Economic Surface Mining of Multiple Seams

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SYNOPSIS

As geological and mining conditions become more complex, and as overall mining economics become more marginal, short- and long-range decision-making regarding multiple-seam surface mining becomes more difficult. The decision-making problem involves a study of economics, cut-off grades and ratios, equipment capabilities, sequencing and selective mining practices.

This paper is concerned primarily with multiple-seam mining of bituminous coal. The research has led to the development of an economic decision-making model for use as a day-to-day tool to aid mine operators and pit geologists to decide what and how to mine.

The model is designed as an aid for feasibility decision-making in multiple-seam situations and for situations where selective mining is needed or desired. In effect, a simulation of the feasibility and preliminary mine planning phases has been developed. The model is divided into four separate segments: decision-making, simulated mining, cost calculations and the determination of the discounted cash flow return on investment.

INTRODUCTION

Concurrent or sequential mining of multiple seams by surface mining is becoming increasingly important, especially in the United States where a booming coal industry is developing in the western part of the country. As geological and mining conditions become more complex and as the overall economics become more marginal, the short- and long-range decision-making in connection with multiple-seam mining becomes more difficult. Deciding what and when to mine and how to mine it will not be easy or straightforward as in some existing, less variable mining areas. The decision-making problem involves a study of economics, cut-off grades and ratios, equipment capabilities, sequencing and selective mining practices.

This paper is concerned primarily with multiple-seam mining of bituminous coal, but it should be realized that the principles can apply to any other mineral that can be mined by multiple-seam surface mining methods. The nomenclature used refers to coal mining.

This research has led to the development of a preliminary, but workable, economic decision-making model for use as a day-to-day tool to aid the mine operators and pit geologists in deciding what and how to mine.

The model itself is designed as an aid for feasibility decision-making in multiple-seam situations and for situations where selective mining is needed or desired. In effect, a simulation of the feasibility and preliminary mine planning phases has been developed. The model is divided into four separate segments: decision-making, simulated mining, cost calculations and the determination of the discounted cash flow return on investment. These segments are explained later. The intention is, in a future project, to expand this work by attempting to define the price-cost-production relationships.

The term 'multiple-seam mining' refers to the simultaneous removal of two or more coal seams from the same pit. This will distinguish it from situations in which two seams are recovered from the same mine, but each in a separate pit. Multiple-seam mining is a very important phase of the stripping industry in the United States today. As in the case of conventional stripping, multiple-seam strip-mining is classified either as area or contour mining. Area strip-mining is practiced on relatively flat terrain. A 'box cut' is made through the overburden to expose the top coal seam. Successive parallel cuts are then made and the overburden spoiled in the previous cut. Contour strip-mining is practiced where the seams occur in rolling or mountainous terrain such as in eastern Ohio and Kentucky and Western Pennsylvania. The overburden above the coal is removed beginning at the outcrop and proceeding along the hillside. This is continued until the depth of the overburden or character of the coal seam become unacceptable economically. There are no official figures for such items as production and employment based on the multiple-seam strip industry alone. The multiple-seam operation is no more than a specialized case of strip mining.

With regard to the western coals, the outlook for the multiple-seam strip-mining industry seems as favorable as that predicted for the entire industry.

A TYPICAL MULTIPLE-SEAM SURFACE COAL MINE

Using a walking dragline and an electric shovel in tandem, Peabody Coal Company, at its Homestead Mine in Ohio County, Kentucky, has developed a method of recovering three seams. These seams are the Kentucky No. 9, No. 11 and No. 13. Data on the overburden which must be removed to recover these seams are presented in Table I.

TABLE I.

OVERBURDEN AND COAL SEAMS – HOMESTEAD MINE

Sandstone, shale and clay	15 to 35 feet
No. 13 coal	12 to 18 inches
Shale, soft limerock and hard limerock cap	30 to 35 feet
No. 11 coal	66 to 72 inches
Shale and soft limerock	55 to 60 feet
No. 9 coal	48 to 54 inches

A Marion 8800 dragline equipped with a 100-cubic yard bucket and a Bucyrus Erie 1050-B shovel equipped with a 33-cubic yard dipper are the primary machines used for stripping. Additional details are given in Table II.

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TABLE II.

EQUIPMENT SUMMARY – HOMESTEAD MINE

Marion 8800 Dragline	
Bucket capacity – cubic yards	100
Boom length – feet	275
Boom angle – degrees	37.5
Digging and dumping radius – feet	248
Bucyrus Erie 1050-B Shovel	
Dipper capacity – cubic yards	33
Boom length – feet	123
Dipper-handle length – feet	76
Dumping radius – feet	139
Two Bucyrus Erie 170-B loading shovels	
Dipper capacity – cubic yards	10
988 Caterpillar front end loader	
Drills	
Bucyrus Erie 50-R	
Bucyrus Erie 61-R	
Trucks	
1 100-ton Mack	
4 70-ton KW Darts	
1 50-ton International	
5 40- and 50-ton Euclids	

Loading is accomplished with two Bucyrus Erie 170-B shovels equipped with 10-cubic yard dippers and a 988 Caterpillar front end loader also equipped with a 10-cubic yard bucket.

The drilling at the Homestead Mine is handled by a Bucyrus Erie 50-R drill and a Bucyrus Erie 61-R drill. The former is used to drill the overburden on the top two seams and the latter the parting over the lower seam. The 61-R drill is equipped with special 65-foot stems to allow the parting above the lower seam to be drilled with a single stroke.

The present pit is approximately three miles long and 120 ft wide. The mining operations can be summarized as follows (see Fig. 1):

(i) The overburden above the No. 13 seam is drilled by the 50-R on 30-ft × 30-ft centers. Ammonium nitrate-fuel oil blasting agent is used.

(ii) The 1050-B removes this overburden conventionally and spoils it in the No. 9 pit so that it lies fairly well against the highwall.

(iii) The No. 13 coal is then loaded with the 988 Caterpillar loader.

(iv) The 50-R penetrates the parting between the No. 13 and No. 11 seams on 25-ft × 25-ft centers.

(v) The 1050-B again removes the overburden, but spoils it in the No. 9 pit, over the back side of the previously spoiled No. 13 overburden. This is done with the shovel sitting on the No. 11 coal.

(vi) The No. 11 coal is loaded using a Bucyrus Erie 170-B loading shovel.

(vii) The 61-R drills the parting above the No. 9 coal on 30-ft × 30-ft centers. The special 65-ft stems allow the parting to be drilled with a single stroke.

(viii) Operating from the spoil in the previous No. 9 cut, the Marion 8800 dragline removes this parting.

The only deviation from this procedure results from the fact that the stripping machines are not exactly balanced with the ratio of overburden over the three seams. This requires that the dragline handle a portion of the parting between the No. 13 and No. 11 seams in order to allow the shovel to maintain the proper distance ahead of the dragline.

A fleet of eleven trucks is being used to transport the coal from the pit to a dumping station located near the river. Sizing of the coal by rotary breakers to a maximum size of $1\frac{1}{2}$ in. is the only preparation required. Barge transportation on the Green River is being used to convey the sized coal.

At the time of the visit, coal was being loaded only six shifts per week. As in the other large operations, stripping equipment was being operated around the clock giving a daily production of 9 000 to 10 000 tons.

VARIABLES AFFECTING THE DECISION-MAKING PROCESS IN MULTIPLE-SEAM MINING

The economic decision-making process in multiple-seam mining (or any other mining) is usually complicated and involves many variables. For surface coal mining some of the variables are as follows:

Physical variables

(i) Ratio of overburden to ore.
(ii) Ratio of overburden and parting to ore.
(iii) Depth of overburden.
(iv) Thickness and variability of ore seam(s).
(v) Parting thickness.
(vi) Dip of seams.
(vii) Physical continuity, that is, continuous thickness, continuous grade, etc.
(viii) Amount of reserves.
(ix) Equipment capacities and capability.
(x) Physical characteristics of overburden.
(xi) Physical characteristics of ore.

Chemical variables

(i) Ore grade.
(ii) Ore quality.
(iii) Ash content.
(iv) Moisture content.
(v) Sulfur content.
(vi) Volatile content.
(vii) Calorific value.
(viii) Fixed carbon content.

Economic variables

(i) Selling price.
(ii) Controllable operating costs.
(iii) Non-controllable operating costs.
(iv) Transportation costs (to market).
(v) Cost of capital.
(vi) Capital expenditures required.
(vii) Production rate.

This is not meant to be an all-inclusive list and it is generalized intentionally. Any attempt to do an economic analysis on a multiple-seam situation would result in consideration of these variables at some point in the analysis. The mine manager is often faced with day-to-day decisions on what to mine and what to leave in the ground. This decision is both an economic one and a physical one in the sense that good mining practice must be followed at all times. This means that drainage patterns, mine road configurations, overburden placement and other similar factors must be considered along with the purely economic factors.

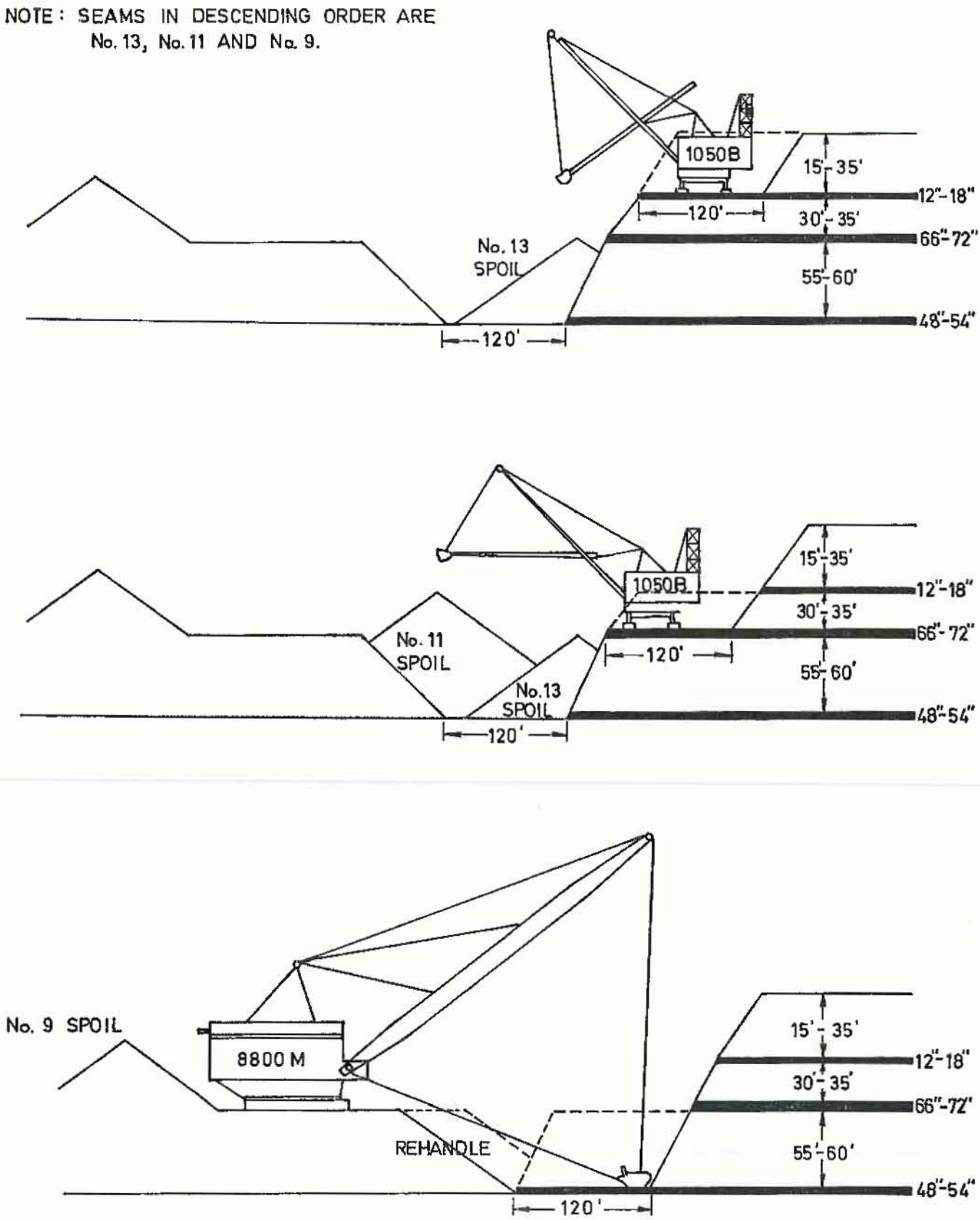

Fig. 1. Cross-sectional views showing stripping cycle: Homestead Mine.

PRELIMINARY STEPS IN THE ECONOMIC EVALUATION OF A MULTIPLE-SEAM SURFACE MINE

Decisions concerning which seams should be or not be stripped are very important to the surface-mining coal industry. These decisions determine whether a company will have the coal reserves to meet future demand and, more importantly, whether the company can realize a maximum return on its investments.

The criteria on which these decisions are based can be classified into three general categories: physical, chemical, and economic. The most important of the physical criteria include the total depth of overburden which must be stripped and the thickness of the coal seam or seams. The maximum tolerable overburden can be determined either from physical or economic considerations. From a physical standpoint, the capability of the stripping machine is the limiting factor. From the economic standpoint, the limiting factor is the familiar stripping ratio which is used in making a feasibility study. 'Stripping ratio' as used here in reference to coal mining is defined as the cubic yards of overburden which must be removed to produce one ton of coal.

In most cases it is a combination of these two which is used in the evaluation of a property. The overburden is first mapped and then the stripping machine is designed specifically for the particular property. The maximum depth of overburden at those mines surveyed by the authors varied from 65 ft to 150 ft and averaged 100 ft.

The chemical criteria involve decisions concerning the chemical variables listed above. At present, the quality of the coal being mined is such that the market specifications and environmental restrictions can be met without sacrificing a major portion of the company's reserves. However, changes can be expected in this regard and chemical parameters are likely to become more and more important.

The feasibility and planning techniques used by most of the larger companies involved in multiple-seam surface mining are:

(i) The prospective property is first drilled on wide centers, greater than one-half mile, to provide information on the extent of the coal seams located on the property as well as the general characteristics of the seams.

(ii) The second phase involves intensive drilling of the proposed property, typically on centers ranging from 300 to 1 000 ft. The information obtained from the exploratory drilling is substantiated by these additional data. This leads to an accurate estimate of tonnage, grade of coal, and nature of overburden.

(iii) The third step is possibly the most important phase of the study. Using the data from the drill analyses, all pertinent factors are mapped for the entire property, mostly using contours for each important item.

The most important factors at this time seem to be the depth of the overburden and thickness of the coal. The importance of the chemical properties seems to increase as the size of the company decreases. This is because the markets of these smaller companies are industrial in nature and have tighter specifications than the electric generation plants serviced by the larger companies. However, ash, sulfur, and the other chemical characteristics are usually mapped by the larger companies to insure that no extensive areas of poor quality coal do exist. Another reason that larger companies do not use chemical properties as limiting factors in a feasibility study is that they make sure contracts with consumers are set up in such a manner as to utilize most effectively the coal in the property in question; that is, the quality of the coal is first determined and a contract is drawn up to fit the coal. It is emphasized again that as the quality of these reserves decreases, these chemical factors will become increasingly important.

(iv) Using the contour maps, the property is then divided into small segments usually by means of the polygonal method. Multiplying polygonal areas by the appropriate depths gives accurate estimates of coal tonnage and overburden yardage which will serve as the actual input to the feasibility study.

(v) There remains one block of information which is required before the study can be completed. This consists of production and cost data for the proposed property. The production data will be considered first.

As mentioned earlier, the company usually has a specific contract in mind when considering the development of a certain property. All the provisions of the contract may or may not be set at the time the feasibility study is undertaken. If the quantity required by the consumer is already known, it is this figure which sets the production requirements of the mine and in turn the amount of overburden which must be removed to meet these requirements. Quality requirements are also stipulated in the contract. Because of the inclusion of penalty clauses, the company usually determines what minimum requirements it can meet with the coal property in question and adopts these figures in the contract.

The actual selling price of the coal also may or may not be set at the time of the study. If it has been agreed upon previously, this value is used as the basis for all economic calculations. If the figure has not been set, then it can become a variable in the calculations, that is, the value can be ranged to determine the effect on the company's return on investment.

The cost information which is required includes both capital and operating cost estimates. In order to arrive at a capital cost estimate, the method of mining must be determined and equipment must be selected. In multiple-seam operations, the mining plan must be tailored to the nature of the material in the overburden, the thickness of the parting between the seam(s) and the type of equipment available on the market.

Using these data, a trial mining plan is developed. The plan includes such items as the determination of stripping and spoiling sequence, loading sequence, pit floor layout, cut width and length and amount of rehandle. This information is given in turn to one of the large manufacturers of stripping equipment, who designs a machine specifically to handle the requirements of this mine. An estimate of the capital cost is also provided by the manufacturer. A list of the necessary support equipment is then compiled. Estimates of the capital cost of this equipment are added to the estimate of the cost of the stripping equipment to give a total figure for the proposed mine.

If the equipment chosen is similar to existing equipment at other mines, historical operating cost data can be used in the study. If no such information is available, then estimates of these costs can be obtained by conventional engineering calculations.

Thus, all the necessary information to complete the study has been obtained. All that remains is the calculation of some economic yardstick which will give some information to the company on the profitability of the proposed venture. The model for this purpose will be presented in the next section.

AN ECONOMIC FEASIBILITY AND PRELIMINARY PLANNING MODEL FOR MULTIPLE-SEAM SURFACE COAL MINES

One of the purposes of an economic feasibility and planning model is to reveal to the company the predicted value of a proposed project using some reliable economic yardsticks.

The yardstick chosen for use in this study is the discounted cash flow rate of return. This method has grown in popularity, especially among the larger companies, during the past two decades. Because of the large amount of information available in the literature on how this method is used, a detailed explanation is not needed here. Some of the reasons for the growing popularity of the discounted cash flow rate of return are, however, given below.

Perhaps the most important reason is that the method takes into account the time value of money. It also considers the entire life of the property, thus accounting for all profits and expenditures. Lastly, the discounted cash flow rate of return is comparable with methods used in the financial world. This allows comparison of the calculated return with the cost of borrowing money.

The model itself is divided into four separate segments: decision-making, the actual mining, cost calculations and the determination of the discounted cash flow return on investment. A summary of the model in block form is presented in Fig. 2.

The decision-making segment is the most important of the four. In this routine are embodied the criteria which determine whether a certain block in a proposed property is strippable or non-strippable. As explained previously, these criteria can be classified as physical, chemical or economic.

The primary physical factors taken into consideration are the thicknesses of the coal seams and the depth of the overburden. The limitations of the machine and the economic stripping ratio concept are built into the maximum overburden figure.

The second physical factor, thickness of the coal seams, is also related to the economic stripping ratio. Situations may exist where, for example, either the coal is too thin to support the weight of the machinery, or is too thin to be uncovered effectively with existing equipment or the coal near the outcrop has suffered too much oxidation. As far as the model is concerned, if any of these situations would occur on the property, the coal in question would not be added to the cumulative tonnage mined.

The chemical factors considered to be relevant include the ash, sulfur and moisture contents and calorific value of the coal. Each seam is considered to have its own individual limits. Other chemical factors (for example, sodium content) may enter the decision-making picture as restrictions on the quality of the coal become more stringent.

Using any number of the above decision criteria, the model makes one of three decisions. If the overburden is not excessive and the coal meets all quality requirements then the overburden will be stripped and the coal removed. If the coal does not meet the required standards but leaving the overburden will create adverse conditions as far as moving equipment, spoil or drainage requirements, or reclaiming the land are concerned, the overburden is stripped and the coal is left in place. Finally, if the coal does not meet requirements and leaving the overburden presents no additional problems, that portion of the property under consideration is left untouched.

The model has been developed to handle the seams in an incremental fashion. Thus, there will be as many complete analyses as there are seams. For example, if the property under consideration contains two seams, the entire property will be classified using the above alternatives as if only one seam were present. The property will then be classified with both seams entering into the analysis. Thus classification of higher seams may change depending on the status of the lowest seam in the analysis. It should be noted here that although each combination of seams is assigned the above values, the complete program is run for the first combination and a rate of return calculated before the second combination is analyzed.

The end result of the decision-making routine is the block-by-block assignment of two variables to each seam involved in the analysis. The first of these variables is the strippability which can range from a value of zero, indicating that none of the overburden above the seam in question will be stripped, to unity, indicating complete stripping. Fractional values are allowed to account for situations where legal or natural barriers might prevent the entire stripping of a certain block. These barriers might include roads, cemeteries and small valleys where the coal has been eroded.

The second of the two variables is the thickness of the coal. If during the routine a certain seam in a block is found not to meet quality requirements, the thickness which has been read into the program from drill logs is re-defined as zero. This has the same effect as assigning the tonnage of this seam in this particular block a value of zero. After the entire property has been classified in this manner, control is shifted to the mining routine.

The values which have been assigned to the different block-seam combinations in the decision-making routine are used to generate the tonnage of coal mined and yards of overburden stripped in each year of the life of the property. The basic formulae used for these calculations are as follows:

$$\text{Overburden (cubic yards)} = \frac{\text{Strippability} \times \text{OB depth} \times \text{area} \times (1 + \text{rehandle})}{27}$$

$$\text{Coal (tons)} = \frac{\text{Strippability} \times \text{coal thickness} \times \text{area} \times \text{weight of coal}}{2\,000}$$

The property is then mined completely by the computer. Again, illustrating the incremental fashion in which the seams are handled, only the top seam will be mined the first time when this routine is executed. The second execution will mine both the top seam and the seam immediately below it and so forth. Running totals of overburden stripped and coal mined are kept as the property is traversed from left to right and from bottom to top.

A required annual production figure, which is read into the program as an input variable, serves as the basis on which the property life is determined. On this basis details are calculated for each year of operation. If it is desirable, cubic yards of overburden removed per year can also be used as the production requirement figure.

The end results of this routine would be for each combination of seams, a property life, annual coal tonnages (for each individual seam and a total), annual overburden yardage (again for each seam and a total), stripping ratios for each year and a total calorific value, also for each year of the life of the mine.

These values are then transferred to the cost routine for use in the calculation of costs of plant supply, mining supply, power, labor, administration, shipping and storage and other miscellaneous costs (that is, property taxes, compensation, insurance, welfare, benefits, etc.). This is accomplished by multiplying unit costs, which have been read into the program as input variables, by the appropriate tonnage or yardage.

Most of the costs have been read into the program as a set value for all seams. However, costs of drilling, explosives, stripping and loading are read into the program for each individual seam. This has been done to account for the fact that different machines may strip the overburden above different seams, more explosives may be used on one seam-overburden combination than on another and drill spacing

may vary from level to level. Also some coal seams are loaded in place, others are ripped using a bulldozer, and still others may be drilled and shot before loading. In the program these costs are calculated separately and then added to the mining supply cost, which is the figure appearing in the output.

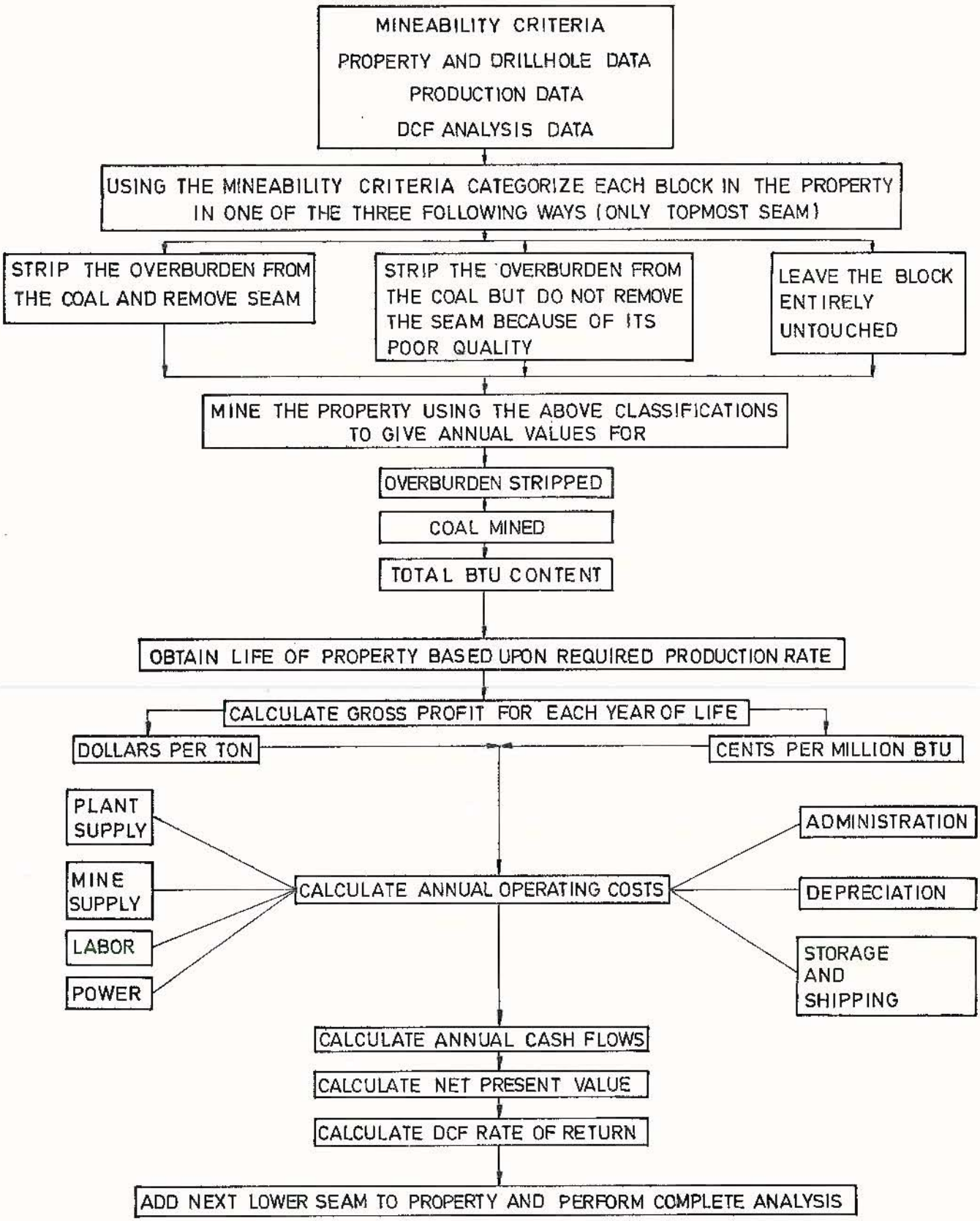

Fig. 2. Block diagram – Multiple-seam economic feasibility study.

The last section of this routine calculates the gross profit in each year of the life of the property. This is done in either of two ways. If the coal is sold on a dollars per ton basis, the gross profit is simply this selling price times the tonnage mined in that particular year. This tonnage is adjusted in accordance with the preparation plant recovery. If the company's contract calls for the coal to be sold for so many cents per million BTU, the gross profit is obtained by multiplying the sale price by the heat content of the coal, in millions of BTU, produced during the year.

Control is then passed to the routine which calculates the discounted cash flow return on investment. The values which are transferred from the cost routine are the operating costs themselves, the gross profits for each producing year and the property life. This routine is capable of handling any property with a life less than or equal to 30 years. The initial production year can be one or any succeeding year. This is to allow any number of development years before the actual production begins.

The present-value calculations have been programmed to begin in year zero. This is a debatable point in discussions of the discounted cash flow method. However, an alternative approach can be handled in a simple manner.

Depreciation can be calculated either by the straight-line or declining balance methods. If the straight-line method is used, capital expenditures can be made in any year during the life of the property. This capability is not built into the declining balance method.

The depletion allowance is calculated in the standard manner. Both a set percentage (10 per cent for coal) of the gross profit in a particular year and 50 per cent of the net profit before taxes in the same year are calculated. The routine determines the smaller of these two values, and it becomes the depletion allowance for the particular year in question.

Values calculated by the program for state and federal taxes are dependent upon the tax structure of the state in which the mine is located. The following four possibilities are provided for in the routine:

(i) no state taxes;
(ii) state tax computed on profit before federal tax;
(iii) state tax derived from federal tax base; and
(iv) state tax computed on profit after federal tax.

The next calculation is that of the profit after taxes and subsequently the cash flow.

Net cash flow = Profit after taxes + depreciation + depletion − capital expenditures − development expenditures ± working capital requirements.

This provides the input on which the present-value calculations are based. The formula used in this calculation is as follows:

$$\text{Present value} = \frac{\text{Net cash flow}}{(1+R)^n}$$

where n is the property life in years and R is an initial trial for the discount rate.

Following this, the net present value is calculated and R is varied depending on whether the net present value is positive or negative. If the value is positive, R is increased by 0.1 per cent and if it is negative, R is decreased by 0.1 per cent. This procedure continues until the absolute value of the net per cent value is less than or equal to five. The latter figure can be varied depending upon the degree of accuracy required in the DCF rate of return.

The first execution of this routine results in a rate of return to the company if only one seam (the topmost) is mined. Control is then passed to the main program where the next seam is added to the analysis, and the procedure which has just been discussed is repeated. As explained earlier, this occurs as many times as there are seams.

The end result of this routine will be a series of rates of return, representing different seam combinations. The relationship between the rates will indicate to the company, (i) if the proposed venture will be profitable, and, (ii) how many seams should be mined to maximize the profitability to the company (based on the DCF rate of return).

A few of the limitations of the program should be discussed. Because of limited storage capacity in the IBM 360 computer which was used in this study, the property which can be handled must be limited to 25 blocks in length and 25 blocks in width. This means that if each block was 500 ft, the maximum dimensions which can be handled are 12 500 ft. Being over two miles, this may not be too great a restriction. However, if the 500-ft spacing does not give the required accuracy, maximum property size will have to be sacrificed in order to gain this accuracy. The second limitation, again due to lack of storage capacity in the computer, is that only four seams can be considered. It has already been stated that property life must be less than or equal to 30 years. Since the lives of most properties do not approach this figure, this really does not present any problem.

CONCLUSION

The model developed here can be a helpful decision-making tool for the mine manager or mine planner. It has been tested with actual operating and cost data from existing bituminous coal mines. It is intended to expand this work to (i) include other minerals and (ii) develop detailed quantitative relationships among the various decision-making variables.

Because of lack of space, the computer program itself or the sample input and output have not been included with this paper.