JPL PUBLICATION 79-122

(NASA-CR-163259) ECONOMIC BASELINES FOR CURRENT UNDERGROUND COAL MINING TECHNOLOGY Final Report (Jet Propulsion Lab.) 65 p HC A04/MF A01 CSCL 08I

N80-25764

Unclas

G3/43 23625

Economic Baselines for Current Underground Coal Mining Technology

Final Report

William B. Mabe

December 15, 1979

Prepared for

U.S. Department of Energy

Through an agreement with
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ABSTRACT

This report describes the calculations of the cost of mining coal using a room and pillar mining method with continuous miner and a longwall mining system. The costs were calculated for the 1975 and year 2000 time periods and are to be used as economic standards against which advanced mining concepts and systems will be compared.

The calculations procedure used was generated by the NUS Corporation for the Electric Power Research Institute under contract RP 435-1. However, some assumptions were changed and some internal model-stored data was altered to obtain a result that more closely represented what was considered to be a standard mine. Coal seam thicknesses were varied from one and one-half feet to eight feet to obtain the cost of mining coal over a wide range. Geologic conditions were selected that had a minimum impact on the mining productivity.

FOREWORD

The data used to perform this analysis was collected in late 1977 and early 1978, as were the economic projections used to predict costs in the year 2000. The economic projections did not foresee the record-breaking inflation experienced since then. Thus, those effects are not reflected in the conclusions reached here. The total effect of this inflation would be to increase the spread between capital and labor costs. To be absolutely accurate, in periods of rapid economic change, the study should be redone at intervals of not more than one year in length.

ACKNOWLEDGMENTS

The work presented here represents interim results from the Advanced Coal Extraction Systems Definition Project, a study being performed at the Jet Propulsion Laboratory, Pasadena, California, for the Fossil Energy Program, United States Department of Energy, via an interagency agreement with the National Aeronautics and Space Administration.

The author would like to express appreciation for comments and contributions made by several individuals. The continuing support of Mr. William Schmidt, of the Division of Fossil Fuel Extraction, U.S. Department of Energy is gratefully acknowledged. Also, Ms. Sylvia Brock, NUS Corporation for implementing the NUS model on the JPL computer; Mr. Robert L. French of JPL for his most able programming support of the analysis; Messrs. Milton L. Lavin, Paul G. Gordon, Gary D. Metts and Elmer L. Floyd of JPL for their very constructive review and comments; and Mr. M. Gyamfi of JPL for the extension of the various cost indexes and coal mine productivity to the year 2000. Finally, I would like to thank Ms. Sue Knaak for her expert preparation of this manuscript.

CONTENTS

Figures

Tables

SECTION I

STUDY OBJECTIVES AND SUMMARY OF RESULTS

A. INTRODUCTION

The Jet Propulsion Laboratory is under contract to the United States Department of Energy to define, develop, and demonstrate advanced systems for underground coal mining. It is required that the systems produce more coal at or below the production costs of existing systems, for use beyond the year 2000. In developing and evaluating an advanced mining concept, a standard must be provided against which the advanced system concept is compared, to determine if the advanced concept fulfills the requirement of being a better system than existing systems. Since mining systems are required to perform in four distinct areas, (economic, miner health and safety, resource conservation, and environmental impact), it is necessary that standards be developed for each of these areas so that the advanced concept can be comprehensively evaluated. The analysis reported here is concerned with the development of the economic standard for an underground mining system.

To be competitive, any new or advanced system must, as a minimum, equal the economic performance of existing systems. Therefore, the economics of existing systems were evaluated and the selling price per ton of clean coal mined, that would result in a 15% return on investment, was determined. This was accomplished for both the room and pillar, using continuous miners, and the longwall mining system. It is important to note that the resulting economic standards are not fixed. As improvements are made in existing systems the standard should be reevaluated and changed as necessary.

A literature search revealed a considerable amount of existing work done in the area of coal mine modeling and cost evaluation. Virginia Polytechnic Institute, Pennsylvania State University, Bureau of Mines (Twin Cities Research Center and Pittsburgh Research Center), and the NUS Corporation had already developed various coal mine simulation models and economic calculation procedures. The NUS Underground Coal Mining Cost Model (Ref. 1) was selected for use in preparing the economic standards reported here because it is uniquely suited to the requirements of this study. This model is constructed in such a way that present-day (1975) costs of mining coal can be calculated for existing coal mining systems. Then, through a series of changes and updates, the cost of coal mined can be recalculated to reflect forecast conditions in any future year. These two sets of calculated costs form the baseline against which advanced coal mining systems mining costs can be compared. The model is also sufficiently general in format so that changes in existing system capability can be accommodated without internal changes to the model. Therefore, system improvements can be factored into the economic standards as they occur, thus assuring a continuing update in the standards. The basic 1975 costs contained in the model were not changed, except as discussed in this report.

B. METHODOLOGY

As indicated above, economic baselines were developed for the two technologies operating in generally good geologic conditions representative of Central Appalachia: (1) overburden depth - 500, 1000-, and 1500-ft; (2) roof conditions - good; (3) seam grade - 0°; (4) gas emission - low; and (5) floor conditions - hard. The room and pillar mining system used continuous miners and the longwall mining system used continuous miners in support. For each technology, production curves were based upon the tables employed by the NUS model, extrapolated to thicker and thinner seams, as shown in Figures 1-1 and 1-2. Summary results of this analysis are shown in Figures 1-3 and 1-4 as cost of clean coal per ton in 1975 dollars, for both room and pillar and longwall mining systems.

Generation of the same economic standards for the year 2000 required the updating of costs and productivity from 1975 to 2000. The costs were updated by projecting the cost indexes for chemical plant equipment mining equipment, electrical power (published by the U.S. Department of Commerce), and miner's wages to the year 2000 by using the economic forecasts published by Data Resources, Inc. (DRI). The ratio of the cost index in 2000 to 1975 yields a factor by which 1975 costs generated by the model are multiplied to obtain the cost in the year 2000.

To complete the economic picture in the year 2000 required the projection of coal mine productivity in Central Appalachia twenty years into the future. Two productivity projections were made: (1) a worst case predicated on information furnished to the MOPPS Interagency Task Force in 1977, and (2) a more optimistic projection made by JPL in the fall of 1978. The worst case projection (Figure 1-5) incorporated the following assumptions:

(1) A baseline productivity in Central Appalachia of eight tons per man-shift in 1975.

(2) A decrease in the average seam thickness from 48-in. in 1975 to 28-in. in 2000.

(3) A decline in productivity until 1980-1985, when the influx of less skilled, younger miners abates.

(4) Stabilization of the effective skill level of the work force.

(5) The realization that very little technology improvement will be available to overcome the adverse factors noted above.

The second, more hopeful projection was based on technology improvements and incentives for improved productivity, in particular:

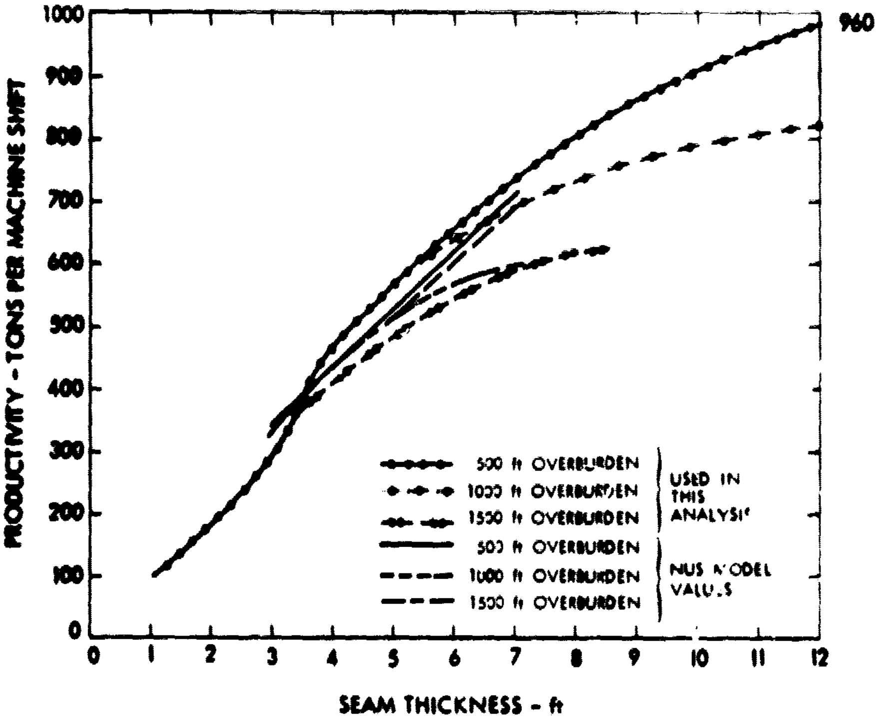

Figure 1-1. Continuous Miner Productivity

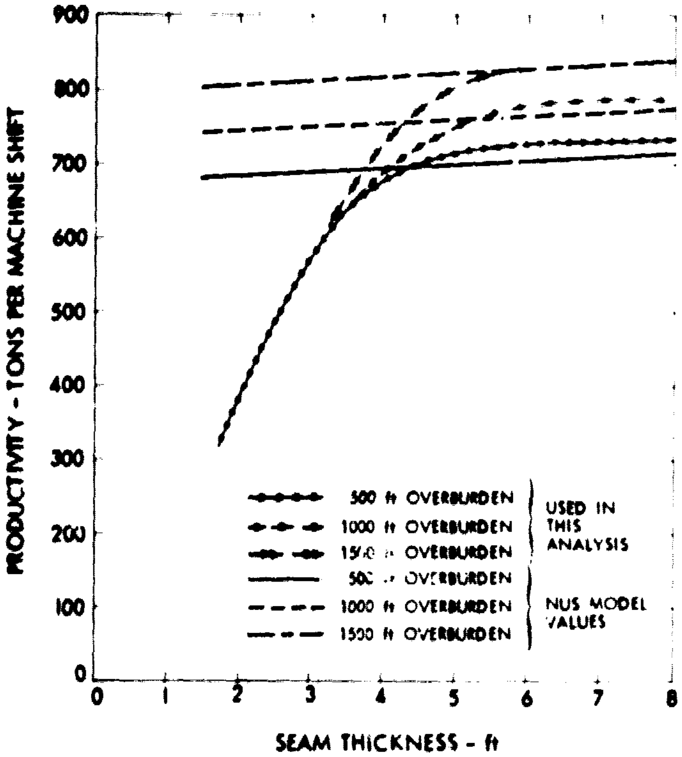

Figure 1-2. Longwall Mining System Productivity

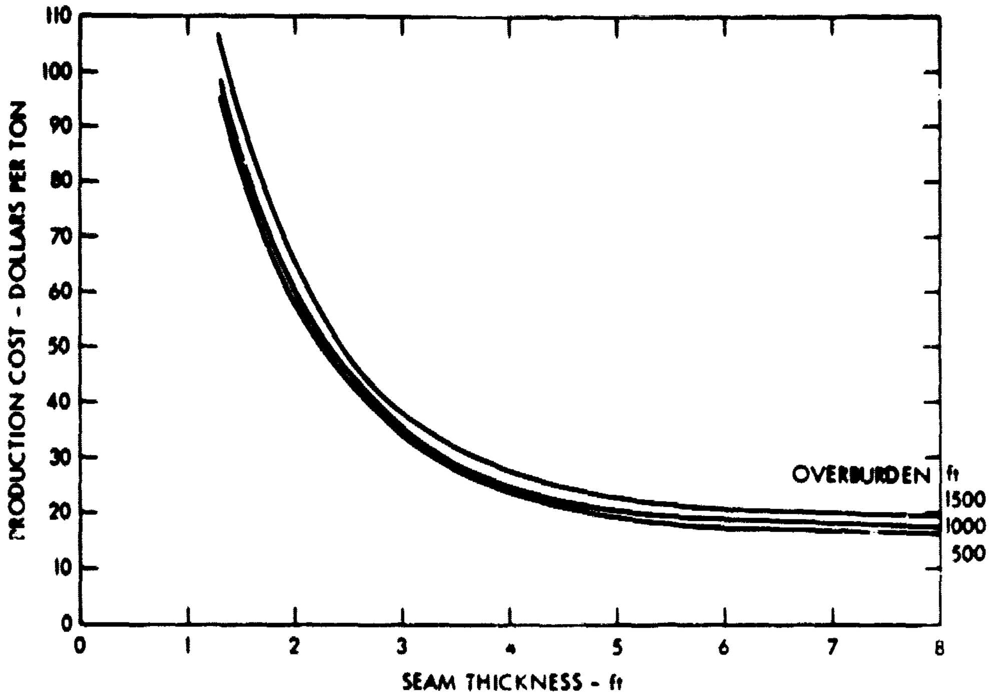

Figure 1-3. Coal Production Cost--Room and Pillar with Miners

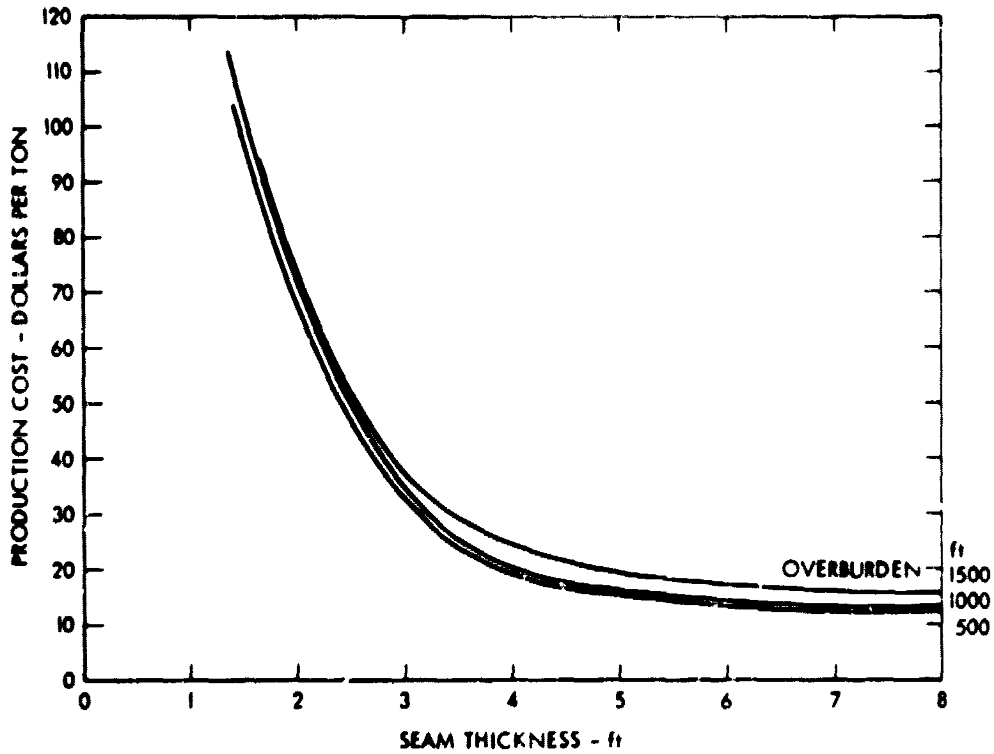

Figure 1-4. Coal Production Cost--Longwall Mining with Continuous Miner Support

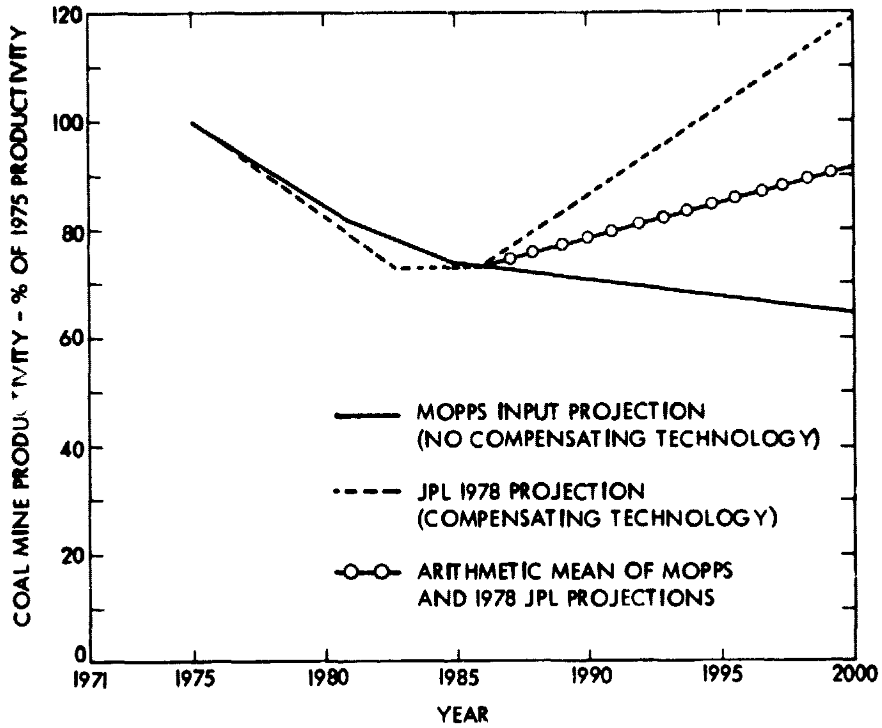

Figure 1-5. Projected Productivity Trends

(1) The productivity decline observed since 1969 has considerable momentum and will continue for a few more years before bottoming out.

(2) The introduction of improved mining equipment in general, including wider use of the longwall and innovative new equipment for Room and Pillar, will lead to substantial increases in productivity.

(3) The wider use of incentive programs to motivate the workforce will be another powerful factor favoring increased productivity.

The JPL projection indicates that a productivity turn-around will occur about 1985 and will gradually improve to within 117% of the 1975 level in the year 2000. The more pessimistic MOPPS study projected a year 2000 productivity which is 64% of the 1975 level.

Because the two productivity projections resulted in such widely divergent predictions for productivity in the year 2000, it was decided to use a mid-range scenario as the nominal projection. Defined as the arithmetic mean value of the optimistic and pessimistic predictions, the nominal scenario resulted in a productivity prediction, for the year 2000, of 91% of the 1975 productivity (see Figure 1-5). Figures 1-6 and 1-7 present the year 2000 cost of coal for both room and pillar and longwall technology, operating with the mid-range productivity forecast.

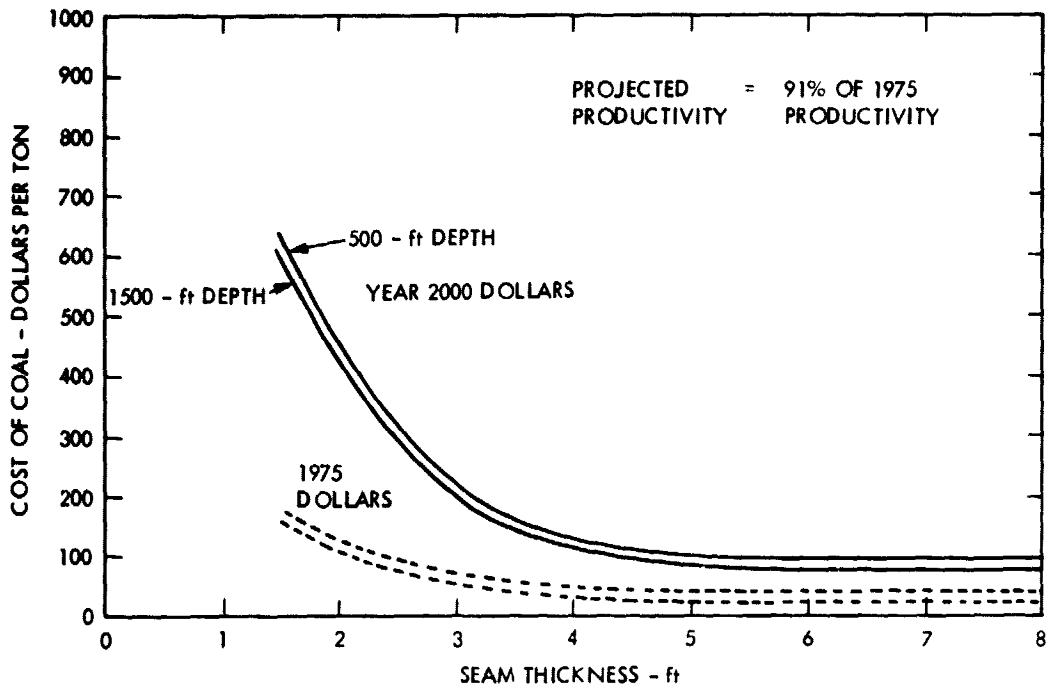

Figure 1-6. Coal Production Cost--Year 2000 Room and Pillar with Continuous Miners

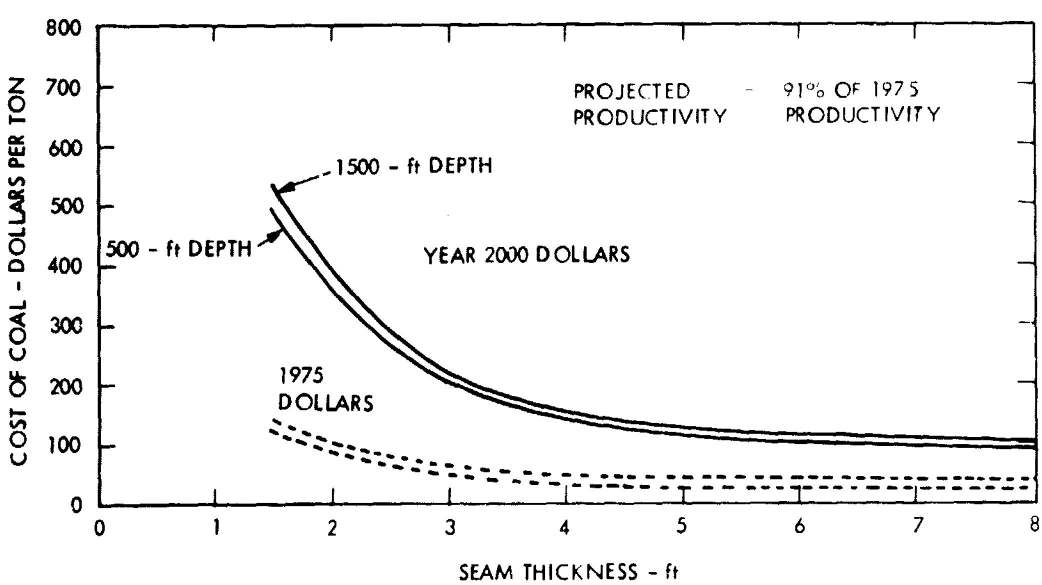

Figure 1-7. Coal Production Cost--Year 2000 Longwall Miner

To give an idea of the possible impacts of inflation, costs were computed in 1975 dollars (dashed lines) and year 2000 dollars (solid lines). These projections indicate that the cost of coal in the year 2000 will be considerably greater than in 1975, even with productivity being 91% of the 1975 level. The question then arises as to how much productivity would have to increase in order to maintain cost of coal at the 1975 level. A parameter study in which the cost of mining coal (using a continuous miner under 500-ft of cover) was calculated for productivities of one, two, and four times the 1975 productivity. The results, shown in Figure 1-8, suggest that productivity in the year 2000 must be nearly two times 1975 productivity to match the 1975 costs. All costs are in 1975 dollars.

The cost model was also analyzed to determine which parameters had the greatest effect on cost. Detailed results from this analysis are presented in Table 5, Appendix E. Examination of the influence coefficients in Table 5 indicates that the three areas that have the largest effect on costs are, in descending order:

(1) Production section equipment, supplies, and materials costs, with a combined influence coefficient of .003223.

(2) Number of hourly and salaried workers, with a combined influence coefficient of .00395.

(3) Interest rate on borrowed capital, with an influence coefficient of .001259.

Note that these findings are very comparable to the theoretical sensitivity analysis previously published in report FE 9036/1.

The cost curves for 1975 and 2000 show that mining costs are relatively insensitive to seam thicknesses between 6.5 and 8 ft; however, below 6.5 ft, costs begin to escalate rapidly. This is of major significance to Central Appalachia, because a major portion of the coal resource in that region in the year 2000 has been predicted to be contained in seams of 4-ft thickness and less. These projections, indicate that research and development on advanced coal mining systems could be profitably directed toward the efficient mining of thin seams. Efficient mining of coal seams carries with it the requirement of: (1) increased productivity, (2) reduced equipment and supplies costs, and (3) a reduced manpower requirement. Reduction of interest rates on borrowed capital is probably not feasible so long as inflation continues at current levels.

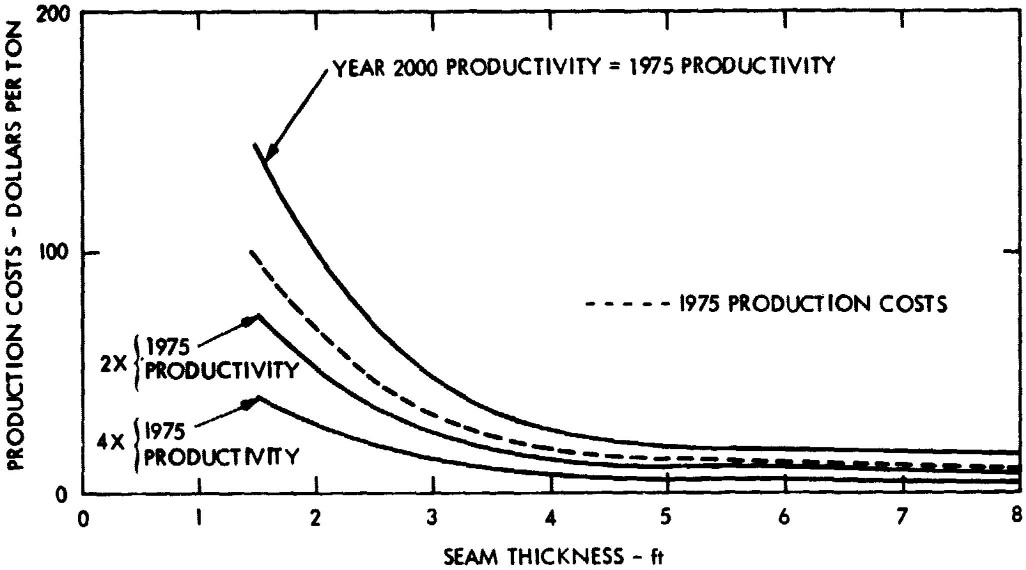

Figure 1-8. Productivity Study--Room and Pillar with Continuous Miner--Year 2000 Costs in 1975 Dollars

SECTION II

REVIEW OF APPLICABLE COST MODELS

A. BACKGROUND

The initial approach taken in this analysis was to hand-calculate the cost of mining coal for one set of very restricted conditions. Very shortly it became clear that a computer model would be required to produce the desired results efficiently. A survey of previous work in coal mine simulation and cost analysis revealed several potentially useful models. Three rather detailed simulations of underground mining have been separately developed by Virginia Polytechnic Institute, Pennsylvania State University, and The Twin Cities Mining Research Center of the U.S. Bureau of Mines. The Morgantown Process Evaluation Office, U.S. Department of Energy, has published a series of costing studies which are very detailed in their treatment of discounted cash flow considerations but much less detailed in describing the production process. Recently, the NUS Corporation (working under contract to the Electric Power Research Institute) constructed an aggregate costing model which incorporates assumptions about the impact of mining conditions on section production. The following paragraphs review each of these models in turn, noting unique capabilities and relevance to the objectives of this baseline study of mining costs.

B. VIRGINIA POLYTECHNIC INSTITUTE MODEL

In an effort to understand and improve the efficiency of the modern, complex, coal mining systems, the Office of Coal Research sponsored a research project at Virginia Polytechnic Institute (VPI). Starting in April 1962, the project was to devise a method whereby the factors which influence mining costs in the immediate production area could be identified. The project was the first such effort and was based on the simulation techniques developed in other industries that use the specialized characteristics of high-speed digital computers.

Two computer programs were developed to simulate activity on a production section. One program was designed specifically to accommodate intricate mining systems and to analyze systems using as many as twelve mining machine units and a maximum of six shuttle cars. The other program was designed to evaluate mining systems in which a maximum of three shuttle cars are used in conjunction with a continuous miner. These programs are event-oriented in their construction.

C. PENNSYLVANIA STATE UNIVERSITY MODEL

The continuing need on the part of mine management for a decision-making tool to replace the costly trial and error method led to a contract between the U.S. Bureau of Mines and Pennsylvania State

University to develop "A Master Environmental Control and Mine Systems Design Simulator for Underground Coal Mining." This contract led to the development of a computer-based simulation model that ties together environmental impacts, geological conditions, materials handling operations, support functions, mining methods, and economics into a comprehensive package for planning, designing, and controlling new or existing coal mining operations. The operation of an entire mine can be simulated via the time-increment method of simulation. In addition to analysis of productivity and cost, this simulation can also be used to study possible impacts on mine health and safety.

D. TWIN CITIES MINING RESEARCH CENTER MODEL

The Bureau of Mines Twin Cities Mining Research Center developed a flexible mining simulation model that can handle a variety of mining methods. This effort was undertaken to provide a simulation system that could be easily applied to describe the mining of coal, salt, copper, etc., without making internal changes to the simulation model (as would be required by the VPI and Penn State models) if they were to be used to model anything other than underground coal mining. The Bureau of Mines model contains the elements common to all production systems; activities or events, equipment, and inventories. Procedures were developed to represent a wide range of interaction between those elements in order to accommodate complex operations. The model has been used for longwall and room and pillar applications to determine the economical feasibility of mining methods within certain geological constraints.

E. BUREAU OF MINES COSTING INFORMATION CIRCULARS

In 1974, the United States Bureau of Mines began issuing a series of information circulars that provide a framework for estimating capital investment and operating costs for coal mines. These studies are meant to assist mine operators in planning new mining operations and are organized around familiar cost summaries: investment in construction, equipment and working capital; manning tables; breakdown of operating costs; treatment of federal and state taxes, including the impact of depletion and depreciation; expenditures on consummables, etc. Capital charges are discounted by the present worth factor and summed to form the present worth of the aggregate mine investment. The authors then calculate the selling price of "run-of-the-mine" coal, assuming constant sales for the life of the mine that amortize the investment, cover the annual operating costs, and allow for an adequate profit. These circulars present a method for capital budgeting that is easily understood, comprehensive, and can be quite useful to the mine operator.

F. NUS CORPORATION MODEL

The NUS Corporation developed an underground coal mining cost model for the Electric Power Research Institute (EPRI). Designed to analyze costs of individual coal mines and to generate minimum acceptable selling prices, this model transforms the Bureau of Mines economic calculations into a computer format. In addition, it has the capability of relating section production to projections for seam thickness, overburden, roof and floor quality, pitch, and methane. Detailed equipment, construction, supplies, and labor costs are stored in the computer and manipulated, as necessary, to calculate the required costs. Section production is obtained from tables which were derived via correlation of empirical and simulation production data on the effect of various combinations of geological conditions.

The wide range of variables which can be accommodated by the cost model facilitates its application to mining situations encountered in any coal producing region of the United States. Optional data inputs are provided to facilitate changes in numerical values. This feature also allows the cost of machinery, construction, labor, etc., to be updated, using cost index projections. Although the model has 1975 cost numbers stored for normal use, year 2000 cost numbers can be generated easily via the optional input feature.

G. SUMMARY

The three simulation models analytically describe and calculate the effects of changes in machinery capability on the mining process and then the production of coal from the system. The primary purpose of the models is to provide mine management with the information necessary to make meaningful planning and operating decisions. However, the Twin Cities Mining Research Center's model does provide for a wider application. In any event, these models are intended to be applied to a very detailed analysis of the mining process, and to study the effects of changes on that process. Both the VPI and Penn State models are strongly oriented toward the analysis of contemporary technology and its extrapolations.

In contrast, the cost studies published by the Bureau of Mines are specific to various seam thicknesses and mine sizes. The application of these studies tends to be limited to mines having comparable characteristics.

The NUS model has characteristics which are a fortunate compromise between the detailed simulation of section-level operations and a very aggregate description of section production. In addition, this model has the capability of relating section production, and consequently the price of coal, to changing geologic conditions. This permits inference of the impact of depletion, work force changes, alteration in work rules and worker motivation, etc., all of which are most pertinent to projections of the cost of coal. In sum, the NUS model appears to be ideally suited to the sort of baseline cost studies required in this study.

SECTION III

DESCRIPTION OF COST MODEL USED

A. THE NUS MODEL

The NUS underground coal mining cost model was developed to facilitate the analysis of coal production cost per ton, for a wide range of mining situations. The intent was to accommodate model applications in coal supply curve development as well as analyses regarding specific mine properties. This wide range of applicability allows JPL to use the model over a series of geological conditions and to generate production costs for a room and pillar mining plan using continuous miners and for a longwall mining system using continuous miners in support. These costs will be used as an economic standard for comparison with the economic characteristics of advanced mining system concepts as they are generated.

The NUS model accepts variables that describe: (1) seam characteristics, (2) mine type, (3) mining system, (4) haulage system, and (5) mine characteristics. This model does not attempt to simulate an operating coal mine. Empirical or simulation data is put into the model that accounts for the effects on machine and mine production caused by geological or other conditions.

A list of the variables accepted by the model is as follows:

(1) Seam Characteristics.

(a) Thickness.

(b) Depth of cover.

(c) Roof conditions.

(d) Floor conditions.

(e) Gas emissions.

(f) Seam gradient.

(2) Mine Type.

(a) Drift.

(b) Shaft.

(c) Slope.

(3) Mining System.

(a) Continuous.

(b) Conventional.

(c) Longwall.

(4) Haulage System.

(a) Track haulage.

(b) Belt haulage.

(5) Mine Characteristics.

(a) Mine size.

(b) Mine life.

(c) Rate of return.

(d) Local and state tax life.

(e) Coal preparation facilities.

(f) Debt-equity ratio.

(g) Cost of money.

The mine model can generate mining costs based on any combination of the above variables. This built-in flexibility enables the model to be applied to most underground coal deposits in any region of the country.

Incorporated into the model are the following major assumptions:

(1) There is a square coal deposit.

(2) A single model of each type of equipment is used to provide typical equipment cost figures, regardless of seam characteristics.

(3) Shuttle cars and belt conveyors are used in the continuous mining system to transport the coal to secondary or main-line haulage.

(4) A single mine development plan (room and pillar) having ten entries in the mains and crossmains (two parallel five-entry systems) is assumed to apply for all continuous mining systems. Pillar dimensions and entry length vary accordingly to roof conditions.

(5) Separate mine development plans are assumed for one-and two-unit longwall mines. Ten-entry systems of mains and crossmains are assumed while a three-entry system of head-and-tailgate entries is used to outline the longwall panels.

(6) Longwall mining systems require five continuous miner production sections in support of each longwall unit. Longwall faces are 500-ft wide.

(7) An equal number of production sections operates each shift (the model can accomodate any number of shifts).

(8) For coal preparation costs both coarse and fine cleaning is required as well as sizing for all underground mining operations. This type of preparation is the most costly technique.

(9) Individual preparation plant reject percentages are assumed for each mining system. These reject percentages apply to any mine situation utilizing the specified mining system.

B. OVERVIEW OF MODEL STRUCTURE

The process of computing a minimum acceptable selling price per ton in the NUS underground mine model follows a building block concept of analysis. The procedure is initiated by the introduction of a number of inputs into Section I (Production Sections Per Shift) of the model. From that point on, the model is self-contained and no further input of information is required for completing the cost analysis. The information developed in Section I is provided as input to Section II (Manpower) and Section III (Equipment and Construction). Section II, in turn, is directly inputted to Section III, IV (Supplies and Material), V (Power), VI (Preproduction Development), and IX (Annual Operating Cost, Working Capital). This approach is continued throughout all of the analysis sections and then funneled back to Section X where the minimum acceptable selling price is computed.

Each of the sections was developed using a combination of empirical data, mining application information, and economic and cost analysis procedures. In addition, an "optional data capability" was built into the program. This means that a desired value for an internally calculated value can be inputted to the program. The internal calculation procedure will be superseded and the inputted value used in the continuing calculations. This program capability allowed JPL to alter some of the assumptions, empirical data, and logic built into the program without internal modification of the model codes. For instance, it was desired to define the machine production rates (tons per machine shift) contained in the program over a wider range of seam thickness and to restrict these rates to a smaller set of geological variables. The "optional data capability" was a great help in using the program since the program could then be readily tailored to the mining characteristics desired by JPL.

C. THE BASELINE MINE

The development of an economic standard for coal mining systems requires a description of a mining system that is representative of the systems in use today. The NUS model provides descriptions of the two most commonly used mining systems along with geologic descriptors of the most prevalent geology that may be encountered. A problem in describing the system was whether to select the assumptions provided by the model for the particular mining system in question, or whether to generate a new value or set of values to replace the assumptions with which there was disagreement.

The first model assumptions to be fixed were those that were applicable to both the room and pillar and the longwall systems, namely:

(1) Seam characteristics

- (a) Thickness - 1 1/2 to 8 ft
- (b) Overburden depth - 500, 1000 and 1500 ft
- (c) Roof conditions - good
- (d) Floor conditions - hard
- (e) Gas emissions - low
- (f) Seam gradient - 0^{o}

(2) Mine type

- drift

(3) Mining system

- Room and Pillar and Longwall

(4) Haulage system

- Track and belt

(5) Mine characteristics

- (a) Mine size - variable
- (b) Mine life - 20 years
- (c) Rate of return - 15%
- (d) Local and state taxes - 50%
- (e) Coal preparation facilities - yes
- (f) Debt-equity ratio - 80/20
- (g) Cost of money - 10%

D. CHANGES TO THE MODEL ASSUMPTIONS

Coal preparation facilities were included in both the room and pillar and the longwall system analyses and the assumptions contained in the model were changed as discussed in this and following sections.

1. Preparation Plant Reject

The NUS model assumes a preparation plant reject percentage for each mining system and holds it constant over the entire range of seam thickness. Reject percentages were 25% for continuous miner room and pillar and 21% for longwall. This assumption appeared to be somewhat oversimplified in that data existed to indicate that the reject percentage tended to increase as the seam thickness decreased.* This is caused in part by the requirement for the mining machine operator to cut a little more of the bottom or top strata to obtain clearance for machinery as the seam thins. On the thick seam end, there is reason to believe that the number and thickness of partings increase as the seam thickens. The effect is not as pronounced a reject percentage increase as with the thinner seams. Therefore, the reject curve presented in Figure 3-1 was constructed using one data point at the 48-in. seam thickness and the above rationale. The minimum reject occurs at about the 6-ft thickness. It was assumed that it would be necessary to mine surrounding strata when operating in the thin seams, which accounts for 50% reject when mining a 24-in. seam (assuming that 48 in. is about the minimum opening for mining purposes).

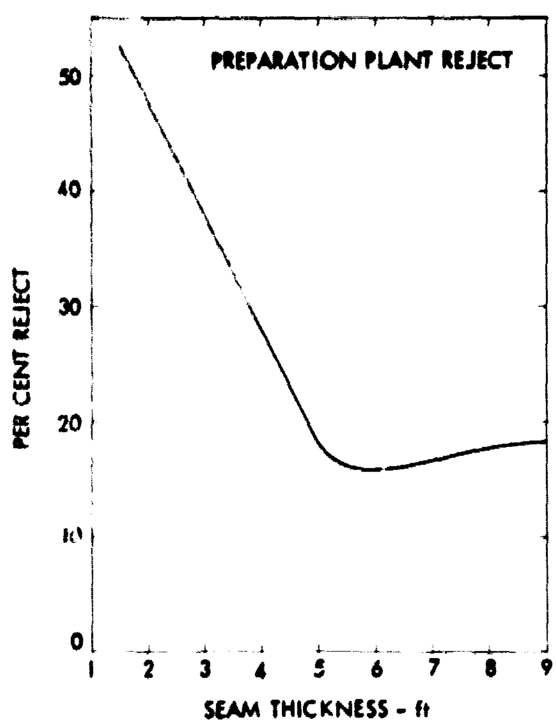

Figure 3-1. Preparation Plant Reject

*Personal communication with a preparation plant foreman in Eastern Kentucky.

3. Longwall System

a. Longwall Production Rate Curve. The NUS model used ten points from a group of longwall production numbers, published in Coal Mining and Processing, December 1970, to develop an equation that describes the longwall productivity. This equation has the following form.

Tons Per Machine Shift Longwall = -662.26 + 5.29 (seam height) + .121 (depth of cover) + 2.55 (face length)

Where all dimensions are expressed in feet.

It was assumed that the face length was 500 ft for this analysis. Substituting 500 ft into the above equation yields,

TPMS = + 612.74 + 5.29 (seam height) + 0.121 (depth of cover). Applying the three depths of cover and allowing seam thickness to vary from 1 1/2-ft to 8-ft yields the method by which the set of three curves presented in Figure 1-2 were generated. It was obvious that the range of seam thickness over which the curves were valid was not as wide as desired. As plotted, the curves indicate that longwall productivity in a 3-ft seam is as large as in an 8-ft seam. This was not felt to be the case and with an absence of valid data it was decided to alter the curves to reflect a decrease in productivity as the coal seam thins. The new productivity curves are shown with bubbles attached and, like the continuous miner productivity curves, all three curves merge at the 3-ft seam thickness. The reasoning here is that the reduced clearance in the thin seam eliminated the production advantages experienced with greater depth of cover. Another interesting but unexplained characteristic noted is that the productivity under 1500-ft overburden is greater than under 500-ft overburden. This would indicate that the added pressure experienced under 1500-foot overburden makes the longwall machine more efficient. However, nothing was done to verify or alter this characteristic.

b. Number of Continuous Miner System Working Sections. The cost model has a built-in assumption that one longwall mining section requires five continuous miners to develop the mine in support of the longwall. This appeared to be a liberal use of continuous miners. A simplified calculation (See Appendix A) indicates that only one continuous miner is required to outline the longwall panels in advance of the longwall machine. This would leave four continuous miners to develop the remaining parts of the mine. JPL made the decision that only two continuous miners were needed for this development (based on Appendix A) so that the mine development would not get too far ahead of the actual production. Using this assumption, the longwall system consisted of one longwall machine and three continuous miner working sections in support.

c. <u>Cost of Longwall Working Section Equipment</u>. Only a single representative cost of a longwall machine was contained in the NUS model, and as was the case for the room and pillar system, it was desired to provide a range of costs that would be applicable for the range of seam thicknesses being analyzed. Discussions with various longwall manufacturers and suppliers and data from the Bureau of Mines provided the basis for the range of costs that were used in the analysis (Figure 3-3). The costs for continuous miner support working sections were indicated previously (see Figure 3-2).

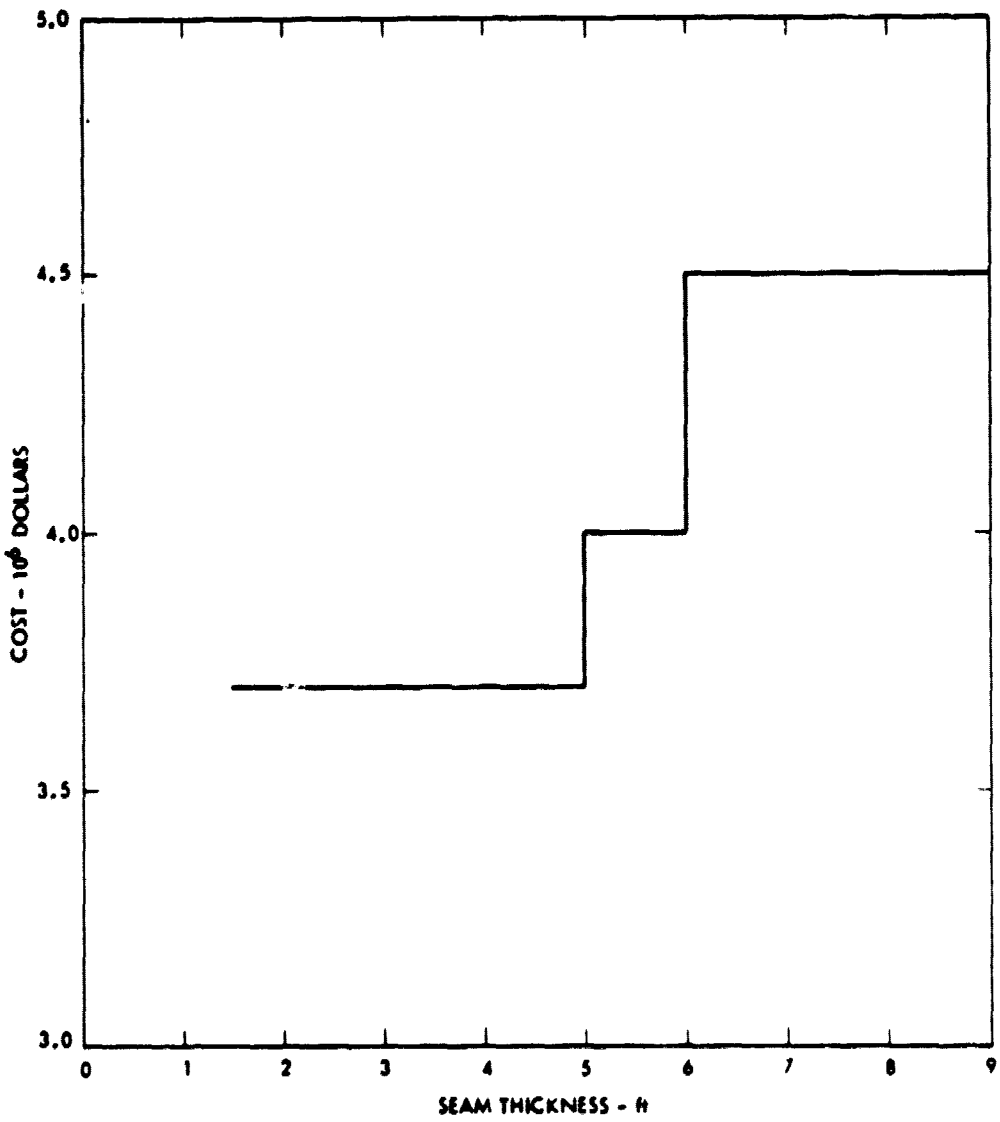

Figure 3-3. 500-ft Longwall Production Section Equipment Cost

E. PROJECTIONS TO THE YEAR 2000

1. Cost and Wage

The NUS model contains a feature that allows the costs and wages to be updated to years other than the base year of 1975. This procedure uses the various wholesale price indexes published by the Department of Commerce as multipliers to obtain the new cost and wage values. The procedure works very well if a price index exists for the year in question. In the case of this analysis it was desired to calculate the cost of mining coal in the year 2000 and there was no cost index available. To overcome this difficulty, JPL plotted the required cost indexes for the years in which they had been published. Then, using Data Resources, Inc., (DRI) long-term forecasting, energy forecasting, and cost forecasting models, cost indexes were constructed for each year through 2000.

There were four indexes required to predict mining costs in the year 2000:

(1) Chemical Plant and Equipment Index. Used in the NUS model to project the costs of preparation plant and surface construction.

(2) Mining Equipment Index. Used to project the cost of mining equipment and supplies both underground and on the surface.

(3) Electric Power Price Index. Used to project the price of electric power to the year in question.

(4) Coal Miners Wage Index. Used to project the rise in coal miner's wages to the year in question.

a. Chemical Plant and Equipment Index. The Data Resources, Inc. (DRI) Macro Forecasting model generates two variables: (a) Plant and Equipment Expenditures, and (b) Industrial Production Index for Chemicals and Products, 1967 = 1.0.

The ratio $\frac{a}{b}$ = price index

The DRI variables were available through the year 1990 and the calculated price indexes indicated an average growth rate as follows:

1978 - 1980	3.7% per year
1980 - 1985	6.7% per year
1985 - 1990	2.8% per year

Data to project the 1990 to 2000 growth rate was not available, therefore, it was assumed to be 2.5% based on the 1985 - 1990 projection. Historical data existed for the Chemical Engineering Plant Cost Index through 1977. Using this data and the projected growth rates indicated above, cost index values for the years up to 2000 were calculated. The projection of Chemical Plant and Equipment Index is presented in Figure 3-4.

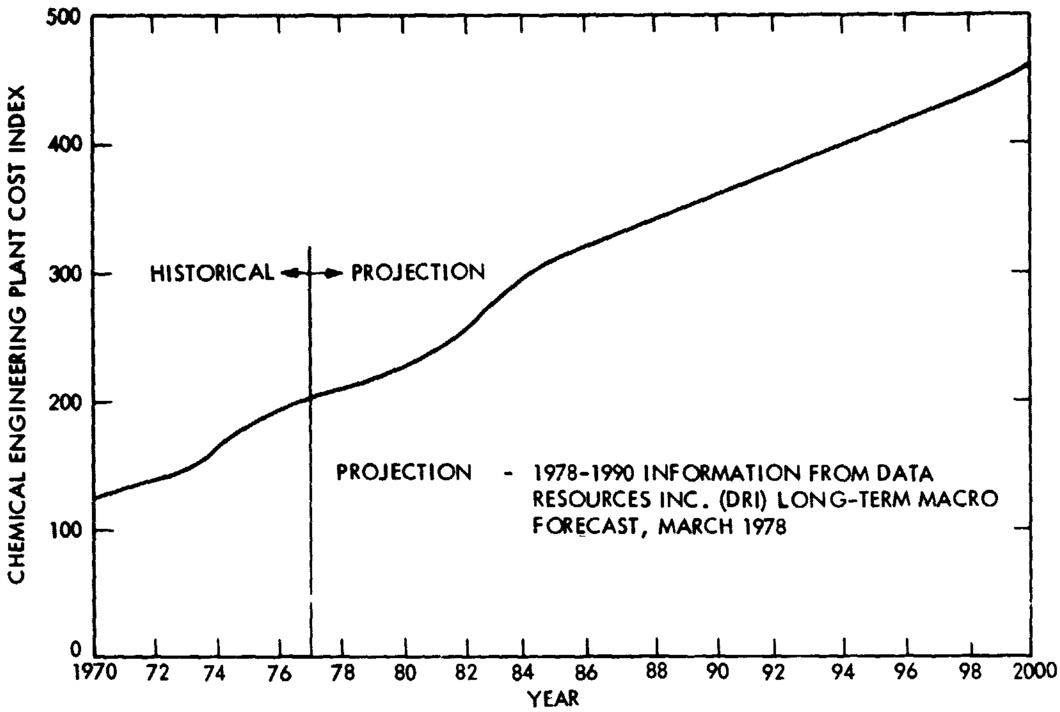

Figure 3-4. Chemical Engineering Plant Cost Index Projection; Historical Data from Statistical Abstracts U.S. Department of Commerce 1977

b. <u>Mining Equipment Index.</u> The DRI Macro Forecasting model was again used to project the mining equipment index. This model generates two additional variables; (c) Plant and Equipment Expenditures, mining, and (d) Industrial Production Index, mining 1967 = 1.0.

The price index for each was approximated by forming the ratio

$$\frac{c}{d} = \text{price index.}$$

By calculating the price index for each year and comparing the growth in the price index from one year to the other, the following growth rates were obtained:

1978 - 1980	12.3%
1980 - 1985	8.4%
1985 - 1990	8.9%

Again, DRI data was not available for the 1990 - 2000 time period so a reduced growth rate was assumed. The curve of historical and projected mining equipment cost index is presented in Figure 3-5.

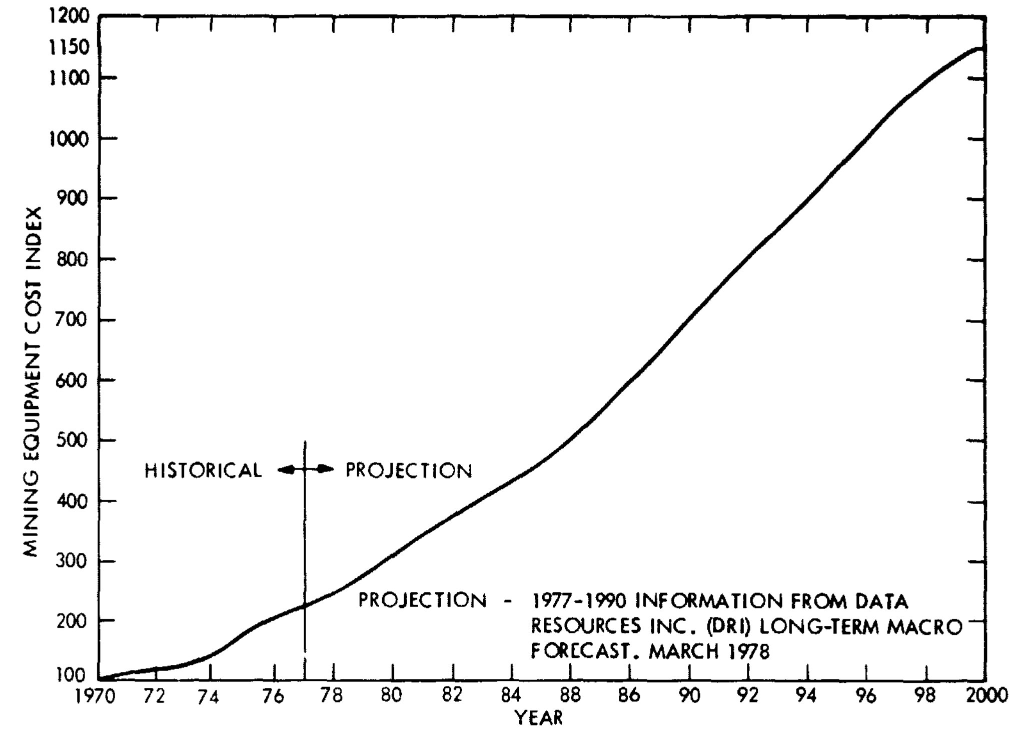

Figure 3-5. Mining Equipment Cost Index Projection; Historical Data from Statistical Abstracts U.S. Department of Commerce--1977

c. Electric Power Price Index. It was assumed that electrical power for mining purposes was the same as industrial electricity. The DRI Energy Forecast calculates and projects the price of industrial electricity in 1978 dollars per million Btu:

1976 - 6.79
1977 - 7.11
1978 - 7.5
1979 - 7.4
1980 - 7.7
1985 - 8.9
1990 - 10.6

Using the above values, the growth rate for the 1976 - 1978 period was 5.1% per year.

1978 - 1980	1.34% per year
1980 - 1985	2.94% per year
1985 - 1990	3.55% per year

Again, DRI data did not exist for the post 1990 time period so using the above growth rates, a value of 4.0% per year was hypothesized for 1990 - 2000.

The historical and projected Electric Power Price Index is presented in Figure 3-6.

d. <u>Coal Miners Wage Index.</u> The DRI Cost Forecasting model generates the hourly wages for coal miners for future years. It was assumed that this projected hourly wage was valid for underground coal miners. The yearly growth rate for the time period in question was then estimated from the average wage table:

1977 - 1980	10.5% per year
1980 - 1985	9.4% per year
1985 - 1990	8.8% per year
1990 - 2000	7.5% per year

Historical wage data from the 1974 and 1978 National Bituminous Coal Wage agreements were plotted and a projected wage curve prepared using the growth rates indicated above. This curve is presented in Figure 3-7.

Additional details as to how these cost projections were made are contained in Appendix B.

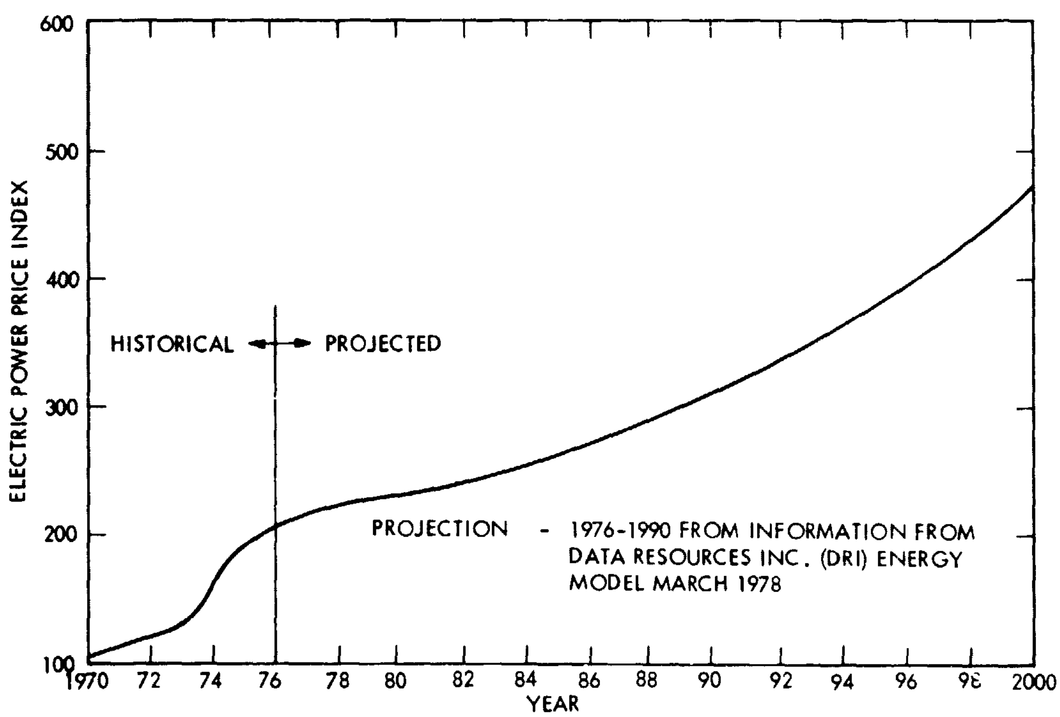

Figure 3-6. Electric Power Cost Index Projection; Historical Data Statistical Data Department of Commerce--1977

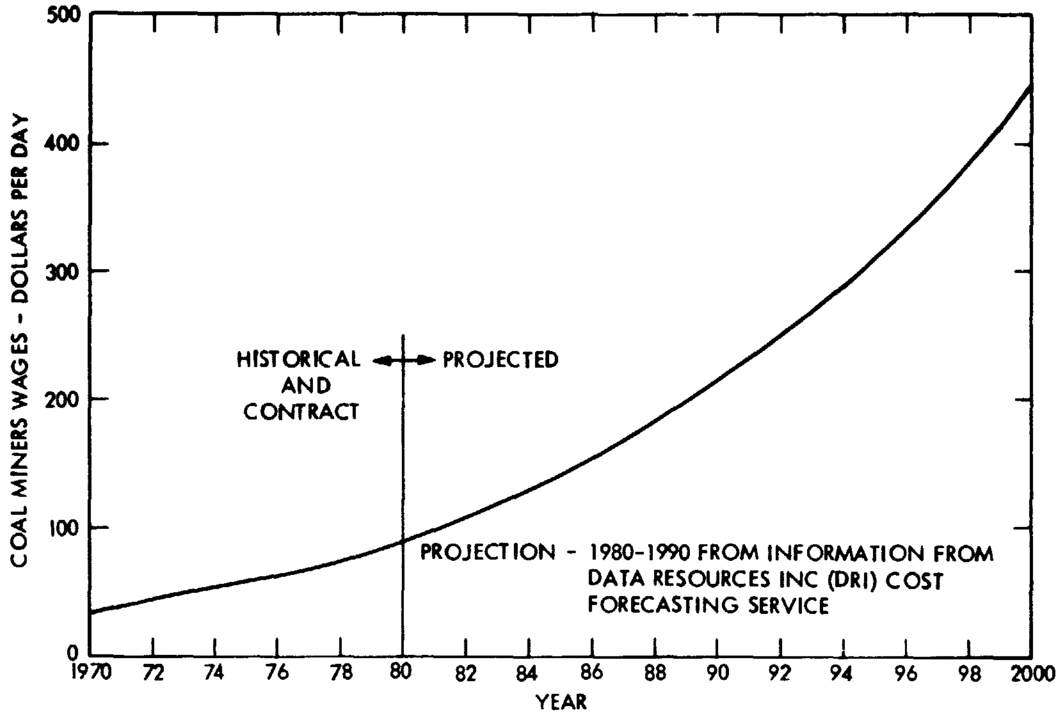

Figure 3-7. Coal Miner's Wage Projection; Current Dollars--Historical Data from National Bituminous Coal Wage Agreement of 1974 and 1978

2. Productivity

Predicting the cost of mining coal in the year 2000 requires the projection of costs as indicated above plus a projection of productivity in terms of tons per man shift or tons per machine shift. The projection of productivity provided to the Mopps study assumed that no technology or incentives would be applied to improve the productivity picture. For comparison purposes, JPL's projection assumed that both technology improvements and incentives were provided. Historical and projected productivity data are shown in Figure 3-8. An explanation of the productivity projection is presented in Appendix C.

3. Year 2000 Costs in 1975 Dollars

Year 2000 mining costs in year 2000 dollars were calculated using the cost index and the productivity projection; the same method by which the 1975 costs were obtained. It was determined that if these costs were converted back to 1975 dollars, then the real change in costs by the year 2000 could be evaluated. This was accomplished through the use of a Gross National Product deflator obtained by the procedure presented in Appendix D. The results of this analysis are shown as dashed curves in Figures 1-6 and 1-7. These data indicate that the real cost of mining in 2000 is 1.8 times the cost in 1975.

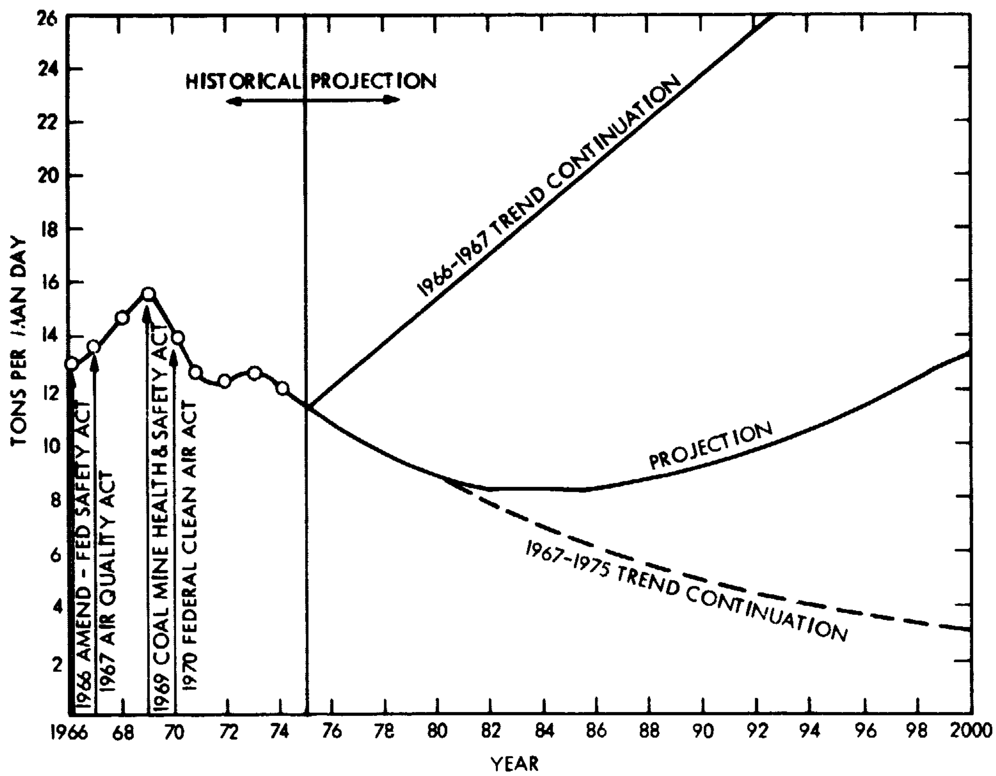

Figure 3-8. Coal Mine Productivity--Historical and Projected

Remembering that the projected productivity in the year 2000 was 91% of the 1975 productivity, a productivity increase of approximately 2 times the 1975 level is needed to maintain costs at the 1975 level.

Figure 2-4 presents the results of a productivity analysis that will give the advanced system planner insight into the problem. Consider the cost curve for an 8-ft seam. The first doubling of productivity produces a cost reduction of 48.3%. If productivity is doubled again, i.e., four times the 1975 production level, the costs are reduced by 72.4%, or only 24.2% lower than that obtained by the initial doubling of the productivity. Clearly, the second doubling of productivity is not as effective in reducing costs as the first. This same characteristic is true at all seam thicknesses, but the percentage reduction for all seam thicknesses varies somewhat. If the productivity in the year 2000 is 35% lower than 1975 productivity, as predicted by the MOPPS study, then this analysis indicates that the cost of coal would be 47.6% greater than the cost would be if the productivity was the same as in 1975.

SECTION IV

DISCUSSION OF RESULTS

The results obtained after all the preceding assumptions and data generation was processed by the NUS cost of coal model are summarized in Figures 1-3, 1-4, 2-2 and 2-3. The cost of mining coal using the two existing systems (room and pillar and longwall) in the base year of 1975, are shown in Figures 1-3 and 1-4. The curves show that the longwall system will produce coal for \$80.00 to \$92.00 per ton compared to \$98.00 to \$103.00 per ton for the room and pillar, when both systems are operating in a 1 1/2-foot coal seam. When operating in an 8-ft seam, the room and pillar produces coal for \$12.50 to \$15.50 per ton compared to \$16.00 to \$19.50 per ton by the longwall method. This analysis would indicate that economically there is little difference in the performance of the two systems. Clearly, the strength of the longwall system lies in areas other than purely economics, such as high extraction efficiency under adverse geological conditions, and health and safety.

The cost of mining coal in seam thicknesses less than four (4) feet escalates rapidly as the seam thins. For the continuous miner it goes from a range of \$19.50 to \$24.50 per ton at 4-ft thickness to a range of \$97.50 to \$103.00 per ton at a 1 1/2-foot seam thickness. The longwall system goes from \$24.00 to \$28.00 per ton at 4 ft to \$81.50 to \$91.50 per ton at the 1 1/2-foot seam thickness. The longwall system appears to generate an advantage economically in the thinner seam thicknesses.

The cost curves generated for the year 2000 maintain the same characteristics as those generated for 1975, as would be expected. In general, they reflect a 5.4 x the 1975 costs. The range of costs for the continuous miner in a room and pillar mine were \$69.70 to \$87.80 per ton in an 8-ft seam and \$619.80 to \$641.90 per ton in a 1 1/2-foot seam. The corresponding ranges for the longwall system were \$94.40 to \$107.80 per ton and \$496.30 to \$535.30 per ton. These costs assume that the projected productivity is attained in the year 2000. The productivity analysis indicated that increases in productivity had a non-linear effect on the lowering of the cost of mining. That is, increasing productivity by a factor of two did not lower the cost of mining by a factor of two. However, decreasing productivity by a factor of two increased the cost of mining by an amount greater than a factor of two. In effect, this penalizes the cost of mining more severely for losses in productivity than it rewards it for gains in productivity, and gives very strong economic reasons to maintain productivity at or above today's levels. It also tempers the desire to strive to make large improvements in productivity because cost improvements diminish sharply as productivity increases.

The analysis was continued in an attempt to identify the largest cost drivers in the mining systems. A single point (continuous miner in room and pillar mine, 5-ft seam thickness, 500-ft depth of cover and the year 2000) was selected and the table of influence coefficients calculated to determine the effect of various parameters on the cost of coal. There were thirty-four different items in the program that affect the cost of coal, however, four of them had an order of magnitude greater effect than the remaining thirty. These were: (1) the cost of production section equipment (.00370), (2) the total hourly labor requirement in men per day (.00305), (3) supplies and material costs per ton (.002475), and (4) interest rate on borrowed money (.001259).

A table of influence coefficients (Table 4-1) serves to point out that the cost of mining coal has many components which must be addressed before large reductions in mining costs can be affected. The sum of the coefficients that are associated with equipments costs, manpower costs, and the cost of money, suggests the arena in which the greatest mining cost reductions can be obtained.

It is not exactly correct to do the summations indicated above because a good number of the variables are dependent on the others, however, an indication of where the large cost drivers are can be obtained. As indicated, equipment costs are the largest single driver, followed by manpower costs, costs of money, and all the other. Using the methods indicated in Table 5, Appendix E, a 20% reduction in equipment costs would reduce the $82.22 per ton cost by $11.12, yielding a $71.10 per ton cost. A corresponding 20% reduction in manpower would reduce the $82.22 per ton cost to $72.51 per ton or a reduction of $9.71.

These influence coefficients also indicate that the mining systems in use today and anticipated to be in use in the year 2000 are capital and equipment cost dominated.

The model also tabulates the four components of the costs; labor, welfare, capital and supplies. If labor and welfare are combined and called the labor charge, and if capital and supplies are combined and called capital charge, and then plotted as in Figures 4-1 and 4-2, it indicates that the room and pillar system is labor-dominated in seams over 4-ft thick, while the longwall system is capital-dominated in seams over 3-ft thick.

Table 4-1. Influence Coefficients

Equipment Costs

Production Section Equipment Cost	.000748
Preproduction Haulage System Cost	.000225
Production Haulage System Cost	.00014
Heavy Equipment Cost	.000195
Ventilation Equipment Cost	.00003
Supplies & Materials Cost/Year	.002475
Dewatering System	.000012
Fire and Safety System	.000012
Communications	.000018
Total	.003855

Manpower Costs

Total Hourly Labor Per Day (man)	.00305
Salaried Personnel Requirement (man)	.00090
Union Welfare Rate/man hour	.000353
Union Welfare Rate/ton	.000699
Average Annual Salary	.00090
Total	.005902

Cost of Money

Rate of Return	.00048
Interest Rate on Borrowed Capital	.001259
Portion of Capital Borrowed	-.000657
Federal Tax Rate	.000389
State Tax Rate	.000019
Total	.001521

Other

Reject Fraction	.00003
Seam Recovery Factor	-.00014
Miscellaneous	.000024
Preproduction Site Preparation	.000049
Production Site and Ventilation Construction	.0000158
Other Surface Construction	.000511
Exploration	.000006
Power Cost per Ton	.000085
Direct and Indirect Development Cost	.000438
Development Time	.000018
Total	.0010368

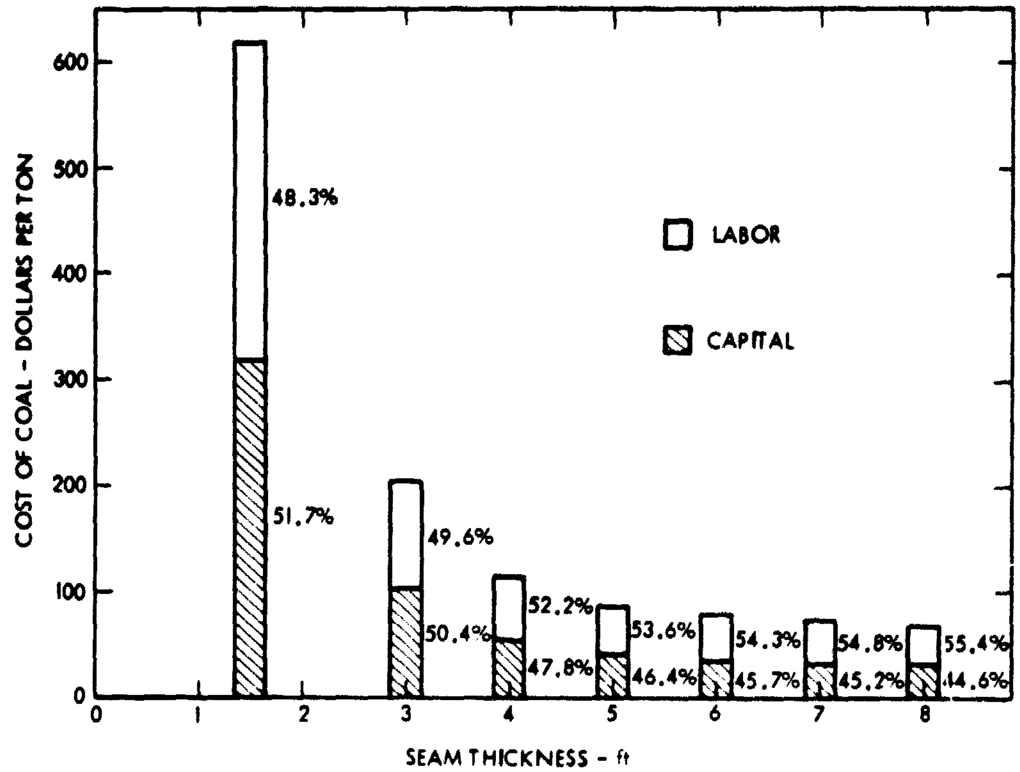

Figure 4-1. Room and Pillar Production Costs (Labor/Capital Split) 500-ft Depth of Cover--Year 2000

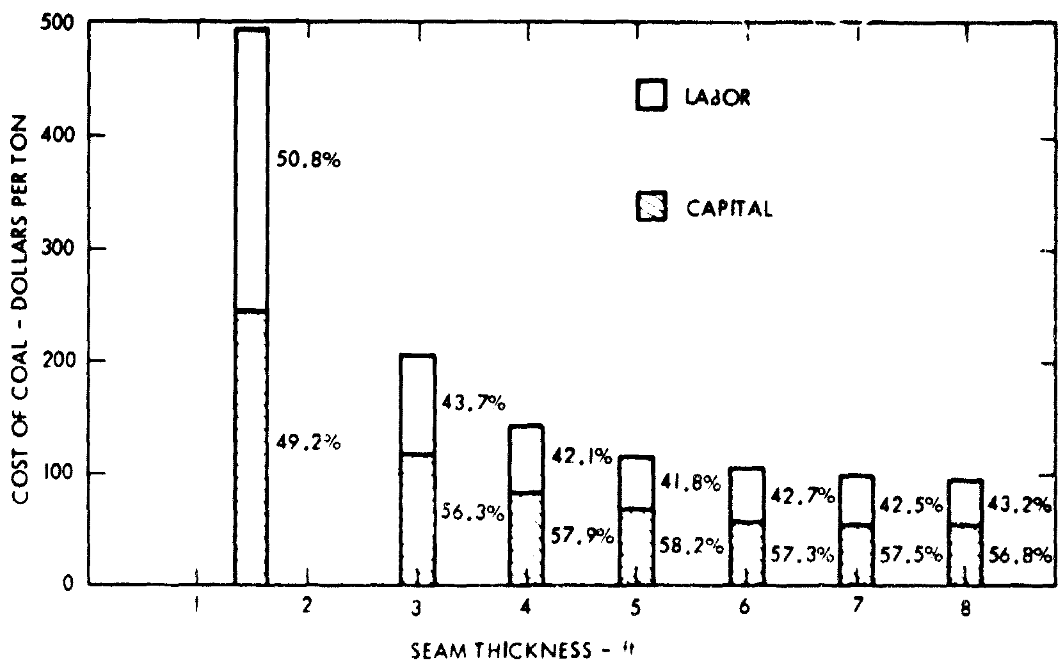

Figure 4-2. Longwall Production Costs (Labor/Capital Split) 500-ft Depth of Cover--Year 2000

SECTION V

IMPLICATIONS FOR MINING SYSTEM DESIGN

The projection of the costs of mining coal in the year 2000 indicates that the price per ton of coal will escalate at a rate slightly above the average inflation rate. This is true, assuming no inordinate pressures from the market place, i.e., a sharp increase in oil prices, an OPEC slow-down in oil production that unduly increases the demand for coal, etc. A breakdown of the cost of coal mining, into its four major parts: (1) equipment-related costs, (2) labor-related costs, (3) cost of money, and (4) miscellaneous results in the observation of another interesting implication. The ratio of equipment-related costs, to labor-related costs was 1.15. This would indicate that, as the coal mining process has evolved over the years prior to 1975, it has gone from a labor-intensive system to a capital-intensive system.

There is nothing basically wrong with this except there is more and more thought being given to automation of the mining system. As more automation is brought into the mine, the cost of equipment escalates and the history of automation in other industries shows that it does not always eliminate labor. Most often it only displaces it to perform other tasks brought on by the automation and in most instances, the new tasks require labor of a higher grade with more technical competence and a higher pay scale. The net effect could be that the cost of coal mining escalates again if the productivity and reliability of the automated system is not greatly increased to offset the additional costs. However, as shown in the productivity analysis of this report, there is a non-linear relationship between productivity increases and the reduction in the cost of coal, as shown in Figure 1-9. Doubling the productivity does not necessarily halve the cost. Therefore, it would appear that the most fruitful direction for advanced system design is toward more simplicity with an attendant lower cost, with or without a reduction in manpower. Some evidence of this approach can be seen in the coal mining industry today. At least one mining company has announced an abandonment of the continuous miner in favor of the conventional mining method using mechanical loaders and self-propelled support equipment.

A second implication indicated by this analysis was noted in the analysis of the productivity of the longwall mining method. The productivity curves used in the original NUS analysis would appear to be too low. Most proponents of longwall would say 900 tons per machine shift is much less than the capabilities of the machine. An average of 900 tons per machine shift equates to a production of 1238 tons per machine shift when the various delays and move times are accounted for. That is, when the machine is actually mining. It can also be expected that this production rate will increase slightly when newer methods of use are devised. This large production output could account to from 40 to 70% of the output of a given mine. While this large production can be considered desirable, a small percentage of

APPENDIX A

LONGWALL SUPPORT REQUIREMENT

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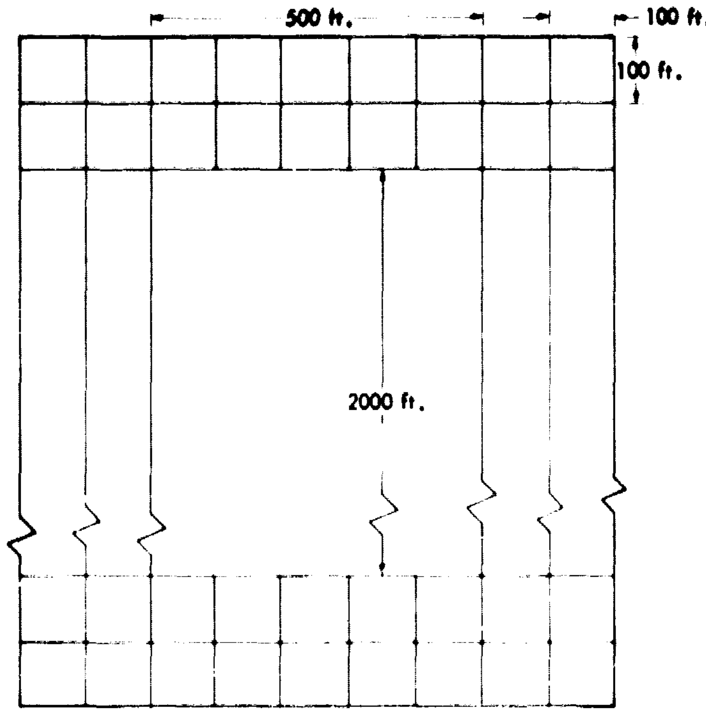
LONGWALL SUPPORT REQUIREMENT



Assume

1 - Longwall panel width	= 500 ft
2 - Longwall panel length	= 2000 ft
3 - Entry spacing	= 100 ft on centers
4 - Crosscut spacing	= 100 ft on centers
5 - Three entry system as shown above	
6 - Entry and crosscut width	= w = 20 ft
7 - Seam height	= h
8 - Coal density	= $85\#/ft^3$

Total tonnage coal removed to outline longwall panel

Total length of entries = 6(2000 + 400) + 6(500) = 14,400 + 3,000
= 17,400 ft.

Total length of crosscuts = 46(200 - 3W) + 10(200 - 3W) = 46(140)
+ 10 (140) = 6,440 + 1,400 = 7,840 ft

Grand total length = 17,400 + 7,840 = 25,240 ft

Total tonnage coal removed by longwall machine

$$\frac{25,240 \times 20 \times h \times 85}{2000} = 21,454 \text{ h tons}$$

Assume seam height = 5 ft

Entry tonnage = 21454 x 5 = 147,270 tons
Longwall tonnage = 66500 x 5 = 332,500 tons

From Production Curves

Continuous miner tons per machine shift = 575 tons/shift
Longwall machine tons per machine shift = ?

Continuous miner can complete entry system in:

$$\frac{14,7270}{575} = 257 \text{ shifts or } 128 \text{ days}$$

Longwall would have to mine at

$$\frac{332,500}{257} = 1294 \text{ tons per shift to just match continuous miner progress}$$

This would be an average production rate that would include the machine move time involved in setting up at the new face. When compared to the average production to be expected from a longwall machine operating in a 5-ft coal seam, it would appear that one (1) continuous miner could outline the longwall panels well in advance of the longwall completing the last panel. The expected longwall machine production rate in a 5-ft seam is 710 tons per shift and the machine would have to produce 1294 tons per shift to match the continuous miner that outlines the panel. Therefore, limiting the number of supporting continuous miners to three (3) would leave two continuous miners to perform the work of driving main headings and production headings to further access the coal boundary.

If the mine is to be developed using multiples of a five-entry system, and using the same dimensions as used to outline the longwall system, then a 100-ft advance of the five-entry system contains 820 ft of entries. To complete the 100-ft advance with one continuous miner would require 8.35 shifts. Using a second continuous miner would add another 100 ft of advance. These two continuous miners could complete 3077 ft of advance of 10 entries in the 257 shifts required to completely mine out a single longwall panel. Therefore, the two continuous miners should be adequate for any mining required to develop the mine in advance of the longwall machine.

APPENDIX B

COST AND WAGE INDEXES
PROJECTIONS FOR THE PERIOD 1978-2000

APPENDIX B

COST AND WAGE INDEXES PROJECTIONS FOR THE PERIOD 1978 - 2000

Development of mining costs for the year 2000, using the NUS Cost of Coal Mining Model, required the projection of four Department of Commerce Cost Indexes from the published 1977 year to the year 2000. To accomplish this projection, information was taken from Data Resources, Inc. (DRI) Long-Term Forecasting, DRI's energy model and DRI's cost forecasting model. The factors generated allowed the construction of the Indexes to the time frame desired. The DRI models referred to are very large, complex models using reliable economic as well as socio-economic parameters as inputs. The model is too large to discuss here, however, an outline of its contents follows.

Outline Summary of DRI's
Long-Term Forecast TRENDLONG0378
For 1977-1990 (as of March 1978)

I. GENERAL OUTLOOK:

The economy returns to potential growth path with moderating inflation.

II. PRINCIPAL EXOGENOUS ASSUMPTIONS:

A. DEMOGRAPHIC:

Projections derived from the Census Bureau, Series II which assumes a fertility rate of 2.1 per woman of child-bearing age, a reduction in the mortality rate, and annual net immigration of 400,000 per year.

B. FOOD PRICES:

Wholesale farm prices rise by an average of 3.5% a year.

III. PRINCIPAL POLICY DIMENSIONS:

A. FISCAL POLICY:

1. 1978 Tax Cut -- $25 billion.

2. Personal tax cuts through the 1980's to offset inflation (no other personal tax cuts).

3. No corporate tax incentives after 1979.

4. Social security: increases scheduled for 1979-1981 effected. 1985 increase foregone.

5. Growth of government purchases: 2.2% real, 8.3% nominal per year.

6. Transfers: 3.7% real growth per year.

7. Budget deficit: approximate balance after 1986.

8. Average federal government spending share of GNP: 21.5%.

B. MONETARY POLICY:

Some tightening in 1980 as inflation picks up. Thereafter, promotes stable credit growth.

(1) Nonborrowed Reserves: growth averages 6.0% per year.

(2) Federal Funds Rate: stabilizes at about 5.8% from 1983.

C. ENERGY POLICY:

Compromise energy bill passed effective July 1, 1978, encompassing a well head tax and a scaled-down industrial use tax.

IV. BEHAVIOR OF ECONOMIC AGENTS:

A. CONSUMERS:

Low inflation and job security increase consumer confidence.

(1) Average annual consumption growth: 3.6%.

(2) Average annual savings rate: 5.9%.

B. BUSINESS:

Decisions made in stable environment.

(1) Average fixed investment share in GNP: 10.6%.

(2) Average after tax profit share: 5.4%.

(3) Average nominal profit growth: 9.0%.

(4) Average real after tax profit growth: 3.4%.

C. STATE AND LOCAL GOVERNMENTS:

Real expenditures dictated by demographics and ability to raise taxes. Average real growth of 3.5% per year.

(1) State and local budget position: small operating surpluses averaging $5.9 billion per year.

D. INTERNATIONAL:

(1) World wholesale prices: 6.0% per year.

(2) U.S. Exchange Rate: Holds steady beyond 1980, as balance of trade moves into small surplus.

V. **OTHER PARAMETERS:**

A. **AVERAGE PRODUCTIVITY GROWTH:** 2.6% per year.

B. **AVERAGE POTENTIAL OUTPUT GROWTH:** 3.2% per year.

C. **INFLATION:**

Capacity utilization, energy, and social security measures dominate short-run picture. Steady improvement begins to show in early 1980's.

D. **CPI:**

(1) Average annual rise: 5.2%.

(2) Peak annual: 5.9% (1978).

E. **HOURLY EARNINGS:**

(1) Average annual rise: 7.0%.

(2) Peak annual: 7.7% (1978).

F. **HOUSING MARKET:**

Settles down to trend in mid-1980's. Demographics imply decline in rate of growth of housing stock.

(1) Year 1990 median new home price: $106,200.

(2) Average annual rise: 6.2%.

G. **UNEMPLOYMENT:**

Close to full-employment rate 4.6% by mid-1980's. Average rate 5.3%.

Table B-1. Detailed Economic Assumptions Behind the DRI Energy Model

	1976	1977	1978	1979	1980	1985	1990
GNP[1]	1706.4	1890.1	2092.6	2302.9	2557.5	3951.6	5799.7
Real GNP[1] (72 dollars)	1274.7	1337.5	1395.0	1449.2	1517.2	1814.7	2104.8
Real GNP (% ch)	6.0	4.9	4.3	3.9	4.7	3.1	2.9
GNP Deflator	5.3	5.6	6.2	5.9	6.1	4.9	4.7
CPI	5.7	6.5	5.9	5.8	5.8	4.9	4.7
WPI	4.6	6.2	6.1	6.1	6.5	5.3	4.8
Unemployment Rate (%)	7.7	7.0	6.4	6.3	6.0	4.9	4.7
Fed. Funds Rate (%)	5.05	5.54	6.94	6.58	7.00	5.65	5.77
Prime Rate (%)	6.84	6.82	8.05	7.77	7.97	6.74	6.85
New High Grade Corp. Bond Rate (%)	8.33	8.06	8.62	8.59	8.82	7.50	7.13
Personal Income[1]	1382.7	1536.7	1697.6	1859.8	2057.0	3132.2	4577.8
Real Disposable Income (% ch)	3.9	4.5	5.0	4.2	4.2	2.9	3.2
Population[2]	214.7	216.9	219.0	221.0	223.1	234.4	245.4
Nuclear Power (QBtu)	2.0	2.7	3.0	3.4	3.9	8.2	13.9

1. In billions of dollars
2. In millions

Table B-2. Rates of Change

	1976-1980	1980-1985	1985-1990
GNP	10.6	9.1	8.0
Real GNP (72 dollars)	4.5	3.6	3.0
GNP Deflator	5.7	5.4	4.5
Personal Income	10.4	8.8	7.9
Population	1.0	1.0	0.9

Source: Data Resources, Incorporated, "The DRI U.S. Long-Term Review," Spring 1978.

As can be seen, the DRI model contains a very large amount of data. JPL used the output from this model to extend the present cost indexes to the year 1990 (the limit of the DRI model) and then generated a rationale to extend to the year 2000. The following discussion will make this process clear.

DERIVATION OF INDEXES

Chemical Plant and Equipment Index

Data generated from Data Resources, Inc. (DRI) Macro Forecasting for the fourth quarters during the period 1978-1990 is as follows:

YEAR	IP & E28*	JQ IND 28**
1978	7.59	1.952
1979	7.99	2.068
1980	9.60	2.294
1981	11.16	2.388
1982	12.15	2.533
1983	13.70	2.747
1984	15.88	2.946
1985	18.01	3.115
1986	19.64	3.287
1987	21.00	3.485
1988	22.74	3.697
1989	24.97	3.909
1990	27.38	4.127

*IP & E28 - - - Plant and Equipment Expenditures (Billions of current dollars)

**JQIND28 - - - Industrial Production Index for Chemicals and Products 1967 = 1.0

Price Index for each year was approximated by the following:

$$\frac{IP\&E28}{JQIND28} = \text{Price Index}$$

For example, price index for 1978 $= \frac{7.59}{1.952} = 3.89$

Following this approach, the price indexes for the period 1978-1990 were calculated and tabulated.

Year	1978	1979	1980	1981	1982	1983	1984
Price Index	3.89	3.86	4.18	4.67	4.80	4.99	5.39

Year	1985	1986	1987	1988	1989	1990
Price Index	5.78	5.98	6.03	6.15	6.39	6.63

With this table, the annual growth rates for the price indexes were calculated. The average growth rates through 1990 were found to be: 1978-1980, 3.7% per year; 1980-1985, 6,7% per year; and 1985-1990, 2.8% per year. The indexes for the years 1978-1990 were estimated using the above growth rates starting with the 1977 historical price index as a growth rate of 3.7% per year for the 1977-1978 period as an approximation. For the post-1990 period, it was hypothesized that the growth rate of the indexes will slow to about 2.5% per year as prices for chemical plants presumably begin to stabilize.

For example, using the above growth rates, 1978 chemical plant index was calculated as follows:

Present Value (PV)	=	204
Number of Years	=	1 yr.
Growth Rate	=	3.7% per year
Future Value (FV) or 1978 Value	=	212

Price index projections for Chemical Plant and Equipment Index, based on current dollars, are as follows:

Year	1978	1980	1982
Chemical Plant & Equip. Index	212	227	258

Year	1985	1988	1990	1992	1995	1998	2000
Chemical Plant & Equip. Index	314	341	360	378	407	439	461

<u>Mining Plant and Equipment Index</u>

Data generated from Data Resources, Inc. (DRI), Macro Forecasting for the fourth quarters during the period 1978-1990 is as follows:

Year	1978	1979	1980	1981	1982	1983	1984
IP&EMI*	5.07	5.78	6.77	7.63	8.18	8.92	10.24
JQINDMI**	1.277	1.292	1.351	1.373	1.412	1.469	1.526

Year	1985	1986	1987	1988	1989	1990
IP&EMI*	11.72	13.33	14.89	16.60	18.44	20.30
JQINDMI**	1.564	1.597	1.643	1.687	1.727	1.772

* IP&EMI - Plant and Equipment Expenditures, Mining. Billions of current dollars

**JQINDMI - Industrial Production Index, Mining 1967 = 1.0

Price Index for each year was approximated by the following:

$$\frac{IP\&EMI}{JQINDMI} = \text{Price Index}$$

As an example, the price index for 1978 is estimated to be $\frac{5.07}{1.277} = 3.97$

Following the same approach, price indexes for the period 1978-1990 were estimated and presented in the following table. This table allows calculation of the annual growth rates.

Year	1978	1979	1980	1981	1982	1983	1984
Price Index	3.97	4.47	5.01	5.56	5.79	6.07	6.71

Year	1985	1986	1987	1988	1989	1990
Price Index	7.49	8.35	9.06	9.84	10.68	11.46

Growth rates for the price indexes for the period 1978-1980 were estimated from the above table to be 12.3% per year, that for 1980-85 were calculated to be 8.4% per year, and for the 1985-90 period the growth rate was found to be 8.9%. Starting with 1977, historical price index for mining plant and equipment index and making use of the estimated growth rates above, the indexes for the 1978-2000 period were estimated using 10% per year growth rate for the 1977-78 period. For the post-1990 period a reduced growth rate was hypothesized.

The following projections are based on current dollars results:

Year	1978	1980	1982	1985	1988	1990	1992	1995	1998	2000
Mining Plant & Equipment Index	246	310	364	464	599	710	800	950	1090	1155

Electric Power Price Index

As an approximation, prices for electric power were taken to be those for industrial electricity. Prices of industrial electricity generated by Data Resources, Inc. (DRI) Energy Forecast with minor modification are as follows:

Year	1976	1977	1978	1979	1980	1985	1990
Price of Industrial Electricity 1978 $/mmBtu	6.79	7.11	7.5	7.4	7.7	8.9	10.6

From the above table, the growth rate for the 1976-78 period was found to be 5.1% per year, and 1.34% for the 1978-80 period. The 1980-85 growth rate was calculated to be 2.94% per year with a slightly higher growth rate of 3.55% per year for the 1985-90 period. With these growth rates and a hypothesized value of 4% per year for the post-1990 period together with a starting historical price index for 1976, the price indexes for the period 1976-2000 were projected.

The electric price index projections obtained are as follows:

Year	1976	1978	1980	1985	1990	1992	1995	1998	2000
Electric Power Price Index (Based on 1978 constant dollars)	205	226	232	268	319	345	388	436	472

Coal Miners Wage Index

Data generated from Data Resources, Inc. (DRI) Cost Forecasting Service for coal miners wages in current dollars are as shown in Table B-3. Coal miners wages were used as an approximation for underground coal miners wages.

Table B-3. Projection of Miners Wages

Year	Hourly Wage (Current Dollars)
1977	8.46
1978	9.44
1979	10.48
1980	11.43
1981	12.71
1982	13.80
1983	14.95
1984	16.53
1985	17.94
1986	19.32
1987	21.30
1988	23.09
1989	24.04
1990	27.34

From Table B-3, the average growth rate for the 1977-80 period was estimated to be 10.5% per year; 9.4% per year for the 1980-85 period; and 8.8% per year for the 1985-90 period. The post-1990 period was hypothesized to be 7.5% per year, resulting in the following:

Year	1990	1992	1994	1995	1996	1998	2000
Daily Wage (Current Dollars)	218.72	252.76	292.09	314.00	337.55	390.08	450.79

Table B-4. Projected Price Indexes

Year	Chemical Plant and Equipment Price Index	Mining Equipment Price Index	Electric Power Price Index	Coal Miners Daily Wages (Current Dollars) $/Day
1976			205	
1977				67.68
1978	212	246	226	75.52
1979				83.84
1980	227	310	232	91.44
1981				101.68
1982	258	364		110.40
1983				119.60
1984	294	428		132.24
1985	314	464	268	143.52
1986	323	505		154.56
1987				170.40
1988	341	599		184.72
1989				192.32
1990	360	700	319	218.72
1991				
1992	378	800	345	252.76
1993				
1994	397	900		292.09
1995	407	950	388	314.00
1996	417	1000		337.55
1997				
1998	439	1090	436	390.08
1999				
2000	461	1155	472	450.79

APPENDIX C

PROJECTION OF EAST KENTUCKY UNDERGROUND COAL MINE PRODUCTIVITY TO YEAR 2000

APPENDIX C

PROJECTION OF E. KENTUCKY UNDERGROUND COAL MINE PRODUCTIVITY TO YEAR 2000

BACKGROUND

Underground coal mining productivity is affected by many factors. In order to project productivity to the year 2000, there must be an identification of some of these factors and an examination of how they affect productivity. Among these factors, the following are identified: equipment type, equipment characteristics, natural conditions, labor-management contract, worker skill and attitude, Federal laws and regulations.

Equipment Type

On the average, continuous miners and longwall shearers yield greater tons per man than other conventional cutters/explosives. Hence, productivity depends to some extent on the type of miner.

Equipment Characteristics

Reliability of mining machinery affects productivity. Reliable machines operate for a comparatively longer period and therefore affect productivity.

Natural Conditions

Productivity increases with thicker seams because both men and machinery have greater room or space to maneuver and a larger amount of resource is available for each cut. For poor roof or floor conditions, relatively more time is spent on control resulting in decreased productivity. Other natural conditions such as gas accumulation, presence of water, nature of partings, etc., affect productivity.

Worker Skill and Attitude

On the average, experienced workers produce more per unit time than new hires. Moreover, new hires and younger aggressive miners have a comparatively negative attitude toward work. Worker attitude affects proper operation of machines, speed and effectiveness of repair and service and, hence, affects productivity. Additionally, there are many young inexperienced foremen.

Managerial Function

The greater the amount of time a manager or foreman spends on productive mining activities, the greater the productivity is likely to be. For instance, in recent years management has spent considerably more time to ensure compliance with health, safety, and environmental regulations and labor contract requirements.

Federal Health and Safety Regulations

Federal regulations such as the 1969 Coal Mine Health and Safety Act, require workers to spend more time on nonproductive activities such as methane checks, rock dusting, inspection, etc. The severity of such regulations affects productivity.

Eastern Kentucky Underground Coal Mine Productivity - Historical

The table below shows the productivity of underground coal mining in Eastern Kentucky. The data shows a 6.22% per year growth in productivity from 1966 to 1969.

Year	1966	1967	1968	1969	1970
Productivity tons/man-day	13.61	13.62	14.81	15.58	14.15

Year	1971	1972	1973	1974	1975
Productivity tons/man-day	12.42	12.37	12.70	12.06	11.36

The trend reversed after 1969 with a negative growth of 10.7% per year from 1969 to 1971. Between 1971 and 1973, there was no significant growth, and for the 1973-75 period, a negative growth of 5.4% per year was experienced. The overall growth for 1969-75 was -5.1% per year. The 1969 peak value of productivity -- 15.58 tons per man-day, was approximately the same as the national value of 15.6 tons per man-day and the 1966-75 trends for both productivities are similar.

Eastern Kentucky Underground Coal Mine Productivity Projection to Year 2000

A number of productivity studies have identified most of the important factors contributing to productivity in underground coal mines. Among the ones identified, the 1969 Coal Mine Health and Safety Act has been shown to contribute significantly to the decline of underground coal mine productivity in the nation, in general, and also in Eastern Kentucky. (See, John Straton (1977), Walton and Kauffman (1977)).

In the near term (1978-1982), the decline will most likely continue but at a slower rate of about 4% per year instead of the 5.4% per year rate for the 1973-75 period. This could be due to the fact that mine workers may have been able to adjust slightly to the conditions imposed by the 1969 Act. Also, there may be a new type of contract. The other factors may continue to affect productivity but not to any significant degree. In the 1982-1985 time frame, productivity may not change appreciably as new, improved mining equipment may be introduced into the market and behavioral factors affecting productivity may not have changed significantly.

In the longer term, 1985-2000, productivity will most likely increase. By 1985, workers may have learned to live with the effect of the 1969 Coal Mine Health and Safety Act. It is anticipated that programs to motivate and encourage young, inexperienced mine workers may have been launched. With the pace of mining equipment R&D, it is likely that new or improved technology would be achieved. Though comparatively thinner seams are anticipated in Appalachia, its effect on productivity is expected to be less severe in the pre-1990 period than the post-1990 period. With these postulations, productivity could grow at 2% per year from 1985-1990 and reverse the downward trend experienced in the post-1969 era. After 1990, it is expected that new mining equipment designed for increased productivity will be in the market and improvements in continuous and longwall mining methods will have been achieved with a resultant increase in productivity. Also, the structure of the mining labor force may have changed. It is assumed that radically new mining methods designed for increased productivity, among other things, would have evolved. If the nation's goal of increasing coal production is to be achieved, it is necessary that incentive programs aimed at motivating the underground mine worker be operational in the 1990's. Therefore, it is assumed here that the underground coal miner on the average may have a positive attitude towards work. On the negative side, coal seams that may be mined in the post-1990 period are likely to be thin seams with poor roof and floor conditions, and these factors could decrease productivity. Taken together, the contributing factors to productivity could cause a 4% per year growth in productivity from 1990-2000. This means that it is not expected that productivity will grow as fast as the pre-1969 period of 6.22% per year, resulting in the following projection.

PROJECTION

Year	1978	1980	1982	1985	1990	1995	2000
Productivity tons/man-day	9.62	8.87	8.17	8.17	9.02	10.97	13.35

APPENDIX D

GNP DEFLATOR

APPENDIX D

GNP Deflator

Data from Data Resources, Inc. (DRI) Macro model of U.S. Economy indicate the following projections for GNP deflator:

Year	1976-80	1980-85	1985-90	1990-2000*
Average GNP Deflator	6.5	6.3	5.4	5.0

To convert 1976 \$ to 1975 \$ use

$$1975\ \$ = \frac{1976\ \$}{(1 + \%\text{GNP deflator for } 1975\text{-}76)}$$

To convert 1977 \$ to 1975 \$ use

$$1975\ \$ = \frac{1977\ \$}{(1 + \%\text{GNP deflator } 1975\text{-}76)\ (1 + \%\text{GNP deflator } 1976\text{-}77)}$$

To convert Year 2000 \$ to 1975 \$ use

$$1975\ \$ = \frac{\text{Year } 2000\ \$}{(1.065)^5 (1.063)^5 (1.054)^5 (1.050)^{10}}$$

$$1975\ \$ = \frac{\text{Year } 2000\ \$}{(3.94)}$$

* JPL Projection

APPENDIX E

DATA

Table E-1. Cost of Coal - 1975

Seam Thickness Feet	Continuous Miner 500 ft Depth	Continuous Miner 1000 ft Depth	Continuous Miner 1500 ft Depth	Longwall 500 ft Depth	Longwall 1000 ft Depth	Longwall 1500 ft Depth
1.5	97.67	103.38	102.28	81.28	84.07	91.71
2.0	68.66	71.95	75.31	57.47	61.57	65.32
2.5	47.30	49.62	51.97	43.40	45.10	48.02
3.0	33.26	35.30	37.04	34.06	35.52	37.58
3.5	23.97	25.09	29.30	27.43	28.73	32.34
4.0	19.46	20.52	24.37	23.81	24.69	27.95
4.5	16.83	17.69	21.28	21.15	22.70	24.81
5.0	15.07	15.82	19.11	19.48	20.85	22.93
5.5	14.07	14.74	17.89	18.40	19.63	21.66
6.0	13.17	14.34	16.79	17.40	18.78	20.52
6.5	12.83	13.85	16.21	17.15	18.59	20.12
7.0	12.48	13.68	15.92	16.77	18.13	19.77
7.5	12.20	13.42	15.84	16.45	17.79	19.55
8.0	12.17	13.20	15.67	16.11	17.51	19.31

Table E-2. Cost of Coal - Projection to Year 2000 Continuous Miner, 91% of 1975 Production Level

Seam Thickness Feet	Depth at 500' $/Ton						Depth at 1000' $/Ton						Depth at 1500' $/Ton					
	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars
1.5	268.3	165.2	31.6	154.7	619.8	157.3	268.3	165.2	31.6	165.4	630.4	160.0	268.3	165.2	31.6	176.8	641.9	162.9
2	186.3	113.5	23.6	107.9	431.3	109.5	186.3	113.5	23.6	115.3	438.7	111.3	186.3	113.5	23.6	123.1	446.5	113.3
2.5	127.8	76.4	17.8	74.4	296.4	75.2	127.8	76.4	17.8	79.7	301.8	76.6	127.8	76.4	17.8	85.2	307.3	78.0
3	88.8	51.5	14.0	52.7	207.0	52.5	88.8	51.5	14.0	56.7	211.0	53.6	88.8	51.5	14.0	60.8	215.1	54.6
3.5	62.6	34.8	11.4	35.8	144.6	36.7	62.6	34.8	11.4	38.9	147.7	37.5	68.9	38.9	12.0	47.3	167.1	42.4
4	50.8	27.4	10.3	28.6	117.1	29.7	50.8	27.4	10.3	31.2	119.6	30.4	57.4	31.7	10.9	39.1	139.1	35.3
4.5	43.5	22.8	9.6	24.8	100.7	25.6	43.5	22.8	9.6	26.9	102.8	26.1	49.8	26.9	10.2	34.5	121.4	30.8
5	38.9	19.9	9.1	21.7	89.5	22.7	38.9	19.9	9.1	24.2	92.1	23.4	44.6	23.7	9.7	30.4	108.4	27.5
5.5	36.1	18.2	8.8	19.9	83.1	21.1	36.1	18.2	8.8	22.2	85.4	21.7	41.7	21.9	9.4	28.1	101.2	25.7
6	33.8	16.8	8.6	18.8	77.9	19.8	34.7	17.4	8.7	21.0	81.7	20.7	39.2	20.3	9.1	26.0	94.6	24.0
6.5	32.7	16.2	8.5	18.3	75.7	19.2	33.4	16.6	8.6	20.2	78.7	20.0	37.7	19.4	9.0	25.1	91.2	23.1
7	31.7	15.5	8.4	17.6	73.2	18.6	32.9	16.3	8.5	19.8	77.4	19.6	37.0	19.0	8.9	24.4	89.3	22.7
7.5	31.0	15.1	8.3	17.0	71.4	18.1	32.2	15.9	8.4	19.3	75.8	19.2	36.8	18.9	8.9	24.2	88.8	22.5
8	30.3	14.6	8.2	16.5	69.7	17.7	31.6	15.5	8.4	18.8	74.3	18.9	36.4	18.7	8.8	23.8	87.8	22.3

Table E-3. Cost of Coal - Projection to Year 2000 Longwall Miner, 91% of 1975 Production Level

Seam Thickness Feet	Depth at 500'						Depth at 1000'						Depth at 1500'					
	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars	Labor	Supplies	Union	Capital	Total Year 2000 Dollars	Total Year 1975 Dollars
1.5	224.9	142.6	27.1	101.7	496.3	126.0	224.9	142.6	27.1	96.7	491.3	124.7	224.9	142.6	27.1	140.6	535.3	135.9
2	154.2	96.4	20.2	84.4	355.3	90.3	154.2	96.4	20.2	98.0	368.8	93.6	154.2	96.4	20.2	112.1	382.9	99.2
2.5	107.1	65.4	15.6	82.0	270.2	68.6	107.1	65.5	15.6	84.2	272.4	69.1	107.1	65.5	15.6	93.3	281.5	71.4
3	77.6	46.1	12.8	70.4	206.9	52.5	77.6	46.1	12.8	73.7	210.2	53.4	77.6	46.1	12.8	79.7	216.1	54.8
3.5	58.8	33.8	11.0	61.4	165.0	41.9	58.5	33.6	10.9	64.6	167.7	42.6	61.8	35.8	11.3	75.1	184.0	46.7
4	49.5	27.7	10.1	54.4	141.7	36.0	48.8	27.3	10.0	57.0	143.1	36.3	52.2	29.5	10.3	65.6	157.6	40.0
4.5	43.2	23.7	9.5	49.0	125.4	31.8	42.7	23.3	9.4	55.4	130.9	33.2	45.9	25.4	9.7	59.2	140.3	35.6
5	39.2	21.1	9.1	46.1	115.5	29.3	38.7	20.7	9.0	51.4	119.9	30.4	41.7	22.7	9.3	55.3	129.1	32.8
5.5	36.9	19.6	8.8	43.2	108.6	27.6	36.4	19.2	8.8	48.2	112.6	28.6	39.4	21.3	9.1	51.7	121.6	30.9
6	34.9	18.3	8.7	40.3	102.2	25.9	35.0	18.3	8.7	45.6	107.7	27.3	37.5	20.0	8.9	48.4	114.8	29.1
6.5	34.1	17.7	8.6	40.2	100.6	25.5	34.0	17.7	8.6	45.2	105.5	26.8	36.5	19.3	8.8	48.3	112.9	28.7
7	33.4	17.3	8.5	39.2	98.4	25.0	33.7	17.5	8.6	44.3	104.1	26.4	36.1	19.1	8.8	46.9	110.9	28.1
7.5	32.9	16.9	8.5	38.1	96.4	24.5	33.3	17.3	8.5	42.7	101.8	25.8	36.1	19.1	8.8	45.4	109.3	27.7
8	32.4	16.7	8.4	36.9	94.4	24.0	32.9	17.0	8.5	41.8	100.3	25.5	35.9	19.0	8.8	44.2	107.8	27.4

Table E-4. Productivity Study

Seam Thickness Feet	PERCENTAGE OF 1975 PRODUCTIVITY							
	100%		200%		400%		600%	
	2000 Dollars	1975 Dollars	2000 Dollars	1975 Dollars	2000 Dollars	1975 Dollars	2000 Dollars	1975 Dollars
1.5	566.80	143.90	293.60	74.50	156.40	39.70	110.20	28.00
2.0	394.00	100.00	205.00	52.00	110.00	27.80	78.00	19.80
2.5	271.00	68.80	141.00	35.90	77.00	19.50	55.00	14.00
3.0	188.00	47.70	100.00	25.40	55.00	14.00	40.00	10.20
3.5	132.50	33.60	71.20	18.10	40.50	10.30	30.20	7.70
4.0	107.40	27.30	58.30	14.80	33.70	8.60	25.50	6.50
4.5	92.40	23.50	52.40	13.30	31.60	8.00	24.60	6.20
5.0	82.20	20.90	42.10	12.00	28.70	7.30	22.60	5.30
5.5	76.30	19.40	44.00	11.20	27.00	6.80	21.60	5.40
6.0	71.10	18.00	41.30	10.50	25.60	6.50	20.40	5.20
6.5	69.10	17.50	40.20	10.20	25.00	6.30	20.00	5.10
7.0	66.80	17.00	39.10	9.90	24.50	6.20	19.60	5.00
7.5	65.70	16.70	38.30	9.70	24.00	6.10	19.30	4.90
8.0	64.80	16.30	37.50	9.50	23.70	6.00	19.00	4.80

Table E-5. Influence Coefficients Continuous Miner; 5-ft. Seam, 500-ft. Depth; Year 2000

PARAMETER		COEFFICIENT	
SYMBOL	BASE VALUE		
REJ	0.18	.00003	Reject fraction
SRF	0.5	-.00014	Seam recovery factor
THLR	197	.00305	Total hourly labor requirements per day (man)
SPR	40	.00090	Salaried personnel requirements (man)
PSEC	30863700	000748	Production section equipment cost
PPHS	9310230	.000225	Preproduction haulage system cost
PHS	26086969	.00014	Production haulage system cost
DWS	709290	.000012	Dewatering system
FSE	741240	.000012	Fire and safety equipment
COMM	958500	.000018	Communications
HEQ	8153640	.000195	Heavy equipment
PEQ	140580	$<10^{-6}$	Personnel equipment
VEQ	1533600	.00003	Ventilation equipment
MISC	1022400	.000024	Miscellaneous
PPVC	2496000	.000049	Preproduction site preparation
PVC	34410331	.000158	Production site & ventilation construction
ME	256000	$<10^{-6}$	Mine entries
OSC	24705405	.000511	Other surface construction
PPC	19712000	$<10^{-6}$	Prep plant cost and unit train loading
EXPL	331600	.000006	Exploration
ABND	256000	$<10^{-6}$	Mine abandonment
SMCT	17.95	.002475	Supplies & materials cost/ton
PCT	0.75	.000085	Power cost per ton
DC	26748845	.000438	Direct and indirect development cost
DT	0.65	.000018	Development time
ROR	0.15	.00048	Rate of return (desired)
COST	0.1	.001259	Interest rate on borrowed capital
DER	0.8	-.000657	Portion of capital borrowed
UWRM	1.4	.000353	Union welfare rate/man-hour
UWRT	0.78	.000699	Union welfare rate/ton
ASAL	20000	.00090	Average annual salary
ROYP	0.5	$<10^{-6}$	Royalty payment rate ($/ton)
FTAX	0.48	.000389	Federal tax rate
STAX	0.02	.000019	State tax rate

How to Use Coefficients

Additional data - Base system cost of coal = $82.22 per ton.

Suppose that a proposed production section equipment cost is reduced by 20%. What is the effect on cost of coal?

ΔPSEC = -20%

ΔCost of Coal = .000748 . (ΔPSEC) = .000748 (-20) = -0.01496

Actual $ change in coal cost would be $82.22 (-.01496) = -1.23 $/ton

New cost of coal = $82.22 - 1.23 = $80.99 per ton