the mine for rebuilding, and transported to the setup area for installation. Whereas, the head drive, tail drive, and shearer installation must wait for the installation of other equipment recovered after them, the face conveyor is recovered, transported, serviced, and immediately installed.

Spare Equipment Installation: This step is not applicable in the NSE transfer.

Shield Installation: The shields are recovered, transported, serviced, and installed in coordination with the installation of the face conveyor sections. Here, the NSE transfer differs from the SE transfer. In the SE transfer, installation of the face conveyor, tail drive, head drive, head drive connecting pan, and shearer is completed prior to the arrival of the first shield to the setup area. In the NSE transfer, the shearer, head drive connecting pan, and head drive are installed after the completion of the conveyor and shield installation. Since these activities are after the shield installation, they occur along the critical path. The tail drive installation occurs after the conveyor is installed, as a non-critical activity.

Two major differences in the SE and NSE transfers are recognized. (1) In the NSE transfer, all face equipment, not just the shields, must be recovered quickly, transported, serviced or rebuilt, and installed. (2) The SE transfer is nearly completed, except for final adjustments and checks, after completion of shield installation. After shield installation in the NSE transfer, the shearer, head drive connecting pan, head drive must be installed and the conveyor chain must be tensioned prior to final adjustments and checks. All of these activities are on the critical path for the NSE transfer but are non-critical for the SE transfer. This extends the execution length of the NSE transfer.

Adjustments and Checks: These steps are the similar for transfers with or without spare equipment for this mine.

Case Study - Mine B

The mine is located in southwest Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted as metallurgical coal. The Pocahontas No. 3 seam is being mined with a seam and cut height ranging from 72 to 78 inches. The mine is a dedicated longwall operation with six active continuous mining development and two longwall sections. The two longwall sections do not operate at the same time due to power, haulage, and preparation plant capacity limitations. Four development or gate entries are used on 120 by 100 foot average centers. The panel length ranges from 4000 to 7000 feet and width averages 600 feet. Three production shifts per day are used on a five workday per week basis. The mine produces 8000 tons of run of mine (R.O.M.) coal per production day with an average of 40% reject. The production crew consists of one supervisor, one shearer operator, one shield operator, one mechanic, and one person in the gate area, for a total of five workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, Dynatrac haulage system, approximate weight 50 tons;
Face Conveyor - Halbach & Braun, 33.75 inch width, twin inboard chain;
Drives - Halbach & Braun, 350 HP motor at head and tail, crossframe discharge system at head;
Stage Loader - Halbach & Braun, 40.6 inch width;
Roof Support - 120 Meco International shields, 4 leg, 808 ton yield pressure, approximate weight 21 tons each.

The mine utilizes the adjacent longwall panel system with an overburden range of 1,500 to 2,400 feet. Ground conditions are relatively good with a sandy shale immediate roof and sandstone main roof. The floor is predominately clayey shale and competent, except when wet.

Transfer - General

The two longwall systems in this mine share a spare set of equipment, with the exception of shields. Every effort is made to schedule transfers of the two systems with a time interval large enough to have the spare equipment available for all transfers. Transfers of the two systems were observed by the researcher, with each observation being four to six hours in length. The first observation occurred during the removal of the shearer and subsequent recovery area roof bolting. At the time of the second visit, shield recovery was observed. The setup area, with spare equipment installed, was examined during the first visit.

With the use of spare equipment, the complete transfer process is planned for approximately nine days, or two weekends and five production days. The strategy is to completely finish the transfer by the seventh day or first full Friday of the move. This provides two full non-production days to get the system operational and in full production mode. It also allows for any problems encountered which may increase the time required for a particular move.

A headgate recovery system is used for the face transfer. All equipment is removed through the headgate entry. With a minimum overburden thickness of 1500 feet, ground conditions in the tailgate area warrant the use of this recovery system. Specialized transfer equipment used at this mine includes:

(1) Inby transport - Eimco 592 diesel scoops (2);

(2) Outby transport - Tools Works Industry (TWI) lowboy rail car;
(3) Walking shield advance - F-frame; and,
(4) Roof bolter - Fletcher Slimline (2) and Dynatrac bolters (2).

This operation uses a comprehensive transfer procedure document, including the only bar chart of all mines in the research. The recovery manual, developed by on-site management, and a time study of a previous transfer were collected for the research. The manual contains divisions of the recovery process into 29 major tasks, each with instructions, required materials, personnel, and shifts. Layout sketches for shield recovery are included in the manual. The installation process was divided into 27 major tasks by the longwall coordinator during an on-site interview.

Personnel requirements for individual transfer activities were provided by the transfer coordinator. With these data, a labor utilization profile was generated (see Figure 1). From this profile, it is evident that more personnel (19 workers) are required at startup leveling off to nearly a constant (11 workers) for the remainder of the recovery. Project management software allows resource tracking during the planning stages of a transfer, as is done in this case. In addition, historical resource data can supplement planning. In either case, accurate resource planning and control is possible.

Transfer Description

The following transfer is typical for Mine B with spare equipment used. All major pieces of equipment except shields were spare and available for installation prior to the beginning of the recovery process.

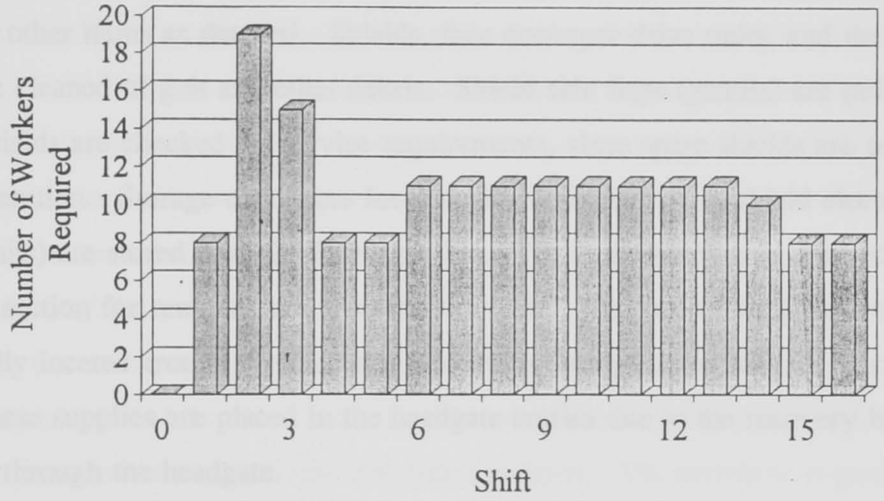


Figure 1 Mine B Labor Utilization Profile

Pre-Transfer Preparation: Pre-transfer work is organized and executed through the longwall coordinator and longwall section foreman. Face equipment preparation is performed by the longwall face crew, with the aid of available utility personnel, if needed. All other preparation work is done by utility personnel. The longwall coordinator stated that past experience justified a great deal of attention to preparation work in order to enhance the efficiency of the transfer.

Pre-transfer preparation includes equipment cleaning and service checks, extra roof support installation, supply delivery and storage, transport route checks and trial runs, and other items as detailed. Shields, face conveyor drive units, and the stage loader are cleaned of gob and other debris. Shield side flaps (guards) are pulled in and all shields are checked for service requirements, since spare shields are not used in this operation. Storage containers for sensitive equipment (i.e. shield electronic control units) are stored near the face stop line. The face conveyor is marked at each third pan section for removal as a three-section unit. All transfer supplies are strategically located around the face stop line in the headgate and tailgate entries. The bulk of these supplies are placed in the headgate entries due to the recovery being primarily through the headgate.

Prior to the initial development of the recovery room, extra roof support is provided by the installation of eight-foot "super" bolts in those headgate and tailgate entries which align with the face stop line and subsequent recovery room. The special "super" bolts are two steel sections each four feet long and are secured by a combination of resin and shell anchors. Mine B does not use the wire meshing procedure to prevent gob flushing during shield recovery. Mine management believes the roof is stable enough and less time will be lost due to gob flushing versus wire mesh installation.

Recovery Room: The mine schedules the start of the recovery process for a Friday second or third shift by altering, if necessary, the production rate of the longwall system as it approaches the face stop line. If production must be increased, as is usually the case, the third or maintenance shift becomes a production shift. If needed, the rate is decreased by simply taking more time to effect production. A late Friday finish allows the weekend to begin equipment disassembly.

The last full cutting pass of the shearer is made as to align the face stop line and what will be the recovery room with an open crosscut in the headgate and tailgate entries. Once the last full cutting pass is made by the shearer, the shields are advanced for the last time and one more cutting pass is made. A hydraulic cylinder built into the shield base connects it to the face conveyor and provides both a means to push the conveyor forward and to advance the shield. The hydraulic cylinders or rams can be extended to advance the face line one full cut (30 to 36 inches). Establishment of the recovery room requires the shearer to make two to four cuts beyond the last advancement of the shields. Ram extensions must be used to push the face conveyor forward for these cuts. In this mine, three foot long, crib blocks are used as extensions between the ram and face conveyor. The conveyor is pushed forward without advancing the shields so that one full cutting pass and another clean-up pass can be made. The shearer is parked at the headgate and the face conveyor is pulled back completely to the shield bases with 3/4-inch chain connected between the shields and conveyor.

The established recovery area is approximately 10 to 12 feet wide from the face stop line to the base of the shields. Roof bolting machines support the newly developed area as soon as it is accessible. Accessibility is provided after the head drive, connecting pan, and shearer have been removed.

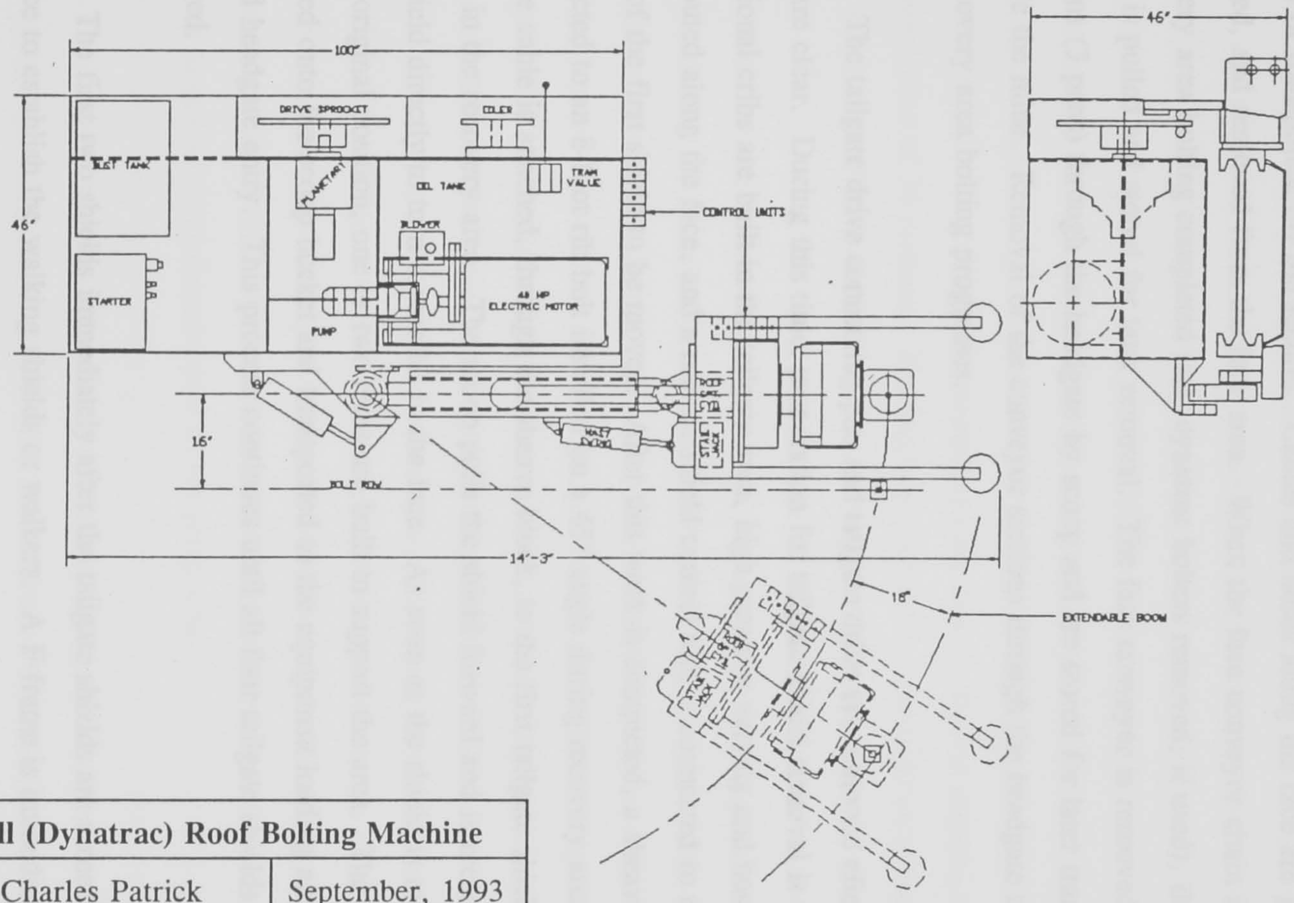
Equipment Removal: Mine B alternately operates two longwall sections at this location and maintains a complete set of spare longwall equipment, except for shields. Therefore, during a transfer, all equipment (other than shields) is being recovered for rebuild. The equipment to be rebuilt can be either transported out of the mine, if time allows, or stored for later removal. Transfer personnel realize that shield recovery is of primary importance and all other equipment is secondary and thus handled accordingly.

As the recovery is still being developed by the last two cuts of the shearing machine, the preparation for headgate drive removal begins. As soon as the last cut is finished, the head drive motor is removed. Bolts between the drive and connecting pan and the face conveyor and stage loader chains are cut with torches. The head drive unit is removed and stored in a headgate entry for later removal. Once the head drive is clear, the "dogbone" connectors and sandwich plates on the connecting pan are removed and the pan is removed and stored similar to the head drive. As soon as the head drive and connecting pan are clear of the headgate crosscut aligned with the longwall face stop line, rails are laid from the existing supply track line in the second headgate entry around the 90° turn to the face conveyor. This will provide a means for the shearer removal.

As the rail track is being extended to the face conveyor, the shearer is simultaneously being prepared for removal. This involves the removal of cowls and cutter drums. The shearer is then trammed to the first normal pan section (previously next to connecting pan). The rail track is laid to the end of this pan section and a rail lowboy (shearer transporter) is pushed by a diesel locomotive to the conveyor. The shearer transporter with a specialized "dynatrac" attachment is positioned to align its dynatrac with the dynatrac of the face conveyor. This action provides the shearer the ability to tram itself directly onto the lowboy. The rail directly under the lowboy is blocked with cribs to provide extra support to withstand the weight of the shearer. The shearer is trammed onto the lowboy and the ranging arms are supported with crib blocks. The shearer power cable, cable handle, water line, and dynatrac chain are cut to free the shearer and lowboy. The assembly is removed by diesel locomotive to a designated area for later removal from the mine for rebuild.

Four activities simultaneously begin, dependent upon available personnel, with the removal of the shearer. Shield lights, shield control units (CIU's) and every third face conveyor connector (dogbone and sandwich plate) are removed along the face line. At the same time, the rail track used to recover the shearer is retracted to its previous supply track position. As the track is being cleared, two narrow chassis roof bolters are brought through the headgate entry to the recovery area. Approximately one hour is needed to remove the track sufficiently to bring in the roof bolters. When the rail track is in its original supply position, a straight section is extended past the headgate crosscut aligned with the longwall stop line. The intersection in the headgate crosscut will be used as an equipment loading area, especially for shield recovery.

At the time of the on-site verification visits to this operation, a new type of bolting machine was being tested. The longwall bolter, made by J.H. Fletcher and Company, operates on the face conveyor similar to the shearer (Figure 2). This bolting machine rides along the conveyor propelled through the Dynatrac chain has an extendible arm for drilling and bolt insertion. Two of these machines are used in tandem with the narrow bolters previously described to quicken the bolting process. The longwall bolters are moved to the recovery area via shield transporters and are installed immediately after removal of the shearer. While they are still in testing, the longwall coordinator reported satisfactory success with the longwall bolters.



Longwall (Dynatrac) Roof Bolting Machine	
Drawn by Charles Patrick	September, 1993
Adapted from Fletcher, 1992	Not to Scale

Figure 2 Longwall (Dynatrac) Roof Bolting Machine (Adapted from Fletcher, 1992)

Upon removal of the track, the face conveyor chain is cut and pulled with a scoop into the headgate area, where it is pieced, loaded on rail lowboys, and either stored or transported off the section. Cables and hoses along the face are gathered, bundled, and removed from the face area. When the face conveyor chain is clear and recovery area bolting completed (and dynatrac bolters removed, if used), the dynatrac chain is pulled and stored for later removal. The face conveyor is removed 15-foot sections (3 pans) through the headgate by scoop and are stored for later transport outside the mine. Removal of the conveyor sections through the headgate continues as recovery area bolting progresses.

The tailgate drive connecting pan and tailgate drive are removed after all other pans are clear. During this time, preparation for tailgate shield removal is done. Additional cribs are built in the tailgate area, high pressure valving and hoses are distributed along the face, and a remote shield control unit is connected to the valve pack of the first shield to be moved. After this work is completed, a sheave block is connected to an 8-foot rib bolt installed on a 45° angle during recovery area bolting. A wire cable is attached, through the sheave block, to the first tailgate shield and a scoop in the recovery area. The scoop pulls the shield forward and is reconnected to the shield directly to turn it parallel to the face. As soon as the shield is moved out of its original position, one or two cribs are built to support the area. The shield is winched onto the scoop bucket and transported to the equipment loading area in the second headgate entry. This process continues until all four tailgate shields are removed.

The first two shields immediately after the tailgate shields are turned parallel to the face to establish the walking shields or walkers. A F-frame is immediately attached to the walkers to provide anchorage for the walkers and line shields. A scoop is located on the headgate side of the walkers. The walkers are positioned flush with the first face shield to be recovered through the headgate. The walker immediately adjacent to the face is advanced and the first face shield is lowered to provide clearance for the second walker to advance and set. The second walker is now set against the roof directly above lowered face shield. The face shield is lowered completely, all hoses, cables, and power are unhooked, and the F-frame and winch from the scoop are used to pull the shield into the recovery room. The scoop winch is used to pull the collapsed shield onto the scoop bucket. The scoop then transports the shield along the face to a rail lowboy in the headgate entry for transport to the new panel. Two shield are transported per trip. Shields require, on average, a removal time of 30 minutes. The longwall coordinator reported an average removal of 16 shields per 8-hour shift.

The first shields to be transported are the tailgate shields in groups of two. Two shields at a 30-minute removal time prior to the first transport yields a 1-hour lag from the start of shield recovery and the start of shield transport. Once the face shield is clear of the walkers, two to three crib blocks are built in the space left unsupported by the shield. Cribs are transported to the recovery area from the headgate entries by the same scoops transporting the shields. The cribs are stored on the toes of the walkers and shields adjacent to the one being currently recovered. After the crib blocks are erected, the walkers are advanced to the tip of the next shield to be recovered. This cycle continues until all face shields are recovered from the face area. The F-frame is then removed from the walkers and they are removed by scoop to rail lowboys for transport to the setup area.

The face area of the old panel is now empty. Support equipment, used during the recovery, is loaded and removed from the section. Permanent ventilation stoppings are erected in strategic locations to develop airways for the adjacent panel, since the current headgate becomes the tailgate for the adjacent panel. Available personnel disassemble the stage loader and section belt conveyor tailpiece at a convenient time. This equipment will be rebuilt and used as spare equipment on another panel.

Spare Equipment Installation: A spare set of longwall equipment, except shields, is available for Mine B. The installation of these spares must begin with enough lead time to insure that the process is finished, except for shield installation, prior to the transport of the first shields from the old panel. The longwall coordinator preferred a minimum of one week lag time. Mine B does not use documented procedural manuals for spare equipment installation. Therefore, the level of detail in this description is limited to information gathered during on-site visits.

Longwall panel ventilation is established and several stoppings in the headgate and tailgate are removed to allow for roadways during setup. Crib blocks are set in the tailgate and bleeders to provide long-term roof support in these areas. Temporary scoop battery charging stations are established in the headgate entries beyond the headgate track. The longwall transformer and pump car are installed in the headgate entries and the section belt tailpiece is properly positioned. The belt structure is installed in the headgate up to the stage loader position.

Cables and hoses are pulled separately down the section belt entry from the transformer location. All cables for longwall face equipment are hung separately on the face. Some cables extend the full face width, including the tailgate power cable, hydraulic return hose, methane monitor cable, water hose, communication cable, welder cable, temporary emulsion hose, and temporary phone line. The shearer power cable and shearer water hose extend only half the face width. Each cable/hose is pulled five to ten feet beyond their desired length and hung on the face with spads and insulated wire.

The face conveyor chain and flights are spotted at the tailgate end of the longwall in direct line of the face conveyor installation area. As this occurs, the tailgate drive and connecting pan are brought in and installed. The face conveyor is transported to the setup area by rail in 15-foot sections. A scoop unloads and positions each section in a pre-marked location. The conveyor chain is fed through the section and the sections of face conveyor are connected together.

The conveyor installation process continues until 100 to 300 feet of conveyor and bottom chain have been installed. The top conveyor chain is then installed along the existing conveyor sections. A wire rope, the length of the installed conveyor, is laid on top of the conveyor and attached to a scoop and conveyor chain. The scoop is trammed toward the headgate pulling the chain the length of the conveyor. The process of alternately installing conveyor sections and chain continues until all conveyor sections, except the head transition pan, has been installed. The top conveyor chains are pulled 20 feet past the last pan section to allow slack for the transition pan and connection of top to bottom chain. The gob plate is installed in the tailgate area as rail track is extended to the panline in the headgate area.

The shearer cowls and drums are spotted in the #1 headgate entry for installation on the shearer. The shearer, transported to the setup area on a rail lowboy, is now aligned with the cowls and drums in the headgate entry. Temporary power is connected to the shearer and the tailgate side cowls and drums are installed. The chainless haulage (Dynatrac) attachment on the lowboy is connected to the panline and the shearer is partly trammed onto the panline. The headgate ranging arm is aligned with the remaining cowl and drum and they are installed. The shearer is trammed completely off the rail lowboy onto the panline, the lowboy Dynatrac is disconnected, and the lowboy removed from the area. The rail track is recovered to the rib line of the #2 headgate entry. A scoop pushes the panline toward the face until the shearer is fully in the stall area and temporary power to the shearer is disconnected.

The headgate transition pan and then the headgate drive are installed. The face conveyor chain is threaded through the top and bottom of the connecting pan and drive. The chain is connected and tensioned across the face. Cables and hoses, which were previously hung on the setup face, are installed onto the face conveyor.

Stage loader installation can begin immediately after tensioning the face conveyor chain. Once installed, the belt structure in the headgate can be completely extended to connect to the stage loader. After the installation of the stage loader and the placement of the face cables and hoses, final wiring of all spare equipment is done. Final cleanup and checks are made in preparation of the face shields arriving from the recovery area. A lag time of one week is desirable between the finish of the setup area preparation and the arrival of the first shields.

Shield Installation: A 1-hour lag exists between the start of shield transport and the installation of shields in the new panel to allow for transport time between the recovery and setup areas. The four tailgate shields are the first to arrive in the setup area on rail lowboys. The first shield is removed from the lowboy by scoop and trammed to the tailgate end of the longwall face. The shield is set in place and the scoop then returns for the next available shield. The shields are placed so that the front base is approximately 2.5-feet from the panline and each ram arm is in line with the conveyor attachment device, or clevis. As the shields are being installed, workers connect the hydraulics and electrical components (lights and CIU's). A temporary emulsion hose is used to open the collapsed shield for clearance. This process continues until all face shields have been installed.

Adjustments and Checks: Final hydraulic and electrical wiring and connections are performed and checked for operation. All electrical equipment are checked for proper grounding and the face conveyor chain is tightened to its operating tension. Temporary cables and hoses are removed from the setup area and transported off the section. Several non-cutting passes are made to check the simultaneous operation of the complete system for interaction problems. Finally, two or three cutting passes are made while the system is monitored for operational effectiveness. If no problems are encountered, the longwall system goes back into full production mode.

Case Study - Mine C

The mine is located in southwest Virginia with all the reserves owned by the mine operator, a major corporation. All mined tonnage, after cleaning, is contracted for metallurgical coal. The Pocahontas No. 3 seam is being mined with a seam and cut height ranging from 65 to 70 inches. The mine is a dedicated longwall operation with four active continuous mining development sections. Four development or gate entries are used with a yield pillar design of 150-foot center stable pillars and 50-foot center yield pillars. The panel width and length average 730 and 6900 feet, respectively. Three production shifts and weekend maintenance are used on a five production workday per week basis. The mine produces 3700 tons of run of mine (R.O.M.) coal per production shift with an average of 32% reject. The production crew consists of one supervisor, two shearer operators, three shield operators, one mechanic, and two electricians, for a total of nine workers. Production equipment includes:

Shearer - Joy 4LS, double drum ranging arm, 720 HP, Supertrac haulage system, approximate weight 50 tons;
Face Conveyor - American Longwall, 39-inch width, twin inboard chain;
Drives - American Longwall, 500 HP motor at head and tail, cross-frame discharge system at head;
Stage Loader - American Longwall, 49 inch width;
Roof Support - 151 Hemscheidt shields, 2 leg, 750 ton yield pressure, approximate weight 16 tons each.

The mine utilizes the adjacent longwall panel system with overburden ranging from 1,050 to 2,700 feet. Ground conditions are relatively good with sandy shale immediate roof and sandstone main roof. The floor is predominately sandy shale and is problematic. Throughout the mine, five to six inches of floor is taken during the mining process to reach a more competent material.

Transfer - General

The complete transfer process is planned for approximately 16 days, or three weekends and 10 production days. The strategy is to completely finish the transfer by the 14th day or second full Friday of the move, given the transfer began on the second or third shift of a Friday. This provides two full non-production days to get the system operational and in full production mode. It also allows for any problems encountered which may increase the time required for a particular move. For this operation, a 16-day transfer is standard, regardless of the availability of spare equipment.

A headgate and tailgate recovery system is used for the face transfer. The tailgate face conveyor drive, tailgate drive connecting pan, and part of the face conveyor is removed through the tailgate entries. Specialized transfer equipment used at this mine includes:

(1) Inby transport - Simmons Rand scoop (603 - recovery, 605 - setup), Petitto mule in recovery;
(2) Outby transport - Difco lowboy rail car, diesel locomotives;
(3) Walking shield advance - F-frame;
(4) Recovery Roof Bolting - Almenco stopers (4 hydraulic, 1 pneumatic).

This operation utilizes a concise transfer manual assigning major tasks to longwall foremen. The manual, developed primarily for recovery by on-site management, was collected for the research. The manual contains divisions of the recovery process into approximately 45 activities, with a listing of each activity's planned execution shift. No layout sketches or drawings were available.

Personnel requirements for individual transfer activities were provided by the transfer coordinator. With these data, a labor utilization profile was generated (see Figure 3). As with mine B, it is evident from this profile that more personnel (30 workers) are required at startup leveling off for the remainder of the transfer to approximately 15 workers and again to 10 workers.

Spare equipment availability fluctuates, since trading of one set of spare equipment occurs between several of the owner's operations. However, a relatively consistent group of spare equipment was available, including the shearer and the face conveyor drives (headgate and tailgate). Therefore, the analysis was done assuming these spares were obtainable. This assumption was also suggested by the longwall coordinator.

Transfer Description

The following transfer is typical for Mine C when spare equipment is used. Spare equipment, available for installation prior to the beginning of the recovery process, includes the shearer and the headgate and tailgate drives for the face conveyor.

Pre-Transfer Preparation: Pre-transfer work is organized and executed through the longwall coordinator and longwall section foreman. Preparation includes equipment cleaning and service checks, extra roof support installation, supply and

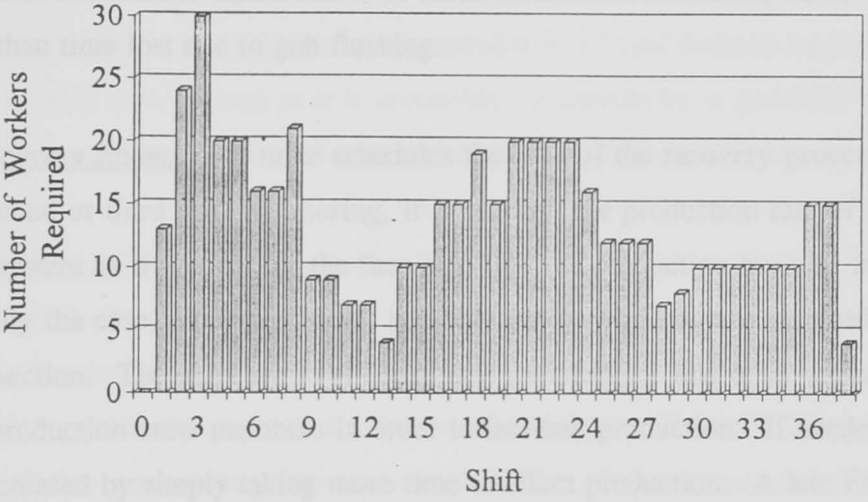


Figure 3 Mine C Labor Utilization Profile

equipment delivery and storage, transport route checks and trial runs, establishment of equipment loading and unloading areas, and other items.

Prior to the initial development of the recovery room, extra roof support is provided by the installation of truss bolts in those headgate and tailgate entries which align with the face stop line and subsequent recovery room. Mine C does not use the wire meshing procedure to prevent gob flushing during shield recovery. Mine management justified this practice due to a sufficiently stable roof and time savings. The longwall coordinator stated that wire mesh installation took more time, on average, than time lost due to gob flushing.

Recovery Room: The mine schedules the start of the recovery process for a Friday second or third shift by altering, if necessary, the production rate of the longwall system as it approaches the face stop line. If production must be increased, as is usually the case, more personnel, typically utility workers, are assigned to the longwall section. The extra workers assist with maintenance and other tasks normally done by production crew members in order to increase production. If needed, the rate is decreased by simply taking more time to effect production. A late Friday finish allows the weekend to begin equipment disassembly.

The last full cutting pass of the shearer is made as to align the face stop line and what will be the recovery room with an open crosscut in the headgate and tailgate entries. Once the last full cutting pass is made by the shearer, the shields are advanced for the last time and one more cutting pass is made. A hydraulic cylinder built into the shield base connects it to the face conveyor and provides both a means to push the conveyor forward and to advance the shield. The hydraulic cylinders or rams can be extended to advance the face line one full cut (30 to 36 inches). Establishment of the recovery room requires the shearer to make two to four cuts beyond the last advancement of the shields. Ram extensions must be used to push the face conveyor forward for these cuts. In this mine, a metal bar approximately three feet long, is used as an extension between the ram and face conveyor. The conveyor is pushed forward without advancing the shields so that one full cutting pass and another clean-up pass can be made. The shearer is parked at the headgate and the face conveyor is pulled back completely to the shield bases.

The established recovery room is approximately 10 to 12 feet wide from the face stop line to the base of the shields. One pneumatic and four hydraulic stopers are moved into the recovery room for the installation of roof bolts to support the newly developed area as soon as it is accessible. Accessibility is provided immediately after the shearer makes its final pass and is parked in the headgate.

Equipment Removal: The last pass of the shearer stops production of the longwall and the headgate belt structure is dismantled, providing enough personnel are available. The belt structure must, at least, be disconnected from the stage loader in order to disassemble the stage loader from the head drive. The head drive is a primary unit for removal to get to other major pieces of equipment on the face, such as the shearer, face conveyor, and shields. The stage loader and belt tailpiece is disassembled and transported to the setup area to be reassembled and connected to the longwall system after the installation of the face conveyor chain.

Upon completion of the recovery area bolting, removal of shield lights and face conveyor chain commence. When the conveyor chain is clear, the head drive and shearer are prepared for removal. The head drive and connecting pan are taken with the drive being stored or transported outside for rebuild. The shearer drums, cowls, and spray arms are removed and a power jumper is connected to allow for loading and disassembly without the master control box. The shearer is then pulled from the panline via two scoops. These scoops pick up the shearer at each end and carry it to the rail loading area in the #2 headgate entry where it is loaded onto a rail lowboy and transported out of the mine.

The Supertrac chain is pulled from the face conveyor by a scoop, loaded and removed from the area. Removal of the face conveyor is accomplished in 15-foot sections (3 pans) by scoop. Three hours after the start of the conveyor removal, the start of their transport to the setup area can begin. The three-hour lag is due to the initial retraction and loading time required for the conveyor. A one-hour lag exists from the start of conveyor transport to the start of their installation in the setup area.

Upon removal of the face conveyor, cables and hoses are gathered, bundled, and removed from the face area. At the same time, the tail drive and connecting pan are removed from the face by scoop and loaded for transport. Since a spare tail drive is available, the old drive and connecting pan are stored or transported outside the mine.

Crib blocks are built in the tailgate entry to prepare for tailgate shield recovery. The three tailgate shields are removed by pulling into the recovery room by a Petitto mule which drags the shield to the loading area in the #2 headgate entry. This and subsequent shields are loaded onto rail lowboys and transported in groups of three to the setup area. Immediately after the removal of each tailgate shield, three crib block supports are built under the exposed area and into the recovery room. Unlike Mine A and B, Mine C does not utilize walkers for shield recovery. Three crib supports are erected in the place of the shield just removed by the Petitto mule. The mule is used to drag the shield to the headgate area where scoops load the shield onto a rail lowboy. This cycle continues until all face shields are recovered from the face area.

The face area of the old panel is now empty. Support equipment, used during the recovery, is loaded and removed from the section. Permanent ventilation stoppings are erected in strategic locations to develop airways for the adjacent panel, since the current headgate becomes the tailgate for the adjacent panel. Available personnel disassemble the stage loader and section belt conveyor tailpiece at a convenient time.

Spare Equipment Installation: The installation of spares must begin with enough lead time to insure that the process is finished prior to the transport of the first non-spare equipment from the old panel. Longwall panel ventilation is established and several stoppings in the headgate and tailgate are removed to allow for roadways during setup. Crib blocks are set in the tailgate and bleeders to provide long-term roof support in these areas. Cables and hoses are pulled separately down the section belt entry from the transformer location. All cables for longwall face equipment is hung separately on the face. Some cables extend the full face width, while others, such as the shearer power cable and shearer water hose, extend only half the face width.

The boxed face conveyor chain and flights are spotted at the tailgate end of the longwall in direct line of the face conveyor installation area. The tailgate drive is spotted in the tailgate entry flush with the face start line. Spotting the conveyor chain, flights, and drive facilitates the efficient installation of the face conveyor. The tail drive connecting pan, tail drive, and gob plate are installed in that order. In the headgate area, the head drive, connecting pan, and shearer are transported to the setup by rail lowboy, unloaded by scoop and stored for later installation. The shearer ranging arms, cowls, and cutting drums will be installed on the shearer as it is being prepared for installation on the face conveyor.

Final cleanup and checks are made in preparation of the non-spare equipment arriving from the recovery area. A lag time of one week is desirable between the finish of the setup area preparation and the arrival of the first equipment from the recovery.

Non-Spare Equipment Installation: The face conveyor is transported from the recovery to the setup area on rail lowboys in 15-foot sections. A conveyor section (three pans) is winched into a scoop bucket and transported to the desired location on the tailgate end of the setup area. The scoop unloads and positions each section in a pre-marked location. Once positioned, a wire rope is fed through the bottom of the section for later pulling of the conveyor chain. Unloading and aligning the face conveyor continues until approximately 200 feet of conveyor sections are positioned. The top and bottom conveyor chain is then installed along the existing conveyor sections. The previously fed wire rope in the bottom of the conveyor is fastened to a 200-foot section of conveyor chain in the tailgate area. A scoop is attached to the other end of the wire rope and trammed toward the headgate pulling the chain the length of the conveyor. Another 200-foot section of conveyor chain is likewise pulled by scoop across the top of the conveyor. The process of alternately installing conveyor sections and chain continues until all conveyor sections, except the head transition pan, has been installed. The top conveyor chains are pulled 20 feet past the last pan section to allow slack for the transition pan and connection of top to bottom chain.

The longwall panel width in Mine C averages 730 feet and the face conveyor and chain are alternately installed in sections of 200 feet. After the third iteration (600 feet) of conveyor and chain installation, approximately 130 feet remains to be setup. After the final conveyor sections are positioned but prior to installation of the chain, the shearer is put onto the face conveyor. The shearer is brought from storage (as spare equipment) and placed on the conveyor by two scoops into a stall which was cut into the end of the face during development of the setup area. This stall provides adequate room to install the shearer arms, cowls and drums. While the shearer is being placed, installation of the conveyor chain begins and is completed approximately two hours after the finish of the shearer.

The setup area is now ready to receive shields from the recovery area. The shields arrive to the setup area on rail lowboys and are transported and placed in the setup face with scoops. As face shields are removed from the recovery area, they are loaded for transport and two shields are transported per trip. They are installed in the setup area in the shortest feasible time, since this activity is critical and can take nearly half of the total critical path time for the longwall setup. The average time to remove a shield from the recovery area and prepare for transport to the setup area is 30 minutes. Therefore, from the start of shield recovery to the start of shield transport at two shields per trip, a lag of one hour occurs. The average transport time from the recovery to the setup area is one hour, resulting in a start-to-start lag of one hour from the beginning of transport to the beginning of installation.

The three tailgate shields are the first to arrive in the setup area. The first shield is removed from the lowboy by scoop with the long axis of the shield oriented perpendicular to the long axis of the scoop. The scoop trams to the tailgate end of the longwall face to set the first shield in place and then returns for the next available shield. The shields are placed so that the front base is approximately 2.5-feet from the panline and each ram arm is in line with the conveyor attachment device, or clevis. As the shields are being installed, workers connect the hydraulics and electricals. A temporary emulsion hose is used to open the collapsed shield for clearance. This process continues until all face shields have been installed.

During shield installation, the arms, cowls and drums are attached to the shearer and the placement of face cables and hoses begin. The hydraulic hose, communication cable, and methane cable are removed from the setup face and placed, one at a time, in the lower of the three compartment trays on the conveyor. The medium voltage electrical cables are placed in similar fashion in the middle compartment and keeper pins on the lower and middle trays are installed. The shearer cable and waterline are removed from the face and laid on the conveyor. The nylon cable holder, or bretby chain, is attached to the cable and waterline in sections. This configuration is placed in the conveyor cable trough, or upper open compartment of the conveyor.

The conveyor headgate connecting pan and drive are installed just after the completion of the shearer drums. Then, the tailgate and headgate drive cables are wired to the drives and the shearer cable is wired to the midface box and the shearer itself. The safety pull cord and phone line are installed along the face. After the headgate drive and face shields are installed, the bottom and top flights of the conveyor chain are connected and the chain is tensioned.

Installation of the headgate conveyor belt structure, belt tailpiece and stage loader can actually begin immediately after the equipment is removed from the recovery area and the setup area has been prepared. However, since the stage loader and tailpiece are somewhat removed from the other face equipment, they are installed when workers are available.

Once all previous activities are completed, final electrical and hydraulic wiring and connections are made. All equipment is taken off temporary power and/or hydraulics and put on their permanent circuits. The longwall face is now ready for final adjustments and checks.

Adjustments and Checks: All electrical equipment are checked for proper grounding and the face conveyor chain is further tightened to its operating tension. Temporary cables and hoses are removed from the setup area and transported off the section. Several non-cutting passes are made to check the simultaneous operation of the complete system for interaction problems. Finally, two or three cutting passes are made while the system is monitored for operational effectiveness. If no problems are encountered, the longwall system goes back into full production mode.

As the final checks are performed on the longwall system in the setup area, a number of support operations are occurring in the gate entries. Included are:

1. Build cribs in bleeders,
2. Build cribs in tailgate to regulator,
3. Move and setup battery charging station and regulate to return,
4. Recover rail track approximately 500 feet in headgate,
5. Move transformer and pump cars to track entry,
6. Rebuild belt and fresh air walls temporarily removed for setup, and
7. Spot longwall supply and belt cars at end.

Recommendations

Data on longwall face transfers were gathered for this research from six companies who operate 38 of the reported 90 active U.S. longwall faces (Merritt, 1993). While only three particular mines were analyzed in detail, the collected database of information on U.S. longwall transfer techniques is quite large. The following recommendations are given with reference to this database and consideration of individual mine conditions, transfer methodology, and management style.

Recommendation 1: Mines A, B, and C have various levels of detail for their transfer plans. However, in each plan, the transfers are described on a micro-basis, rather than a macro-basis. There is no description of task interaction or the relationships between tasks. Transfer supervisors have good knowledge of these interactions from personal experience and transfer execution is well managed. However, the complex interaction and changing nature of a transfer's critical path(s) can overwhelm even the best of managers. Also, there is no method, other than shift-to-shift assignments, to most effectively allocate resources, especially personnel.

It is recommended to develop a scheduling process to more efficiently plan and control face transfers. A variety of inexpensive project management software packages can provide the capability to schedule transfers and keep track of resource utilization on an on-going basis. Further, this software can, with timely updating, provide information on the shifting nature of the critical path, and the resultant transfer activities where resources must be concentrated.

Recommendation 2: Mines A and C use sixteen-day time allotments for all transfers, including two weeks (ten production days) and three weekends (six non-production days). During discussions with the longwall coordinators, they indicated that any particular move may not actually take the total time. Normally 14 days were sufficient, allowing the final weekend (2 non-production days) for adjustments. In some cases, the transfer durations were less than 14 days.

The 16-day allotments are accepted by transfer supervisors and workers as the finish target time and, subsequently, assume no incentive to finish earlier. It is recommended to attempt a transfer in as short a time as possible. By changing the policy from an assumed 16 days to the earliest possible finish time, management instills an incentive to their personnel to increase efficiency.

Lost production potential for a longwall mining system is between $45 and $100 per minute (Hedges, 1984; Tucker, 1985). Using the lowest figure, every day of production gained in Mines A and C increases profit by more than $43,000. The actual figure may be higher depending on potential monetary gain per minute of production for these mines.

Recommendation 3: Information gathered in this research revealed a growing number of longwall companies are not installing screening over the face shields in the recovery area. Most companies have indicated more concern with the time lost from the installation of screening than the time saved by preventing gob flushing with screening. The geologic condition of the immediate roof primarily dictates the use of screening. A friable, easily broken material, such as weak shale, is good during the normal operation of a longwall since it does not tend to cantilever over the shields. However, this type of material creates excessive gob flushing into the recovery area when shields are removed.

The immediate roofs for Mines B and C are sandy shale and overburden thickness is greater than 1,500 feet in both mines. These mines are currently not using screening to secure the roof above the shields. Gob flushing was not identified as a problem, but the longwall coordinators indicated that shield recovery time could greatly vary. Large variations in shield recovery time may denote roof-shield interaction problems during shield removal.

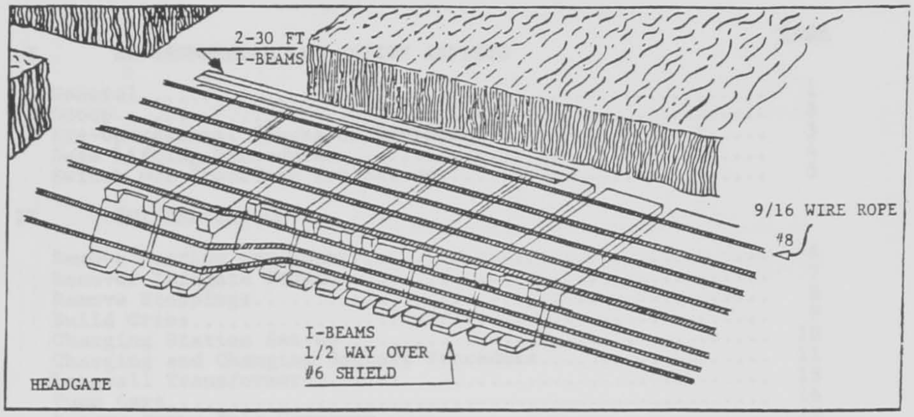
It is recommended to investigate the feasibility of attempting a transfer with screening. Feasibility is determined by a comparison of the time and cost savings of not using screening versus the extra time lost due to gob flushing into the recovery area when shields are removed. The reaction of the roof to unloading after a shield is removed can be simulated during the normal longwall production sequence. The time from unloading to roof failure could be determined by leaving a shield down while the adjacent shields are loaded until roof failure above the unloaded shield. By repeating this process, the average time of unloading to roof failure could be found. If this time is sufficiently greater than the time to support the roof with crib blocks in the place of a removed shield, screening may not be necessary.

Appendix C-1

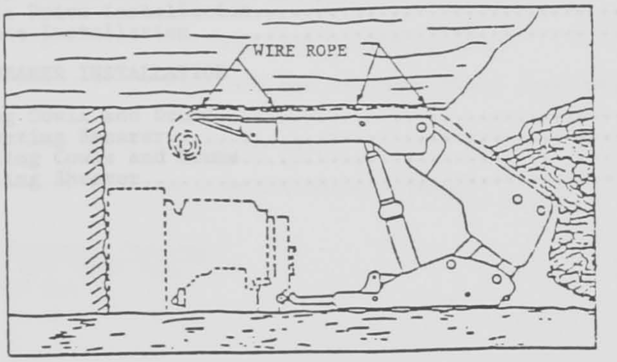
Mine A - Recovery and Installation Manual Excerpts

INDEX

INSTALLATION OF 30 FT. I-BEAMS



1. Hang #9 wire rope and ding to wire mesh.
2. Take 2-30 ft. I-beams to headgate and tailgate, lay both I-beams on top of drives and face conveyor.
3. The end of I-beams must be evenly located in middle of #6 shield at the headgate and in the middle of #116 shield at the tailgate.
4. Raise both I-beams together to roof at both headgate and tailgate.
5. Lower and advance #2 and #5 shield on the headgate end under I-beams and set shield.



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I. ENVIRONMENTAL AND SAFETY ASPECTS

II. INITIAL SET-UP

III. CABLES AND HOSES LAYOUT

IV. PANLINE INSTALLATION

V. SHEARER INSTALLATION

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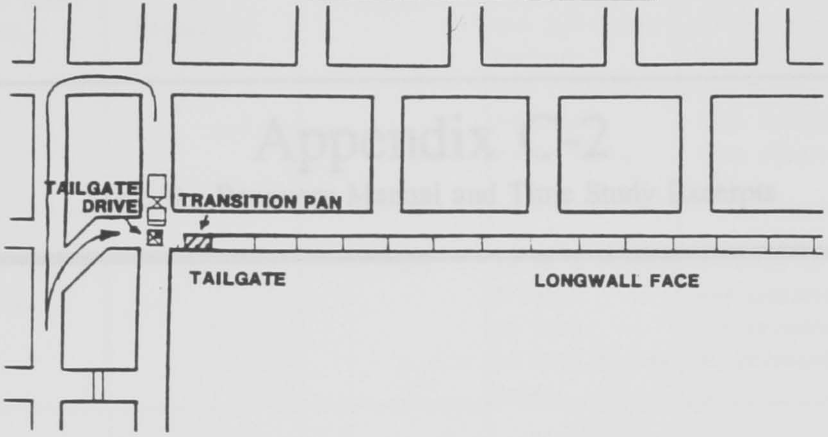
TAILGATE DRIVE INSTALLATION

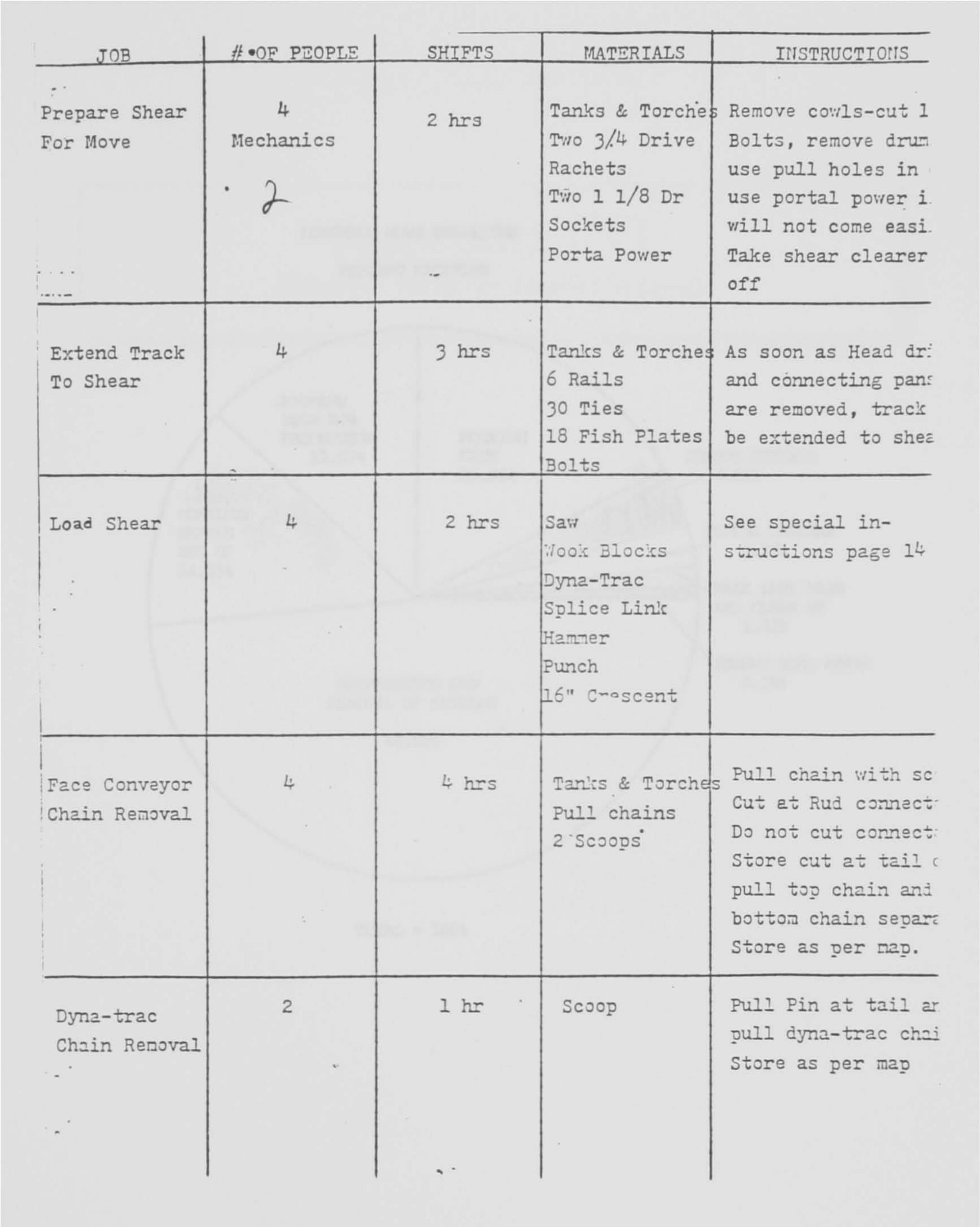


1. Place remaining conveyor chains on transition pan.
2. Hook wire rope and 10 foot roof bolt to conveyor chains and place on top of transition pan.
3. Hook winch rope on scoop to tailgate drive.
4. Spot tailgate drive in line with transition pan.
5. Unhook winch rope from tailgate drive.
6. Back scoop around block (as indicated).
7. Push 10 foot roof bolt and wire rope through tailgate drive.
8. Remove 10 foot roof bolt from wire rope.
9. Push tailgate drive with scoop next to transition pan.
10. Hook wire rope to scoop and pull conveyor chains slack through tailgate drive.
11. Bolt tailgate drive to transition pan.
12. Remove wire rope from scoop and conveyor chains.

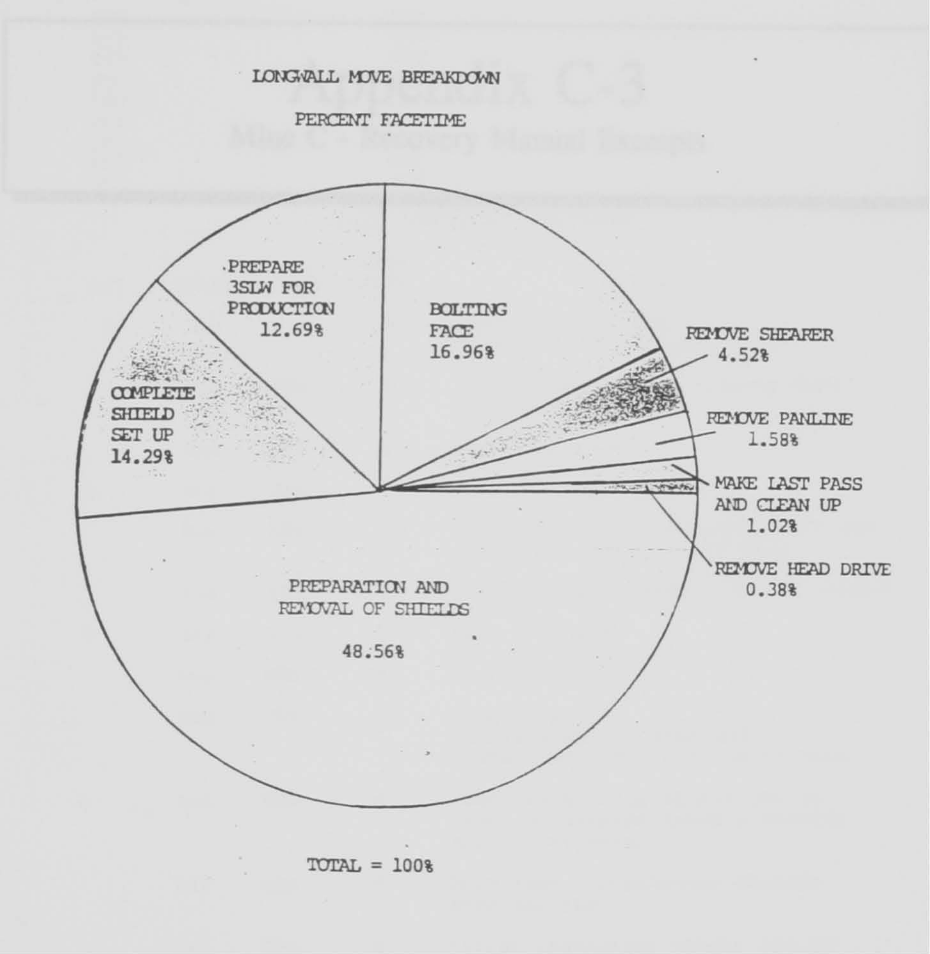
Tools and Equipment Required:
Scoop with winch rope
10' Roof bolt

Appendix C-2

Mine B - Recovery Manual and Time Study Excerpts



JOB	# OF PEOPLE	SHIFTS	MATERIALS	INSTRUCTIONS
Prepare Shear For Move	4 Mechanics 2	2 hrs	Tanks & Torches Two 3/4 Drive Rachets Two 1 1/8 Dr Sockets Porta Power	Remove cowls-cut 1 Bolts, remove drum use pull holes in use portal power i will not come easi Take shear clearer off
Extend Track To Shear	4	3 hrs	Tanks & Torches 6 Rails 30 Ties 18 Fish Plates Bolts	As soon as Head dr and connecting pan are removed, track be extended to shea
Load Shear	4	2 hrs	Saw Wook Blocks Dyna-Trac Splice Link Hammer Punch 16" Crescent	See special instructions page 14
Face Conveyor Chain Removal	4	4 hrs	Tanks & Torches Pull chains 2 Scoops	Pull chain with sc Cut at Rud connect Do not cut connect Store cut at tail pull top chain and bottom chain separ Store as per map.
Dyna-trac Chain Removal	2	1 hr	Scoop	Pull Pin at tail a pull dyna-trac chai Store as per map


LONGWALL MOVE BREAKDOWN
PERCENT FACETIME
PREPARE 3SLW FOR PRODUCTION 12.69%
BOLTING FACE 16.96%
REMOVE SHEARER 4.52%
COMPLETE SHIELD SET UP 14.29%
REMOVE PANLINE 1.58%
MAKE LAST PASS AND CLEAN UP 1.02%
REMOVE HEAD DRIVE 0.38%
PREPARATION AND REMOVAL OF SHIELDS 48.56%
TOTAL = 100%

Appendix C-3

Mine C - Recovery Manual Excerpts

CREW AND SHIFT ASSIGNMENTS

FOREMAN SYMBOL	SHIFT
SEV	Day
WIN	3rd
TPT	2nd
ROH	Day
DEV	3rd
POR	2nd
DON	Day
BOB	2nd
BLU	3rd

TASK SCHEDULE - RECOVERY

DAY	SHIFT	FRMN	CREW SIZE	TASK
1	3rd	WIN	10	Place mesh on AFC. Attach ropes and hang mesh.
	Day	SEV	8	Finish hanging and dinging mesh. Mine 1 pass.
	2nd	TPT	8	Mine 2 passes
2	3rd	WIN	8	Mine 2 passes
	Day	SEV	8	Place 2nd rolls of mesh in AFC and attach to 1st roll and hang
	2nd	TPT	8	Finish dinging mesh. Mine 2 passes.
3	3rd	WIN	8	Mine 2 passes
	Day	SEV	8	Mine 2 passes
	2nd	TPT	8	Mine 1 pass. Take shearer to head and install one row of bolts on face.
4	3rd	WIN	8	Continue bolting single row in front of shields using 2 stopers and 2 Fletchers.
	DAY	SEV	8	Bolt face. Disconnect shields from panline.
	2nd	TPT	8	Finish installing single row of bolts and disconnecting shields from panline. Install extensions,

FACE TERMINATION 3-North

ITEM		# REQUIRED
Air compressors		1
Air line		1000′
Air line connectors		30
Stoper hammers		2
Stoper wrenches w/socket		2
Stoper dust boxes		2
Assortment stoper steels		25
Rib drills		1
Rib drill bolt wrenches		2
Ding wire tool		10
Wire mesh-12.75 ga. 1 1/2" opening with 5/8" ropes pre-installed on 36" centers	100′ x 20 110′ x 20′	10 rolls 2 rolls
Wire mesh for gate headings	16′ x 25′	2 rolls
Rib boards		100
Rib bolts and resin		100
Conventional bolts 72"		250
Plates		400
Headers		1000
Orange rib mesh 5′x 164′		5 rolls
Fletcher bits		as required
Stoper bits		as required
Mule		1
Scoop with charger		2
Wire cutters		9
Assortment pull chains		45
Cribs		5000
Mules		2
Loading ramp		1

Appendix D

Simulation Program Listing and Sample Output

```
'************************************************************
'*                        ACT.EXE                           *
'* SIMULATION OF LONGWALL FACE TRANSFER PROJECT SCHEDULING *
'*                      IN QBASIC 4.5                       *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This QBasic program implements the experi-*
'* mental simluation model of a longwall face transfer     *
'* by the Monte Carlo method. Project scheduling analytical*
'* procedures are combined with probability-based activity *
'* duration parameters to conduct scheduling analysis.     *
'*                                                          *
'* A longwall face transfer, which involves removal of     *
'* longwall eqiupment in a used panel, transport, and      *
'* reassembly in a new panel, can be well represented      *
'* through project management techniques.  The transfer is *
'* divided into activities joined by predecessor/successor *
'* relationships,  reflecting the sequential nature of the *
'* transfer.  Activity durations are represented by        *
'* probability distribution functions called randomly to   *
'* provide time data for each iteration of the project     *
'* scheduling computations.                                 *
'*                                                          *
'* The program simulates the transfer process for the user *
'* specified iterations and produces an output file,       *
'* ACTIVITY.DAT, containing data on each activity for each *
'* iteration.  This file is used by the STATS.EXE program  *
'* to determine critically indexed paths and activities,   *
'* generate project duration frequency distribution data.  *
'*                                                          *
'* HISTORY                                                  *
'*       Created By:    Charles Patrick                     *
'*       Date Created:  July, 1993                          *
'*       Revised By:                                        *
'*       Date Revised:                                      *
'*       Revision Notes:                                    *
'* INPUTS:                                                  *
'*       An input file, DATA.FIL, contains a topological   *
'*       list of activities, probability distribution      *
'*       parameters, and activity relationships.           *
'*                                                          *
'* OUTPUTS:                                                 *
'*       An output file, ACTIVITY.DAT, contains activity   *
'*       early/late start/finish, slack, critical path(s),*
'*       and project duration on every activity for each   *
'*       iteration of the simulation.                      *
'*                                                          *
'************************************************************
```

```
'************************************************************
'*                       MAIN PROGRAM                       *
'************************************************************
'*                                                          *
'* DESCRIPTION:  The main program reads the input file,     *
'* defines and controls the subroutines and functions of    *
'* the simulation, and controls overall model execution     *
'*                                                          *
'* HISTORY                                                  *
'*       Created By:    Charles Patrick                     *
'*       Date Created:  July, 1993                          *
'*       Revised By:                                        *
'*       Date Revised:                                      *
'*       Revision Notes:                                    *
'*                                                          *
'* INPUT:       DATA.FIL                                    *
'*                                                          *
'* OUTPUT:      ACTIVITY.DAT                                *
'*                                                          *
'* CALLS:       LOADDATA, CALCULATEDURATIONS, FORWARDPASS,  *
'*       REVERSEPASS, FINDCRITPATH, WRITECRITACTIVITIES.    *
'*                                                          *
'* CALLED BY:  none                                         *
'*                                                          *
'************************************************************
'
'************************************************************
'*       DECLARATIONS OF SUBROUTINES AND FUNCTIONS          *
'************************************************************
'
  DECLARE SUB writecritactivities ()
  DECLARE SUB findcritpath (i%)
  DECLARE SUB reversepass (j%)
  DECLARE SUB forwardpass (i%)
  DECLARE SUB calculatedurations ()
  DECLARE SUB loaddata ()
  DECLARE FUNCTION token$ (x$, n%)
  DECLARE FUNCTION rand# (iseed&)
'
'************************************************************
'*       DECLARATIONS OF RANDOM FUNCTIONS                   *
'*       USED IN "CALCULATEDURATIONS"                       *
'************************************************************
'
  DECLARE FUNCTION beta# (a#, b#, iseed&)
  DECLARE FUNCTION expon# (mean#, iseed&)
  DECLARE FUNCTION gama# (b#, a#, iseed&)
  DECLARE FUNCTION rnorm# (xmn#, std#, iseed&)
```

```
   DECLARE FUNCTION triag# (xl#, xm#, xh#, iseed&)
   DECLARE FUNCTION unfrm# (ulo#, uhi#, iseed&)
   DECLARE FUNCTION weibl# (b#, a#, iseed&)
'
' Max number of edges linking activities
   CONST maxedge% = 2000
' Max number of activities
   CONST maxact% = 400
'
' This structure is used to hold information about edges
' that originate from a particular activity. It contains a
' pointer to an edge, and a pointer to the next pointer in
' the list.
'
TYPE PtrType
   EdgePtr AS INTEGER
   NextPtr AS INTEGER
END TYPE
'
TYPE ActType              ' This record describes an activity
   label AS STRING * 8 ' The name of the activity
   DurType AS INTEGER  ' The duration type
   DurParam1 AS DOUBLE ' Parameters 1, 2, 3, and 4
   DurParam2 AS DOUBLE ' that are used to generate a
   DurParam3 AS DOUBLE ' duration for this activity
   DurParam4 AS DOUBLE ' for each pass.
   dur AS DOUBLE  ' Duration...calculated for each pass
   ES AS DOUBLE   ' Early Start time
   EF AS DOUBLE   ' Early finish time
   LS AS DOUBLE   ' Late Start time
   LF AS DOUBLE   ' Late Finish time
   ToPtr AS INTEGER ' Pointer to list of acts. to connect to
   FromPtr AS INTEGER ' Pointer to list of preceding acts.
END TYPE
'
TYPE EdgeType             ' This structure describes an edge
   ToAct AS INTEGER    ' Pointer to list of edges going to
                       ' other activities
   FromAct AS INTEGER ' Pointer to a list of edges that come
                       ' from other activities
   ConType AS INTEGER ' The type of connection (FS, SS, FF)
   ConVal AS DOUBLE    ' The value of FS, SS, or FF
END TYPE
'
COMMON SHARED numact%     ' No. activities (<= maxact%)
COMMON SHARED numpasses% ' No. passes to run
COMMON SHARED edgecount% ' No. edges used (<= maxedge%)
COMMON SHARED ptrcount%   ' No. pointers used (<= maxedge*2)
```

```
COMMON SHARED totalslack ' Best value for total slack so far
COMMON SHARED stackptr%  ' Pointer to top of path stack
COMMON SHARED currentslack ' The slack for the current path
'
DIM SHARED critpath(maxact% + 1) AS INTEGER
   ' Best crit path so far
'
DIM SHARED critstack(maxact%) AS INTEGER
   ' Stack containing current path
DIM SHARED Edges(maxedge%) AS EdgeType
   ' A list of edges
DIM SHARED PtrList(maxedge% * 2) AS PtrType
   ' Storage for pointers
DIM SHARED activity(maxact%) AS ActType
   ' Info on all of our activities
'
' Below are possible values for contype%
'
CONST fstype% = 0 ' finish-start
CONST sstype% = 1 ' start-start
CONST fftype% = 2 ' finish-finish
CONST sftype% = 3 ' start-finish
'
' Real processing begins here....
'
edgecount% = 0 ' No edges allocated yet
ptrcount% = 0  ' No pointers allocated yet
'
CALL loaddata  ' Load in the data.
'
' Trying to keep all of the data from all of the passes in
' memory at the same time, along with the other info we
' need, is in excess of the 640K limit of MS-DOS. Therefore,
' the data is written to the "ACTIVITY.DAT" file where it
' can be manipulated later.
'
KILL "activity.dat" ' Make sure the old data file is gone
OPEN "activity.dat" FOR OUTPUT AS 1 ' Open the new data file
PRINT #1, numact%    ' Start by saving number of activities
PRINT #1, numpasses% ' and the number of passes to expect
'
FOR pass% = 1 TO numpasses% ' Do this for all of the passes
      '
      ' Since most activities have a random duration, a new
      ' set of durations must be calculated before beginning
      ' each pass.
      '
      CALL calculatedurations
```

```
'
' For all practical purposes, the first activity
' should have a start time of 0, and a Finish time
' equal to the duration of the activity.
'
activity(1).ES = 0
activity(1).LS = 0
activity(1).LF = activity(1).dur
activity(1).EF = activity(1).dur
'
' For all other activities, start at their Early Start
' value and end with ES + their duration.
'
FOR i% = 2 TO numact%
  activity(i%).ES = activity(1).ES
  activity(i%).EF = activity(i%).ES + activity(i%).dur
NEXT i%
'
' Now perform the forward pass. Since this function is
' called recursively, tell it that it is starting with
' the first activity.
'
CALL forwardpass(1)
'
' Prepare for the reverse pass by first assuming that
' Late Finish is the same as the Early Finish time,
' and the Late Start is the Late Finish time minus the
' duration of the activity.
'
FOR i% = 1 TO numact%
  activity(i%).LF = activity(numact%).EF
  activity(i%).LS = activity(i%).LF - activity(i%).dur
NEXT i%
'
' Now perform the reverse pass. This function is also
' called recursively, so tell it to start with the
' last activity.
'
CALL reversepass(numact%)
'
' Now that all the Start/Finish times have been
' adjusted, write the data to a file for later use.
'
FOR i% = 1 TO numact%
   PRINT #1, activity(i%).label
   PRINT #1, activity(i%).dur
   PRINT #1, activity(i%).ES
   PRINT #1, activity(i%).EF
```

```
        PRINT #1, activity(i%).LS
        PRINT #1, activity(i%).LF
      NEXT i%
      '
      ' Now look for the critical path.
      ' First, set the stack pointer equal to 0 to be sure
      ' to start storing the path at bottom of the stack.
      '
      stackptr% = 0
      '
      ' Need to start out with a total slack time larger
      ' than anything expected. Therefore, set to the Late
      ' Finish time of the final activity.
      '
      totalslack = activity(numact%).LF
      '
      ' Findcritpath is called recursively and must start
      ' with the first activity.
      ' Set the currentslack variable to 0 before calling.
      ' The variable, currentslack, indicates how much
      ' overall slack time exists between the first activity
      ' and the activity being checked in findcritpath.
      '
      currentslack = 0
      '
      CALL findcritpath(1)
      '
      ' Upon finding the critical path, write length of the
      ' path to data file, then write the path itself.
      '
      ' First, calculate the length of the path....
      '
      i% = 2 ' Path has to have at least 2 activities
      WHILE (critpath%(i%) > 0) ' Loop until the end
        i% = i% + 1 ' and increment length each time through
      WEND             ' the loop.
      i% = i% - 1    ' Back up one position (started at 0).
      PRINT #1, i%      ' Now write out the length....
      FOR j% = 1 TO i% ' and the path itself.
        PRINT #1, critpath(j%)
      NEXT j%
      '
      ' Write out all the critical activities.
      '
      CALL writecritactivities
   NEXT pass%
   CLOSE #1      ' Close data file.
END
```

```
'************************************************************
'*                  SUBROUTINE LOADDATA                     *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This subroutine opens the input file,      *
'* DATA.FIL, reads in the data, and stores data in the      *
'* appropriate variable list.                               *
'*                                                          *
'* HISTORY                                                  *
'*        Created By:    Charles Patrick                    *
'*        Date Created:  July, 1993                         *
'*        Revised By:                                       *
'*        Date Revised:                                     *
'*        Revision Notes:                                   *
'*                                                          *
'* INPUT:      none                                         *
'*                                                          *
'* OUTPUT:     none                                         *
'*                                                          *
'* CALLS:      TOKEN                                        *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'************************************************************
'
SUB loaddata
'
  DIM tempstr AS STRING * 8 ' Temporary space for strings
  OPEN "data.fil" FOR INPUT AS 1 ' Open data file and
  INPUT #1, x$                   ' read first line
  numact% = VAL(token$(x$, 1)) ' 1st token = no. activities
  numpasses% = VAL(token$(x$, 2)) ' 2nd token = no. passes
'
' Token is function to transform data to numeric values.
'
' Now process main portion of file. Each activity has a
' record.
'
  FOR i% = 1 TO numact% ' For each activity...
     INPUT #1, x$       ' Read the activity record
'
' Activity label first
'
     activity(i%).label = token$(x$, 1)
'
' Duration type is second
'
     activity(i%).DurType = VAL(token$(x$, 2))
```

```
' Followed by four duration parameters
'
    activity(i%).DurParam1 = VAL(token$(x$, 3))
    activity(i%).DurParam2 = VAL(token$(x$, 4))
    activity(i%).DurParam3 = VAL(token$(x$, 5))
    activity(i%).DurParam4 = VAL(token$(x$, 6))
'
' Start by assuming all Start/Finish times = 0
'
    activity(i%).ES = 0
    activity(i%).EF = 0
    activity(i%).LS = 0
    activity(i%).LF = 0
' Also start with null pointers to the connection edges
'
    activity(i%).ToPtr = 0
    activity(i%).FromPtr = 0
'
  NEXT i%
'
' The next part of the input file contains a list of edges.
' The information contained about each edge consists of the
' activity it originates from, the activity it connects to,
' connection type (SS, FF, SF, FS), and finally, the value
' associate with that connection.
'
  edgecount% = 0  ' No edges are used at this point
  DO UNTIL EOF(1) ' To read the whole file...
    INPUT #1, x$ ' Read the next record
'
' First token is the label of the originating node. Pull it
' off of record just read in and search through list of
' activites to find activity number it is associated with.
'
    tempstr = token$(x$, 1)
    FOR i% = 1 TO numact%     '
      IF tempstr = activity(i%).label THEN FromAct% = i%
    NEXT i%
'
' Repeat for second token, which is destination activity.
'
    tempstr = token$(x$, 2)
    FOR i% = 1 TO numact%
      IF tempstr = activity(i%).label THEN ToAct% = i%
    NEXT i%
'
' Get next available space in edge list and copy in infor.
'
```

```
     edgecount% = edgecount% + 1
     Edges(edgecount%).FromAct = FromAct%
     Edges(edgecount%).ToAct = ToAct%
     Edges(edgecount%).ConVal = VAL(token$(x$, 4))
     type$ = token$(x$, 3)
     SELECT CASE type$
         CASE "FS"
            Edges(edgecount%).ConType = fstype%
         CASE "SS"
            Edges(edgecount%).ConType = sstype%
         CASE "FF"
            Edges(edgecount%).ConType = fftype%
         CASE "FS"
            Edges(edgecount%).ConType = fstype%
     END SELECT
'
' Upon saving all the information about this edge, put it in
' two lists. First list is indexed by activity that edge
' starts with and second list is indexed by activity that
' edge connects to.
'
' First, allocate a pointer.
'
     ptrcount% = ptrcount% + 1
'
' Then check if any other edges are found up to this point
' that originate from same activity.  If not, then this
' pointer will be added as the first pointer in the list.
'
     IF activity(FromAct%).ToPtr = 0 THEN
        activity(FromAct%).ToPtr = ptrcount%
'
' If one or more edges are listed as originating from this
' activity, then go to end of list and append new pointer.
'
     ELSE
'
' Start at the beginning of the list
'
        i% = activity(FromAct%).ToPtr
'

' Find the end of the list
'
        DO UNTIL PtrList(i%).NextPtr = 0
'
' Move to the next pointer in the list
'
```

```
           i% = PtrList(i%).NextPtr
        LOOP
'
' Add new pointer to the end
'
        PtrList(i%).NextPtr = ptrcount%
     END IF
'
' Assign edge to look at
'
     PtrList(ptrcount%).EdgePtr = edgecount%
     PtrList(ptrcount%).NextPtr = 0 ' End of list (for now)
'
' Repeat for destination node.  This information is needed
' to traverse the reverse path.
'
     ptrcount% = ptrcount% + 1 ' Allocate a pointer
     IF activity(ToAct%).FromPtr = 0 THEN ' First in list?
        activity(ToAct%).FromPtr = ptrcount% ' Move it in...
     ELSE ' In no, find end of the list
        i% = activity(ToAct%).FromPtr
        DO UNTIL PtrList(i%).NextPtr = 0
           i% = PtrList(i%).NextPtr
        LOOP
'
' Append our new pointer to the end
        PtrList(i%).NextPtr = ptrcount%
     END IF
'
' Assign edge to refer to and this is end of list (for now).
'
     PtrList(ptrcount%).EdgePtr = edgecount%
     PtrList(ptrcount%).NextPtr = 0
  LOOP
'
' All done. Close the file and return.
'
  CLOSE #1
'
END SUB
'
'***********************************************************
'*             SUBROUTINE CALCULATEDURATIONS               *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This subroutine calculates the durations  *
'* for each activity based on the Duration Type, and the   *
'* Duration Parameters. It loops through all activites and *
```

```
'* checks the duration type and then passes the duration    *
'* parameters to the appropriate random number function.    *
'*                                                          *
'* HISTORY                                                  *
'*       Created By:    Charles Patrick                     *
'*       Date Created:  July, 1993                          *
'*       Revised By:                                        *
'*       Date Revised:                                      *
'*       Revision Notes:                                    *
'*                                                          *
'* INPUT:      none                                         *
'*                                                          *
'* OUTPUT:     none                                         *
'*                                                          *
'* CALLS:      Probability distribtion functions            *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'************************************************************
'
SUB calculatedurations
'
' For ease of reading and amount of typing, the three
' parameters are assigned to the variables a, b, and c.
'
  FOR i% = 1 TO numact%
     a# = activity(i%).DurParam1
     b# = activity(i%).DurParam2
     c# = activity(i%).DurParam3
     d# = activity(i%).DurParam4
     activity(i%).dur = -1
      WHILE (activity(i%).dur < 0)
'
         SELECT CASE activity(i%).DurType
            CASE 1
               activity(i%).dur = a#
            CASE 3
               seed& = c#
               activity(i%).dur = weibl#(a#, b#, seed&)
               activity(i%).DurParam3 = seed&
            CASE 4
               seed& = c#
               activity(i%).dur = unfrm#(a#, b#, seed&)
               activity(i%).DurParam3 = seed&
            CASE 5
               seed& = c#
               activity(i%).dur = rnorm#(a#, b#, seed&)
               activity(i%).DurParam3 = seed&
```

```
            CASE 6
               seed& = d#
               activity(i%).dur = triag#(a#, b#, c#, seed&)
               activity(i%).DurParam4 = seed&
            CASE 8
               seed& = c#
               activity(i%).dur = gama#(a#, b#, seed&)
               activity(i%).DurParam3 = seed&
            CASE 10
               seed& = c#
               activity(i%).dur = beta#(a#, b#, seed&)
               activity(i%).DurParam3 = seed&
            CASE 11
               seed& = b#
               activity(i%).dur = expon#(a#, seed&)
               activity(i%).DurParam2 = seed&
         END SELECT
      WEND
  NEXT i%
END SUB
'
'************************************************************
'*                   SUBROUTINE FORWARDPASS                 *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This subroutine, called recursively,       *
'* computes the Early Start and Early Finish times for all  *
'* activities. The argument is the activity number with     *
'* which to start.  It will then call itself for each       *
'* activity it can connect to, until it reaches the final   *
'* activity.                                                *
'*                                                          *
'* HISTORY                                                  *
'*        Created By:    Charles Patrick                    *
'*        Date Created:  July, 1993                         *
'*        Revised By:                                       *
'*        Date Revised:                                     *
'*        Revision Notes:                                   *
'*                                                          *
'* INPUT:      none                                         *
'*                                                          *
'* OUTPUT:     none                                         *
'*                                                          *
'* CALLS:      Itself                                       *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'************************************************************
```

```
SUB forwardpass (i%)
'
' Start with pointer to list of edges that connect to other
' activities. Each time through main loop, traverse an edge
' to another activity and call this routine for that
' activity. At end of main loop, update pointer to find next
' edge. Process repeated until all edges traversed.
'
  ptr% = activity(i%).ToPtr
'
' Repeat this loop until all edges have been traversed.
'
  DO UNTIL ptr% = 0
'
' First, get actual pointer to edge and determine which
' activity it connects to.
'
     ep% = PtrList(ptr%).EdgePtr
     j% = Edges(ep%).ToAct
'
' Then, depending upon type of connection, ompute the Early
' Start time in the variable "temp".
'
     SELECT CASE Edges(ep%).ConType
         CASE fstype%
            temp = activity(i%).EF + Edges(ep%).ConVal
         CASE sstype%
            temp = activity(i%).ES + Edges(ep%).ConVal
         CASE fftype%
            temp = activity(i%).EF + Edges(ep%).ConVal -
                   activity(j%).dur
         CASE sftype%
            temp = activity(i%).ES + Edges(ep%).ConVal -
                   activity(i%).dur
     END SELECT
'
' If new Early Start time is greater than the current ES
' time, accept it and update the early finish time as well.
'
     IF temp > activity(j%).ES THEN
         activity(j%).ES = temp
         activity(j%).EF = temp + activity(j%).dur
     END IF
'
' After updating the ES time for this activity, proceed to
' next activity and, eventually, to the final activity.
'
     CALL forwardpass(j%)
```

```
' Move to next edge in list and continue through loop with
' same procedure.
'
     ptr% = PtrList(ptr%).NextPtr
  LOOP

END SUB
'
'************************************************************
'*                  SUBROUTINE REVERSEPASS                  *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This reverse pass subroutine works almost *
'* identically to the forward pass and computes the Late    *
'* Start and Late Finish times.  It is called recursively, *
'* with an argument of the activity number to start with.  *
'* From that point, the routing works backward, calling     *
'* itself for each activity which connects to it until the *
'* starting activity is reached.                            *
'*                                                          *
'* HISTORY                                                  *
'*       Created By:    Charles Patrick                     *
'*       Date Created:  July, 1993                          *
'*       Revised By:                                        *
'*       Date Revised:                                      *
'*       Revision Notes:                                    *
'*                                                          *
'* INPUT:       none                                        *
'*                                                          *
'* OUTPUT:      none                                        *
'*                                                          *
'* CALLS:       Itself                                      *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'************************************************************
'
SUB reversepass (j%)
'
' Start with pointer to list of edges that connect to
' argument activity from other activities. Each time through
' the loop, traverse edge backwards to an earlier activity.
' For each of these activities, the "reversepass" function
' is called again. At end of loop, pointer is updated so
' next edge can be found. This process is repeated until all
' edges have been checked.
'
  ptr% = activity(j%).FromPtr
```

```
' The following loop will be repeated until traversing all
' edges leading up to this activity.
'
  DO UNTIL ptr% = 0
'
' First, get the actual pointer to the edge and see which
' node it comes from.
'
     ep% = PtrList(ptr%).EdgePtr
     i% = Edges(ep%).FromAct
'
' Then, check to see what type of edge is assigned and
' compute a Late Finish time depending on it.
'
     SELECT CASE Edges(ep%).ConType
        CASE fstype%
           temp = activity(j%).LS - Edges(ep%).ConVal
        CASE fftype%
           temp = activity(j%).LF - Edges(ep%).ConVal
        CASE sstype%
           temp = activity(j%).LS - Edges(ep%).ConVal +
                  activity(i%).dur
        CASE sftype%
           temp = activity(j%).LF - Edges(ep%).ConVal +
                  activity(j%).dur
     END SELECT
' If computed late finish is less than earliest Late Finish
' so far, then update Late Finish and Late Start times.
'
     IF temp < activity(i%).LF THEN
        activity(i%).LF = temp
        activity(i%).LS = temp - activity(i%).dur
     END IF
'
' Now call "reversepass" again for the connecting node.
'
     CALL reversepass(i%)
'
' Since finished checking this edge, now move the pointer to
' the next edge in the list.
'
     ptr% = PtrList(ptr%).NextPtr
  LOOP  ' Traverse through all activities.
'
END SUB
'
'
'
```

```
'***********************************************************
'*                  SUBROUTINE FINDCRITPATH                 *
'***********************************************************
'*                                                          *
'* DESCRIPTION: This is a recursive function to find a      *
'* critical path.  Each time it is called, it adds the      *
'* current activity to the stack and adds the slack time    *
'* of the current activity to the over all slack time up    *
'* to this point. When it reaches the final activity it     *
'* checks to see if the slack time for the path it has      *
'* just traversed is better than the best overall slack     *
'* time so far.  If it is, that path will become the new    *
'* critical path.                                           *
'*                                                          *
'* HISTORY                                                  *
'*       Created By:    Charles Patrick                     *
'*       Date Created:  July, 1993                          *
'*       Revised By:                                        *
'*       Date Revised:                                      *
'*       Revision Notes:                                    *
'*                                                          *
'* INPUT:       none                                        *
'*                                                          *
'* OUTPUT:      none                                        *
'*                                                          *
'* CALLS:       Itself                                      *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'***********************************************************
'
SUB findcritpath (i%)
'
' First, add this activity to the stack by incrementing the
' stack pointer and then copying in the activity number.
'
  stackptr% = stackptr% + 1
  critstack(stackptr%) = i%
'
' The currentslack variable is going to change, so save it's
' value in "lastslack" to know what the slack time was up to
' this point.
'
  lastslack = currentslack
'
' Start by setting a pointer to the first of the activites
' which can be moved to, from this activity.
'
```

```
  ptr% = activity(i%).ToPtr
'
' Then, cycle through all edges which originate from this
' activity. When ptr% is equal to 0, number of edges that
' originate from this activity will be exhausted.
'
  DO UNTIL (ptr% = 0)
'
' Get the first edge.
'
      ep% = PtrList(ptr%).EdgePtr
'
' Check to see where that edge goes.
'
      j% = Edges(ep%).ToAct
'
' If it DOES NOT go to the final activity, then compute a
' new "currentslack" and recurse into "findcritpath" with
' the next activity.
'
      IF (j% <> numact%) THEN
         currentslack = lastslack + activity(i%).LF -
                        activity(i%).EF
         IF ABS(activity(i%).LF - activity(i%).EF) < .001
            THEN CALL findcritpath(j%)
         ELSE
'
' If it DOES go to the last activity, then end of this path
' has been reached. Now check if the total slack for this
' path is less than the best total slack found so far. If it
' is, set the new total slack to our current total slack and
' copy the path just traversed from stack into "critpath"
' array.
'
         IF stackptr% + 1 >= pathlen% THEN
            totalslack = currentslack ' Save new best slack
            FOR k% = 1 TO stackptr%   ' Copy new path
               critpath(k%) = critstack(k%)
            NEXT k%
            critpath(stackptr% + 1) = j% ' Last activity
            critpath(stackptr% + 2) = -1 ' Terminate path
                                         ' with a -1.
         END IF
      END IF
'
' Upon completing current edge, go on to the next edge.
'
      ptr% = PtrList(ptr%).NextPtr
```

```
  LOOP
'
' Upon looping through all edges, drop back to previous
' level. Decrement stack pointer so this node will no longer
' be on the stack.
'
   stackptr% = stackptr% - 1
'
END SUB
'
'
'************************************************************
'*              SUBROUTINE WRITECRITACTIVITIES              *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This subroutine writes out all activites   *
'* that were critical.                                      *
'*                                                          *
'* HISTORY                                                  *
'*         Created By:    Charles Patrick                   *
'*         Date Created:  July, 1993                        *
'*         Revised By:                                      *
'*         Date Revised:                                    *
'*         Revision Notes:                                  *
'*                                                          *
'* INPUT:       none                                        *
'*                                                          *
'* OUTPUT:      none                                        *
'*                                                          *
'* CALLS:       none                                        *
'*                                                          *
'* CALLED BY:  Main Program                                 *
'*                                                          *
'************************************************************
'
SUB writecritactivities
'
'  Check for activity criticality.
'
   FOR j% = 1 TO numact%
      IF ABS(activity(j%).LF - activity(j%).EF) < .0001
             THEN PRINT #1, j%
   NEXT j%
'
' Now that critical activities have been written out, write
' out E*O*L flag which will tell programs that read data
' file that critical activities list end has been reached.
'
```

```
  PRINT #1, "E*O*L"
'
END SUB
'
'************************************************************
'*                       FUNCTION TOKEN                     *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This is a simple function to retrieve      *
'* token n% from string x$. It assumes the that a space is *
'* to be used for the token seperator.                      *
'*                                                          *
'* HISTORY                                                  *
'*        Created By:    Charles Patrick                    *
'*        Date Created:  July, 1993                         *
'*        Revised By:                                       *
'*        Date Revised:                                     *
'*        Revision Notes:                                   *
'*                                                          *
'* INPUT:       none                                        *
'*                                                          *
'* OUTPUT:      none                                        *
'*                                                          *
'* CALLS:       none                                        *
'*                                                          *
'* CALLED BY:  LOADDATA                                     *
'*                                                          *
'************************************************************
'
FUNCTION token$ (x$, n%)
'
   token$ = ""                  ' First assume a null token.
   t$ = LTRIM$(RTRIM$(x$))      ' Make a working copy &
                                ' strip leading/trailing spaces.
'
' Following loop strips leading tokens from input string.
' Loop starts with 2 because there is no need to execute the
' loop if want the first token... already at that point.
'
  FOR i% = 2 TO n%
' First, try to find a space which will indicate where the
' token ends. If no space is found, no tokens remaining and
' exit using the assumed null value which was set above.
'
     startch% = INSTR(t$, " ")
     IF startch% = 0 THEN EXIT FUNCTION
'
'
```

```
' Now know where this token ends, so get everything that
' comes after it and strip off any leading spaces.
'
     t$ = LTRIM$(MID$(t$, startch%))
  NEXT i%
'
' To get to this point, there must be token there to use.
' Check to see where this token ends by searching for space.
' If space is found, strip off anything that comes after it.
'
  endch% = INSTR(t$, " ")
  IF endch% > 0 THEN t$ = LEFT$(t$, endch% - 1)
'
' Whatever is left at this point is our token.
'
  token$ = t$
END FUNCTION
'
'***********************************************************
'*                    FUNCTION BETA                        *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random variate    *
'* which comes from an BETA probability distribution.      *
'*                                                         *
'* HISTORY                                                 *
'*       Created By:    Osman Balci                        *
'*       Date Created:  April, 1987                        *
'*       Revised By:    Charles Patrick                    *
'*       Date Revised:  July, 1993                         *
'*       Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                         *
'* INPUT:        a# = shape parameter 1                    *
'*               b# = shape parameter 2                    *
'*               iseed& = random number generator seed     *
'*                                                         *
'* OUTPUT:       none                                      *
'*                                                         *
'* CALLS:        none                                      *
'*                                                         *
'* CALLED BY:  CALCULATEDURATIONS                          *
'*                                                         *
'***********************************************************
'
FUNCTION beta# (a#, b#, iseed&)
   x# = gama#(1!, a#, iseed&)
   PRINT x#
   PRINT gama#(1!, b#, iseed&)
```

```
   beta# = x# / (x# + gama#(1!, b#, iseed&))
END FUNCTION
'
'***********************************************************
'*                    FUNCTION EXPON                       *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random variate    *
'* which comes from EXPONENTIAL probability distribution.  *
'*                                                         *
'* HISTORY                                                 *
'*       Created By:    Osman Balci                        *
'*       Date Created:  April, 1987                        *
'*       Revised By:    Charles Patrick                    *
'*       Date Revised:  July, 1993                         *
'*       Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                         *
'* INPUT:      mean#  = Mean of exponential distribution   *
'*             iseed& = random number generator seed       *
'*                                                         *
'* OUTPUT:     none                                        *
'*                                                         *
'* CALLS:      none                                        *
'*                                                         *
'* CALLED BY:  CALCULATEDURATIONS                          *
'*                                                         *
'***********************************************************
'
'
' Exponential distribution function
'
FUNCTION expon# (mean#, iseed&)
   r# = rand#(iseed&)
   expon = -mean# * LOG(r#)
END FUNCTION
'
'***********************************************************
'*                    FUNCTION EXPON                       *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random variate    *
'* which comes from a GAMMA probability distribution.      *
'*                                                         *
'* HISTORY                                                 *
'*       Created By:    Osman Balci                        *
'*       Date Created:  April, 1987                        *
'*       Revised By:    Charles Patrick                    *
'*       Date Revised:  July, 1993                         *
```

```
'*        Revision Notes: Changed from FORTRAN to QBasic   *
'*                                                         *
'* INPUT:      b#     = scale parameter                    *
'*             a#     = scale parameter                    *
'*             iseed& = random number generator seed       *
'*                                                         *
'* OUTPUT:     none                                        *
'*                                                         *
'* CALLS:      none                                        *
'*                                                         *
'* CALLED BY:  CALCULATEDURATIONS                          *
'*                                                         *
'***********************************************************
'
'  Gamma distribution function
'
FUNCTION gama# (b#, a#, iseed&)
   IF (a# < 1!) THEN
      DO
         x# = rand#(iseed&) ^ (1! / a#)
         y# = rand#(iseed&) ^ (1! / (1! - a#))
         z# = x# + y#
      LOOP UNTIL (z# <= 1!)
      w# = x# / z#
      dummy# = w# * (-LOG(rand#(iseed&))) * b#
   ELSE
      ka# = a#
      ak# = ka#
      c# = a# - ak#
      IF (a#>=5!) AND (rand#(iseed&)<c#) THEN ka# = ka#+1!
      DO UNTIL (rand#(iseed&) > test#)
         pr# = 1!
         FOR i& = 1 TO INT(ka#)
            pr# = pr# * rand#(iseed&)
         NEXT i&
         dummy# = -LOG(pr#)
         IF (a# > 5!) THEN
            gama# = dummy# * b#
            EXIT FUNCTION
         END IF
         test# = (dummy#/ak#)^c * EXP(-c*(dummy#/a-1!))
      LOOP
      dummy# = dummy# * (a# / ak#)
      gama# = dummy# * b#
   END IF

END FUNCTION
'
```

```
'************************************************************
'*                    FUNCTION RNORM                        *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This function returns a random variate     *
'* which comes from a NORMAL probability distribution.      *
'*                                                          *
'* HISTORY                                                  *
'*        Created By:    Osman Balci                        *
'*        Date Created:  April, 1987                        *
'*        Revised By:    Charles Patrick                    *
'*        Date Revised:  July, 1993                         *
'*        Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                          *
'* INPUT:      xmn#   = mean of normal distribution         *
'*             std#   = standard deviation                  *
'*             iseed& = random number generator seed        *
'*                                                          *
'* OUTPUT:     none                                         *
'*                                                          *
'* CALLS:      none                                         *
'*                                                          *
'* CALLED BY:  CALCULATEDURATIONS                           *
'*                                                          *
'************************************************************
'
'   Normal distribution function
'
FUNCTION rnorm# (xmn#, std#, iseed&)
   STATIC even%, enorm#

   IF (even% > 1) THEN
      DO UNTIL (w# <= 1!)
         ua# = 2! * rand#(iseed&) - 1!
         ub# = 2! * rand#(iseed&) - 1!
         w# = ua# * ua# + ub# * ub#
      LOOP
      w = SQR(-2! * LOG(2#) / w#)
      dummy# = ua# * w#
      enorm# = ub# * w#
      even% = 1
   ELSE
      even% = 2
      dummy# = enorm#
   END IF
   rnorm# = dummy# * std# + xmn#
END FUNCTION
'
```

```
'***********************************************************
'*                    FUNCTION TRIAG                       *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random variate    *
'* which comes from a TRIANGULAR probability distribution. *
'*                                                         *
'* HISTORY                                                 *
'*        Created By:    Osman Balci                       *
'*        Date Created:  April, 1987                       *
'*        Revised By:    Charles Patrick                   *
'*        Date Revised:  July, 1993                        *
'*        Revision Notes: Changed from FORTRAN to QBasic   *
'*                                                         *
'* INPUT:      xl#    = Lowest value of the interval       *
'*             xm#    = Mode (shape paameter)              *
'*             xh#    = Highest value of the interval      *
'*             xh# - xl# = scale parameter                 *
'*             iseed& = random number generator seed       *
'*                                                         *
'* OUTPUT:     none                                        *
'*                                                         *
'* CALLS:      none                                        *
'*                                                         *
'* CALLED BY:  CALCULATEDURATIONS                          *
'*                                                         *
'***********************************************************
'
'   Triangular distribution function
'
FUNCTION triag# (xl#, xm#, xh#, iseed&)
   rn# = rand#(iseed&)
   bma# = xm# - xl#
   cma# = xh# - xl#
   IF (rn# <= bma# / cma#) THEN
      triag# = xl# + SQR(bma# * cma# * rn#)
   ELSE
      triag# = xh# - SQR(cma# * (1! - rn#) * (xh# - xm#))
   END IF
END FUNCTION
'
'***********************************************************
'*                    FUNCTION UNFRM                       *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random variate    *
'* which comes from a UNIFORM probability distribution.    *
'*                                                         *
```

```
'* HISTORY                                                  *
'*        Created By:    Osman Balci                        *
'*        Date Created:  April, 1987                        *
'*        Revised By:    Charles Patrick                    *
'*        Date Revised:  July, 1993                         *
'*        Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                          *
'* INPUT:        ulo#   = lower bound                       *
'*               uhi#   = upper bound                       *
'*               iseed& = random number generator seed      *
'*                                                          *
'* OUTPUT:       none                                       *
'*                                                          *
'* CALLS:        none                                       *
'*                                                          *
'* CALLED BY:  CALCULATEDURATIONS                           *
'*                                                          *
'************************************************************
'
'   Uniform distribution function
'
FUNCTION unfrm# (ulo#, uhi#, iseed&)
   unfrm# = ulo# + (uhi# - ulo#) * rand#(iseed&)
END FUNCTION
'
'************************************************************
'*                    FUNCTION WEIBL                        *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This function returns a random variate     *
'* which comes from a WEIBULL probability distribution.     *
'*                                                          *
'* HISTORY                                                  *
'*        Created By:    Osman Balci                        *
'*        Date Created:  April, 1987                        *
'*        Revised By:    Charles Patrick                    *
'*        Date Revised:  July, 1993                         *
'*        Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                          *
'* INPUT:        b#     = scale parameter                   *
'*               a#     = scale parameter                   *
'*               iseed& = random number generator seed      *
'*                                                          *
'* OUTPUT:       none                                       *
'*                                                          *
'* CALLS:        none                                       *
'*                                                          *
'* CALLED BY:  CALCULATEDURATIONS                           *
```

```
'*                                                         *
'***********************************************************
'
'  Weibull distribution function
'
FUNCTION weibl# (b#, a#, iseed&)
   weibl# = (-b# * LOG(rand#(iseed&))) ^ (1! / a#)
END FUNCTION
'
'***********************************************************
'*                    FUNCTION RAND                        *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This function returns a random number     *
'* between 0 an 1. This is a multiplicative linear congru- *
'* ential random number generator which works ONLY for     *
'* 32-bit computers.                                       *
'*             z(I) == a Z(I-1) (mod m)                    *
'* where:      ==   is the congruence sign                 *
'*             a    = 7**5 or 16807                        *
'*             m    = (2**31) - 1 or 2147483647            *
'*             Z(0) = ISEED                                *
'*                                                         *
'* HISTORY                                                 *
'*       Created By:    Osman Balci                        *
'*       Date Created:  April, 1987                        *
'*       Revised By:    Charles Patrick                    *
'*       Date Revised:  July, 1993                         *
'*       Revision Notes: Changed from FORTRAN to QBasic    *
'*                                                         *
'* INPUT:      iseed& = random number generator seed       *
'*                                                         *
'* OUTPUT:     none                                        *
'*                                                         *
'* CALLS:      none                                        *
'*                                                         *
'* CALLED BY:  CALCULATEDURATIONS                          *
'*                                                         *
'***********************************************************
'
'  Random Number Generator Function
'
FUNCTION rand# (iseed&)
   iseed& = 16807 * iseed& * (MOD 2147483647)

   IF (iseed& <= 0) THEN iseed& = iseed& + 2147483647
   rand# = iseed& / 2147483647
END FUNCTION
```

```
'**********************************************************
'*                                                        *
'*                      STATS.EXE                         *
'* SIMULATION OF LONGWALL FACE TRANSFER PROJECT SCHEDULING *
'*                    IN QBASIC 4.5                       *
'*                                                        *
'**********************************************************
'*                                                        *
'* DESCRIPTION:  This QBasic program performs computations *
'* on the output file from the ACT.EXE simulation program. *
'* This program determines critically indexed paths and   *
'* activities, and generates frequency distribution data  *
'* of the transfer project duration.                      *
'*                                                        *
'*   HISTORY                                              *
'*        Created By:    Charles Patrick                  *
'*        Date Created:  July, 1993                       *
'*        Revised By:                                     *
'*        Date Revised:                                   *
'*        Revision Notes:                                 *
'*                                                        *
'*   INPUTS:                                              *
'*        An input file, ACTIVITY.DAT, contains data on   *
'*        each activity for every iteration.              *
'*                                                        *
'*   OUTPUTS:                                             *
'*        An output file contains critically-indexed paths *
'*        and activities, and project duration frequency  *
'*        distribution data.                              *
'*                                                        *
'**********************************************************
'
'**********************************************************
'*                     MAIN PROGRAM                       *
'**********************************************************
'*                                                        *
'* DESCRIPTION:  The main program reads the input file,   *
'* performs the computations to generate the output. This *
'* program reads the input data, controls the subroutines *
'* for sorting activities, paths, and durations, and      *
'* writes the results to an output file.                  *
'*                                                        *
'* HISTORY                                                *
'*        Created By:    Charles Patrick                  *
'*        Date Created:  July, 1993                       *
'*        Revised By:                                     *
'*        Date Revised:                                   *
'*        Revision Notes:                                 *
```

```
'*                                                         *
'* INPUT:      ACTIVITY.DAT                                *
'*                                                         *
'* OUTPUT:     Output file (user-specified)                *
'*                                                         *
'* CALLS:      SORTCRITPATHS, SORTCRITACTS.                *
'*                                                         *
'* CALLED BY:  none                                        *
'*                                                         *
'***********************************************************
'
'***********************************************************
'*        DECLARATIONS OF SUBROUTINES AND FUNCTIONS        *
'***********************************************************
'
DECLARE SUB sortcritpaths ()
DECLARE SUB sortcritacts ()
DECLARE FUNCTION token$ (x$, n%)
'
' Set maximum addressed activities
'
  CONST maxact% = 500
'
' Define activity characteristics
'
  TYPE acttype
     label AS STRING * 8
     dur AS DOUBLE
     ES AS DOUBLE
     EF AS DOUBLE
     LS AS DOUBLE
     LF AS DOUBLE
  END TYPE
'
' Establish counters and number of activities
'
  COMMON SHARED pcount%, numact%, dcount%
'
' Establish number of critical paths, durations, activities,
' counters, and pointers
'
  DIM SHARED path$(300), count%(300), durations(1000),
             durcounts%(1000)
  DIM SHARED activity(maxact%) AS acttype
  DIM SHARED crit%(maxact%)
  DIM SHARED ptr%(1000)
'
'
```

```
' Set the number of histogram intervals (categories) for
' project duration frequency distribution.
'
   categories% = 8
'
   OPEN "activity.dat" FOR INPUT AS 1  ' Open input file.
'
   dcount% = 0                 ' Set counter to 0.
'
   FOR i% = 1 TO 100           ' Set "count" variable.
      count%(i%) = 0
   NEXT i%
'
   INPUT #1, x$                ' Read number of activities in
   numact% = VAL(x$)           ' the input file.

   FOR i% = 1 TO numact%       ' Set critical counter, "crit".
      crit%(i%) = 0
   NEXT i%

   INPUT #1, x$                ' Read number of iterations
   numpass% = VAL(x$)          ' performed.
   pcount% = 0
'
' Read the individual activity data.
'
   FOR i% = 1 TO numpass%
      FOR j% = 1 TO numact%
         INPUT #1, activity(j%).label
         INPUT #1, activity(j%).dur
         INPUT #1, activity(j%).ES
         INPUT #1, activity(j%).EF
         INPUT #1, activity(j%).LS
         INPUT #1, activity(j%).LF
      NEXT j%
'
' Find the highest Late Finish and set parameters for
' sorting critical paths and activities, and generating
' histogram data.
'
      IF (i% = 1) THEN
         largest = activity(numact%).LF
         smallest = largest
      ELSE
         IF (activity(numact%).LF>largest) THEN largest =
            activity(numact%).LF
         IF (activity(numact%).LF<smallest) THEN smallest =
            activity(numact%).LF
```

```
    END IF

    found% = 0
    FOR j% = 1 TO dcount%
       IF ABS(durations(j%)-activity(numact%).LF)<.01 THEN
          durcounts%(j%) = durcounts%(j%) + 1
          found% = 1
          j% = dcount% + 1
       END IF
    NEXT j%
    IF found% = 0 THEN
       dcount% = dcount% + 1
       durations(dcount%) = activity(numact%).LF
       durcounts%(dcount%) = 1
    END IF
    INPUT #1, pathlen%
    p$ = ""
    FOR j% = 1 TO pathlen%
       INPUT #1, x$
       p$ = p$ + x$ + " "
    NEXT j%

    j% = 1
    found% = 0
    WHILE (found% = 0 AND j% <= pcount%)
       IF p$ = path$(j%) THEN
          count%(j%) = count%(j%) + 1
          found% = 1
       END IF
       j% = j% + 1
    WEND
    IF (found% = 0) THEN
       pcount% = pcount% + 1
       path$(pcount%) = p$
       count%(pcount%) = 1
    END IF

    INPUT #1, x$
    WHILE (x$ <> "E*O*L")
       j% = VAL(x$)
       crit%(j%) = crit%(j%) + 1
       INPUT #1, x$
    WEND
 NEXT i%

Call subroutine to sort and count critical paths

 GOSUB sortcritpaths
```

```
   FOR i% = 1 TO pcount%
'
' Use PRINT command here, but user-sent to output file with
' DOS command, "STATS >filename.ext".
'
      PRINT count%(ptr%(i%)); ": ";
      t$ = token$(path$(ptr%(i%)), 1)
      PRINT RTRIM$(activity(VAL(t$)).label);
      t$ = token$(path$(ptr%(i%)), 2)
      j% = 2
      WHILE (t$ <> "")
         PRINT " - "; RTRIM$(activity(VAL(t$)).label);
         j% = j% + 1
         t$ = token$(path$(ptr%(i%)), j%)
      WEND
      PRINT
   NEXT i%
'
   PRINT
'
' Call subroutine to sort and count critical activities
'
   GOSUB sortcritacts
   FOR i% = 1 TO numact%
      IF (crit%(ptr%(i%)) > 0) THEN PRINT crit%(ptr%(i%));
                  ":  "; activity(ptr%(i%)).label
   NEXT i%
'
   PRINT
'
' Determine and set the histogram interval size.
'
   catsize = largest - smallest
'
   IF (catsize < 1) THEN catsize = 1
   catsize = catsize / (categories% - 1)
   catsize = INT(catsize * 100 + .5) / 100
'
   PRINT largest; "   "; smallest  ' Print histogram range.

   start = smallest - catsize / 2
   start = INT(start * 100 - .5) / 100
'
' Establish and print interval width and number of
' occurences of individual project durations within the
' intervals.
'
   FOR x = start TO largest STEP catsize
```

```
      PRINT x; "-"; x + catsize - .01; ": ";
      catcount% = 0
      FOR i% = 1 TO dcount%
         IF (durations(i%)>=x AND durations(i%)<(x+catsize))
            THEN
            catcount% = catcount% + durcounts%(i%)
         END IF
      NEXT i%
      PRINT catcount%
   NEXT x
   INPUT x$
'
   STOP
'
'***********************************************************
'*                  SUBROUTINE SORTCRITPATHS               *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This subroutine sorts and counts the      *
'* critical paths for all iterations.                      *
'*                                                         *
'*   HISTORY                                               *
'*        Created By:    Charles Patrick                   *
'*        Date Created:  July, 1993                        *
'*        Revised By:                                      *
'*        Date Revised:                                    *
'*        Revision Notes:                                  *
'*                                                         *
'*   INPUT:         none                                   *
'*                                                         *
'*   OUTPUT:        none                                   *
'*                                                         *
'*   CALLS:         none                                   *
'*                                                         *
'*   CALLED BY:     Main Program                           *
'*                                                         *
'***********************************************************
'
sortcritpaths:
   FOR i% = 1 TO pcount%  ' Set pcount counter.
      ptr%(i%) = i%
   NEXT i%
'
   offset% = pcount% \ 2
'
   DO WHILE offset% > 0
      limit% = pcount% - offset%
      DO
```

```
         switch% = 0
         FOR i% = 1 TO limit%
            IF (count%(ptr%(i%))>count%(ptr%(i% + offset%)))
               THEN
               temp% = ptr%(i%)
               ptr%(i%) = ptr%(i% + offset%)
               ptr%(i% + offset%) = temp%
               switch% = i%
            END IF
         NEXT i%
         limit% = switch% - offset%
      LOOP WHILE switch%
      offset% = offset% \ 2
   LOOP
   RETURN
'
'************************************************************
'*                  SUBROUTINE SORTCRITACTS                 *
'************************************************************
'*                                                          *
'* DESCRIPTION:  This subroutine sorts and counts the       *
'* critical activities for all iterations.                  *
'*                                                          *
'*   HISTORY                                                *
'*        Created By:    Charles Patrick                    *
'*        Date Created:  July, 1993                         *
'*        Revised By:                                       *
'*        Date Revised:                                     *
'*        Revision Notes:                                   *
'*                                                          *
'*   INPUT:          none                                   *
'*                                                          *
'*   OUTPUT:         none                                   *
'*                                                          *
'*   CALLS:          none                                   *
'*                                                          *
'*   CALLED BY:      Main Program                           *
'*                                                          *
'************************************************************
'
sortcritacts:
   FOR i% = 1 TO numact%
      ptr%(i%) = i%
   NEXT i%
'
   offset% = numact% \ 2
'
   DO WHILE offset% > 0
```

```
      limit% = numact% - offset%
      DO
         switch% = 0
         FOR i% = 1 TO limit%
            IF (crit%(ptr%(i%))>crit%(ptr%(i% + offset%)))
               THEN
               temp% = ptr%(i%)
               ptr%(i%) = ptr%(i% + offset%)
               ptr%(i% + offset%) = temp%
               switch% = i%
            END IF
         NEXT i%
         limit% = switch% - offset%
      LOOP WHILE switch%
      offset% = offset% \ 2
   LOOP
   RETURN
'
'***********************************************************
'*                       FUNCTION TOKEN                    *
'***********************************************************
'*                                                         *
'* DESCRIPTION:  This is a simple function to retrieve     *
'* token n% from string x$. It assumes the that a space is *
'* to be used for the token seperator.                     *
'*                                                         *
'*   HISTORY                                               *
'*        Created By:    Charles Patrick                   *
'*        Date Created:  July, 1993                        *
'*        Revised By:                                      *
'*        Date Revised:                                    *
'*        Revision Notes:                                  *
'*                                                         *
'*   INPUT:         none                                   *
'*                                                         *
'*   OUTPUT:        none                                   *
'*                                                         *
'*   CALLS:         none                                   *
'*                                                         *
'*   CALLED BY:     Main Program                           *
'*                                                         *
'***********************************************************
'
FUNCTION token$ (x$, n%)
'
   token$ = ""              ' First assume a null token.
   t$ = LTRIM$(RTRIM$(x$))  ' Make a working copy &
                            ' strip leading/trailing spaces.
```

```
' Following loop strips leading tokens from input string.
' Loop starts with 2 because there is no need to execute the
' loop if want the first token... already at that point.
'
  FOR i% = 2 TO n%
' First, try to find a space which will indicate where the
' token ends. If no space is found, no tokens remaining and
' exit using the assumed null value which was set above.
'
     startch% = INSTR(t$, " ")
     IF startch% = 0 THEN EXIT FUNCTION
'
' Now know where this token ends, so get everything that
' comes after it and strip off any leading spaces.
'
     t$ = LTRIM$(MID$(t$, startch%))
  NEXT i%
'
' To get to this point, there must be token there to use.
' Check to see where this token ends by searching for space.
' If space is found, strip off anything that comes after it.
'
  endch% = INSTR(t$, " ")
  IF endch% > 0 THEN t$ = LEFT$(t$, endch% - 1)
'
' Whatever is left at this point is our token.
'
  token$ = t$
END FUNCTION
```

Mine A - NO SPARE EQUIPMENT

9 : 5-10-100-105-120-130-300-310-315-1300-1310-1320-1400-1410-1240-1500-1800
207 : 100-105-120-130-200-205-210-305-310-315-1300-1310-1320-1400-1410-1240-1500-1800
784 : 100-105-120-130-520-810-815-820-825-830-900-1700-1300-1310-1320-1400-1410-1240-1500-1800
9 : 300
207 : 305
207 : 205
207 : 210
207 : 200
216 : 315
216 : 310
784 : 1700
784 : 830
784 : 820
784 : 825
784 : 900
784 : 520
784 : 810
784 : 815
1000 : 130
1000 : 100
1000 : 105
1000 : 120
1000 : 1320
1000 : 1400
1000 : 1410
1000 : 1500
1000 : 1240
1000 : 1300
1000 : 1310
1000 : 1800

296.1233 222.3347
217.05 - 227.58 : 1
227.59 - 238.12 : 0
238.13 - 248.66 : 3
248.67 - 259.2 : 88
259.21 - 269.74 : 334
269.75 - 280.28 : 375
280.29 - 290.82 : 181
290.83 - 301.36 : 18

Appendix E-1

Mine A Scheduling Diagrams - Spare Equipment

Appendix E-2

Mine A Scheduling Diagrams - No Spare Equipment

Appendix E-3

Mine B Scheduling Diagrams

Appendix E-4

Mine C Scheduling Diagrams

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M.S. Mining Engineering, West Virginia University, Morgantown, WV, 1982.

B.S. Mining Engineering Technology, West Virginia Institute of Technology, Montgomery, WV, 1980.

EXPERIENCE

8/85 - 12/93 Assistant Professor of Industrial Technology, Department of Industrial Education and Technology, Morehead State University, Morehead, KY. Duties: 1) coordinate Construction/Mining Technology curriculum and student advising; 2) teach courses in mining and construction systems/processing/ computer applications; 3) develop and execute research; 4) manage MSU Energy Research Laboratory; 5) develop departmental curriculum.

9/82 - 8/85 Research Associate, Mining & Energy Resources Division, College of Engineering, University of Pittsburgh, PA. Duties: 1) generate research proposals; 2) teach courses in mine plant, explosives engineering, and industrial computer applications, engineering fundamentals; 3) direct longwall database research ($60K); 4) coordinated undergraduate student seminar; and, 5) sponsor SME student chapter.

5/76 - 8/80 Engineering Assistant, Island Creek Coal Company, Paintsville, KY. Summer Cooperation Education positions with duties: 1) underground and surface surveyor; 2) develop surface mining permits; 3) shaft/slope inspector.

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12-17-93

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