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A LINEAR PROGRAMMING APPROACH TO SHORT TERM PLANNING  
FOR OPEN PIT HAULBACK COAL MINES

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A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Mining Engineering).


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ABSTRACT

A short term planning technique for coal haulback mining operations was investigated using Linear Programming. A straight forward formulation of the problem was constructed which considered most of the usual requirements and constraints of a typical planning model. The direct Linear Programming solution could not be reached due to the size of the problem and computer code limitations.

The model was modified by refining the linear constraints, redefining the variables, and applying a priority-type objective function. The model modifications illustrate concepts which may be useful to planners and analysts involved in similar planning problems.

The planning technique was tested on a multi-seam, geologically-complex coal deposit. The case study proved the ready applicability of the method. The optimal production plan developed for the case study was checked for practical implementation. A waste stripping plan for the optimal production plan was obtained by minimizing the stripping requirement fluctuations over the planning horizon.

Despite the fact that the formulation was developed with a strong emphasis towards a specific case, simple modifications can be made for its application to other operations.

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## CHAPTER 1

## INTRODUCTION

## 1.1 Introduction

For the past decade, a continuous increase in the price of fuels has been present world-wide. This price hike has forced non oil-producing countries to maximize the extraction of their own resources in order to avoid insurmountable foreign deficits. With this idea in mind, an approach for the development of a mining production plan for low-quality coal deposits is discussed.

Mine production planning consists of determining the sequence of extraction for each portion of the deposit over a given time horizon. Such a sequence is subjected to various considerations, such as mining methods, equipment characteristics, geological features of the deposit, coal quality distribution, and economic objectives.

Production planning is commonly subdivided into three categories depending on the planning horizon: long range, short range, and production scheduling. The first category, long range planning, usually applies to one to five year time periods with a planning horizon which can vary from

five years to the entire life of the reserve. Short term planning is done on a monthly to yearly basis, and production scheduling applies to shift-to-shift, daily, or weekly schedules.

In this thesis, a computerized approach to short term planning for open pit haul-back coal mines is presented. This approach is developed by analyzing a general Linear Programming formulation of the problem. The objective function and linear constraints are re-formulated seeking a flexible and computational efficient formulation. The short term planning approach is tested on a case study based on real data, and its principle is of wide application.

The objective used as an example to develop the formulation is to optimize the resource utilization. The approach uses operations research techniques, such as Linear Programming (L.P.) and Digital Simulation.

The planning system is based on a numerical model of the deposit, or block model, that is specifically designed as a production planning data base. Thus, the present work is subdivided into two main sections. First, the model of the deposit is generated. This is covered in Chapter 2. Second, the planning algorithm is discussed and developed in Chapters 3, 4, and 5. Chapter 6 covers the test case study.

The conclusions and recommendations are covered in

## Chapter 7.

### 1.2 Problem Definition

In the detailed evaluation stage of a mining operation the pit limits, minable reserves, and equipment demands throughout the life of the operation are calculated. These studies are generally done separately, in two phases. First, the determination of reserve limits and pit design are conducted. Second, the designed pit is subjected to a long term planning study. This long term plan allocates different zones of the deposit to be mined in several consecutive time periods. In this later phase, the equipment requirements and ore production are estimated (Couzens, 1979).

This evaluation procedure does not yield reliable results in some cases. These cases are operations where mined coal quality control is critical for the marketability of the product, and the attainment of that quality presents problems from a mining standpoint. The difficulty in producing coal within certain quality ranges is due primarily to two factors: the spatial coal quality distribution within the deposit, and the lack of flexibility of the mining method. Haul-back surface coal mining

operations are an example of such a case, as they may be characterized as having a very inflexible mining method particularly if the coal quality distribution is adverse. Most coal mining companies base their production on medium to long term delivery contracts. Such contracts clearly specify bounds for the quantity and frequency of the shipments, physical requirements of delivered coal, and the important parameters that determine the coal quality. These parameters vary with the future use of the coal by the consumer and with the local environmental laws. For steam coal, as an example, sulphur, ash, moisture, volatile matter content, and calorific value determine its quality and coal samples are analyzed for these parameters. If the contracted quality values are not met, severe economic penalties are applied to the producer, ranging from reduction in price by penalization to rejection of the shipment or even voiding the contract.

The quality of the coal can be improved by costly washing plant treatment. However, if no washing treatment is available, the only two methods that can help improve the coal quality are selective extraction and blending. Blending the coal can be performed in stockpiles, by extracting coal from several faces simultaneously, or by a combination of both methods. In-pit blending is commonly

the most inexpensive, but it requires a careful study of the mining sequence. A production plan that includes blending optimization will maximize the marketable reserves. This plan allows production quality forecasting and provides a more realistic estimation of salable coal reserves.

Open pit coal mine production planning faces two major problems. The first is to guarantee coal production within contract requirements. In practice, this is attained by combining a proper mining advance orientation and a mining plan that yields acceptable blending results. Second, when high and sudden changes of stripping requirements occur, careful strip planning must be done. Failure to take this into account may result in having an oversized stripping fleet, using costly contracted equipment, or discontinuing coal extraction until the stripping operation can regain its lead. In most cases, this is a trade-off situation and a solution of compromise is taken.

Simultaneously, good judgement must be made on the size of the initial dump area in order to guarantee smooth dump progress and to avoid later rehandling. This is particularly important if the coal overburden shows sudden variations that compromise the haul-back refilling operation.

Consequently, the problem presents the following

objectives:

- 1) to develop a method for defining a mining production plan that will guarantee the compliance of the contract requirements and maximizes the resource utilization
- 2) to estimate the stripping equipment fleet required to achieve such a plan
- 3) to forecast the coal production, by mining periods, throughout the life of the mine
- 4) to estimate the salable reserves

In addition to the theoretical development, a case study is used to check the practicality and ready implementation of the approach. Data from a multi-seam coal deposit currently being worked as a truck and shovel haul-back strip mining operation will be used.

The complexity of the deposit presents problems in dump and strip planning, and the coal quality variability forces the use of blending methods to meet the contractual requirements. The approach developed in this thesis to solve the problem of providing a short term mining schedule for a multi seam coal operation as outlined above requires the use of digital computers for its solution. Mathematical optimization techniques are used to model the deposit and simulate the mining operation progress.

This thesis has three major areas of investigation:

1) Computer modelling of geologically complex coal deposits for production planning applications.

2) Development of an integrated technique for coal reserve estimation and mine planning.

3) Computer code development for the implementation of the solution technique.

### 1.3 Review of Previous Investigations

Much has been done and published about ore body modeling (Bideaux, 1979; Manula et. al., 1979; Rendu and David, 1979; Barnes M., 1979; Banfield and Wolf, 1979). In fact, ore body modelling has reached a high degree of sophistication, and standard interpolation techniques - including classical geostatistics - are included in many commercial computer packages.

New techniques have been developed, and models such as the Gridded Seam Model of MINTEC, Inc. are specifically designed for modelling coal seams. However, these models fail to provide the user with a manageable data base for optimizing techniques, and leave the planning stage to a trial-and-error approach. On the other hand, the use of optimizing techniques for coal production scheduling is

seldom found in the literature. An exception is the optimization of dragline operations, although flat seams are assumed and coal quality is usually disregarded in these studies.

Some notable papers on mine production scheduling have been published by Kim, 1967; Wilke and Reimer, 1979; Davis and Johnson, 1979; Bott and Badiozamani, 1982; Johnson, 1969; and Erikson and Pana, 1966. These studies leave a gap in applying the short term planning techniques to coal strip mining operations. In coal mining, long term schedules fail to ensure that individual coal shipments will not be rejected or severely penalized because of their low quality. This is due to the general fact that long term plans work with averages over wide areas of the coal seams. In practice, blending is done on a short term basis and any planning method that does not take this fact into account may result in a plan which is infeasible in practice. No proper planning technique has been successfully developed to solve this problem to date. It is this gap that this thesis attempts to fill.

## CHAPTER 2

### COAL DEPOSIT PLANNING BLOCK MODEL

#### 2.1 Definition of Orebody Planning Block Model

The model is a discrete representation of the coal deposit obtained by dividing the mineralized zone into units (commonly called blocks). These blocks are stored as a numerical array of values of determined mining-related parameters such as coal quality, tonnage, geological features, and spatial configuration.

There are several ways of representing a deposit as a numerical model. Deposits of different geologic types call for different techniques for storing the data. Also, the objective of the model, i.e. the future use to which it is destined, will require different approaches for the deposit representation.

Two major objectives should be considered when creating a computer model of a deposit: Reserve Estimation and Production Planning. For coal deposits, the former objective requires only the creation of a set of two-dimensional arrays that contains the quality and quantity values of each coal block. This is performed by coal seam and the data from each block are stored within the

grid according to its relative location. Thus, a coal seam is represented by a set of numerical arrays, each of them relative to one seam parameter, i.e. thickness, ash %, BTU content, etc. With this set of grids, simple algebraic operations allow the calculation of reserves, average quality values, overburden volumes, and stripping ratios. The generated grids constitute what is referred to herein as the Mineral Inventory Model (MIM.).

The second objective, production planning, needs a further step in the modelling process: the discrete units of the model (blocks) should be able to represent the mining advance in order to provide a data base suitable for production planning and simulation. These blocks are created by superimposing a three-dimensional grid over the total volume of the deposit, and assigning coal and waste quantities to each block. Many block sizes and shapes can be used. Blocks that contain one or several types of material can also be considered. This type of block model will be referred to as the Planning Block Model (PBM.).

## 2.2 Mineral Inventory Model Generation

The development of a valid MIM. is a complex task and a good deal of effort should be devoted to its generation

and validation. The general layout of a coal MIM generation is shown in Figure 2.1. The process includes the use of some utility programs for data processing and graphics, statistics and report generation. These programs are of vital importance in validating the model and in error discovery during its generation. Interpolation is the most important suboperation involved in generating the MIM. Two main decisions must be made for its execution:

- a) Selecting the grid size and grid orientation
- b) Selecting the gridding technique

The block size is primarily determined by the density of data points and future use of the block model. The grid orientation is chosen so that the generated cells correspond to the actual mining cuts.

The gridding technique is selected taking into account the amount of data available and the characteristics of the parameters to be interpolated. The most suitable technique for each parameter should be used. For coal quality purposes, geostatistics is recommended if sufficient data is available, whereas for seam topstructure elevation or topographic elevation, linear interpolation with trend analysis may be more suitable. In case of insufficient data to perform meaningful geostatistical analysis, polygon methods and inverse square distance interpolation have been

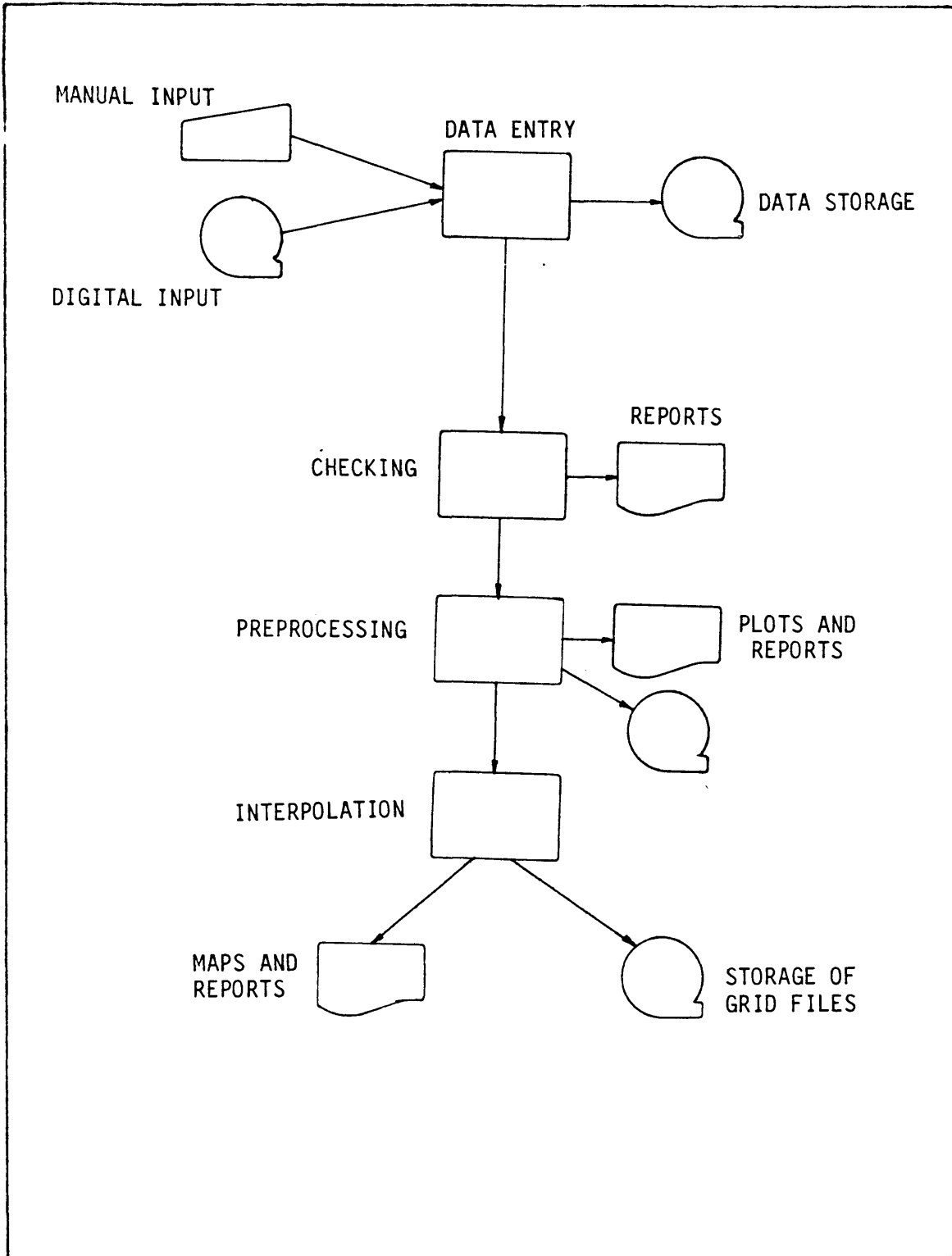


Figure 2.1. Mineral Inventory Generation Flowchart

often applied to many coal deposits. In fact, taking into account computing costs vs. accuracy as well as the fact that coal is a relatively homogeneous medium, the moving average method has proven one of the most suitable gridding techniques for coal quality.(Quilling, 1979). Interpolation of coal-related variables is carried out over an area that covers the whole deposit. Then the interpolated data is restricted to the area within the seam boundaries. The seam boundaries are defined by property lines, outcrops, faults and wash-outs, previously digitized from maps.

One difficulty not often discussed in the literature is the presence of discontinuities in the seams; discontinuities have their origin in faults and wash-outs. These must be treated differently in the interpolation process depending on their geologic origin and the variable to be interpolated. For example, if the fault does not seem to affect the thickness of the coal, interpolation of this variable can be done by assuming that the fault is non-existent. However, other variables, such as seam topstructure are obviously affected by the discontinuity and have to be interpolated independently within the continuous zone of the seam. Nevertheless, often a continuity trend exists between both sides of the fault. In this case, some influence of the values of one side of the fault over the

values on the other side must be considered. This is performed by the inclusion of some trend factor in the interpolation (CPS-1 support staff, 1979). Fault lateral displacement and useless oxidized coal at the fault contacts are usually simulated by blanking the area in between the coal seam-fault contacts.

Reverse faults are particularly complicated to model. In this case, a grid point (x,y) has two grid values (z), and this cannot be handled by gridding programs. A solution to this problem is to treat both sides of the seam as different seams in interpolating the seam topstructure. For interpolation of quality values, the coordinate system of the seams is changed to represent continuity between the two parts on each side of the fault. Some commercial computer packages have interpolation capabilities to account for handling faults. In the case study, three different gridding algorithms were used: linear interpolation for the topographic surface, linear interpolation with fault considerations for the seam topstructure, and inverse squared distance for the ash content and seam thickness.

### 2.3 Planning Block Model Generation for Truck Shovel Haulback Mining Operations

The PBM. converts a set of bidimensional data into a three-dimensional data base. The general approach is as follows (Figure 2.2):

1.-Superimpose a hypothetical three-dimensional grid over the deposit. This grid defines a set of regular blocks (all equal in shape and size). The block dimensions are selected so that the generated blocks represent logical mining units for the production plan.

2.-Determine which blocks contain coal. This is inferred from the gridded data of the MIM.

3.-Calculate the coal quality and volume, and parting volume within each block, as well as locating the seam within each coal bearing block.

4.-Generate an outer bound of the final pit. This is usually done by projecting the pit slopes from the coal boundaries.

5.-Modify the size of blocks to take into account faults, equipment capabilities and mining procedures. This is done by transferring material from one block to the blocks overlaying or underlaying it in order to simulate more accurately the actual bench geometry.

The selection of the three-dimensional grid size is done taking into consideration the equipment size. Mining shovels are designed for a specific ,or standard, bench

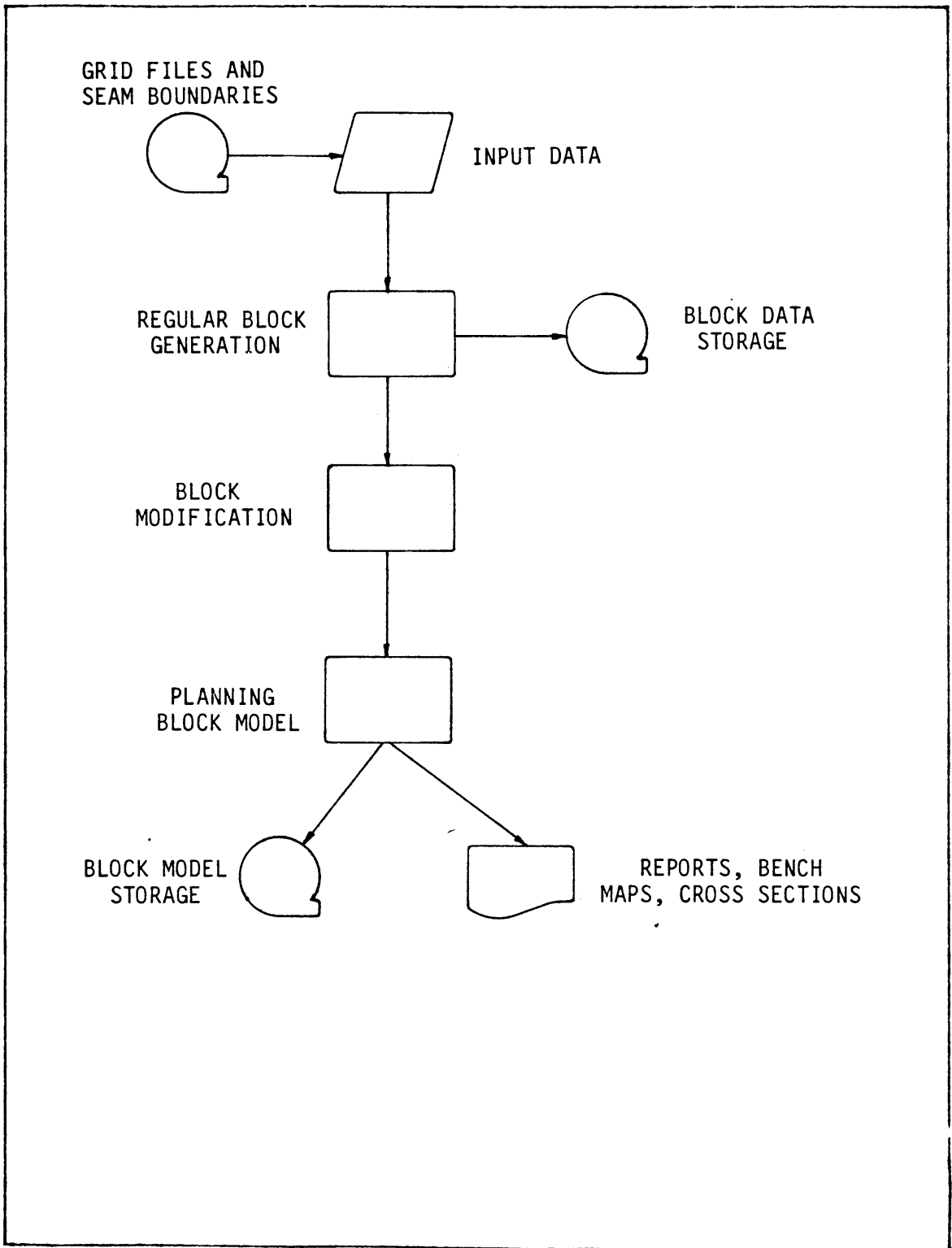


Figure 2.2. Planning Block Model Generation Flowchart

height. Nevertheless, they can work economically within a range of heights. The block height chosen emulates the standard excavation of the shovel. Benches are assumed to be horizontal and the relative location of the grid within the deposit follows the bench levels determined from the engineering design. The width of the blocks is matched with the bench berm. The length is selected primarily considering the planning horizon and geology.

Once the grid size is determined, an analysis of the location of the seams and topography within the grid is carried out by comparison with the MIM. grids. Knowing the bench elevation of the block and the elevation and thickness of each seam, the volumes of coal and waste above and below the seam within a block can be calculated. During the planning stage, the values of the parameters involved in the interpolation are assumed constant within each block: the seam is assumed horizontal (constant topseam elevation), and of uniform thickness and quality.

The block composition is an approximation of the real geometric distribution of the materials. For horizontal or near horizontal seams this does not present a problem. However, in linearizing and levelling steeply pitching seams, errors in these estimations may occur. Also, the accuracy of this estimation decreases as the block size

increases. The result from the linearization is that the continuity of the seams is broken in the model, and a discrete step representation is adopted (Figure 2.3). Finally, further modification of the block size is performed to simulate the mining procedures more accurately. The assumption of horizontal benches is not realistic in many cases, as benches directly above coal seams tend to follow the seam elevation whenever possible. In addition, the bench height does not remain constant. As the bench dips following the seam, the bench height increases until it reaches the limit of the shovel. Waste blocks located one above the other are grouped together if the total mining height is within the excavation limits of the equipment.

Consequently, the final PBM. model contains blocks of the following types:

a) air blocks: blocks completely above the topographic surface. They are disregarded for planning purposes.

b) topo blocks: blocks that contain the air-ground interface. They contain a variable amount of rock and the soil layer.

c) waste blocks: blocks that contain only waste rock. They have the standard bench height, as defined on page 14. Therefore all contain the same volume of rock.

d) coal blocks: They contain coal and waste rock in

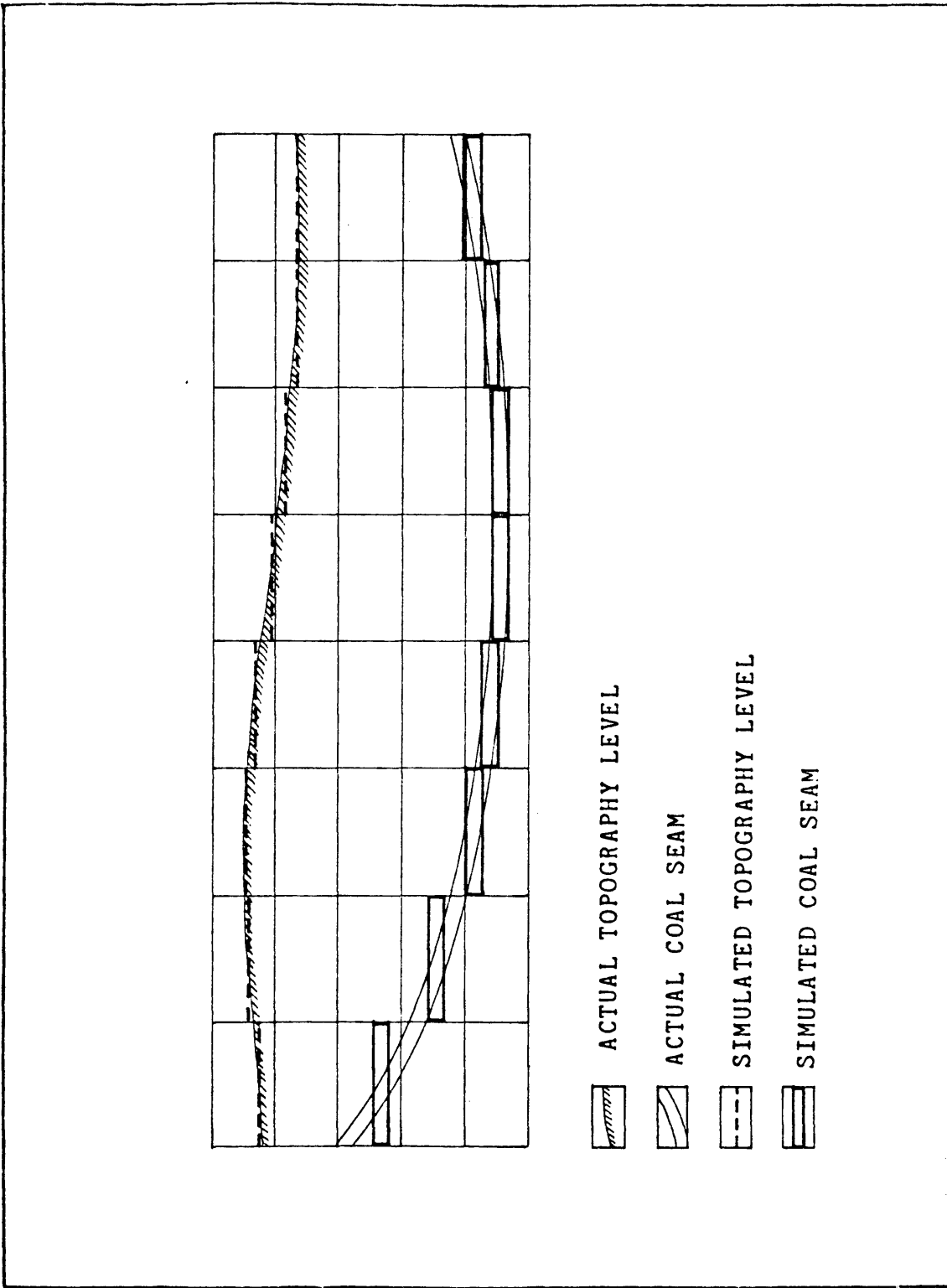


Figure 2.3. Deposit Block Model

variable amounts. Waste can be located above the seam, below the seam or in both places.

e) outside-pit blocks: blocks that fall outside the generated pit boundaries. These are treated as air blocks.

## CHAPTER 3

## THE MINING SYSTEM

## 3.1 Coal Strip Mining Unique Features

An important characteristic of coal haul-back mining concerns the mining method itself. In this mining method, the pit advances laterally. Once the initial cut is made, mining progresses as a continuous operation in which the overburden is hauled to the back of the pit and dumped in for refilling. This backfill is used to restore the original topographic profile as required by law. Although the exact geometrical structure of an open pit haulback mine depends on that of the deposit, the general structure is based on parallel benches and a constant advance orientation (Figure 3.1).

Most surface coal mining operations work under a long term delivery contract. This contract specifies strict quality bounds on the delivered coal. The most important consequence of the long term contract is that blending becomes a key operation. A low quality coal block becomes salable at a profit if it is uncovered, extracted, and blended with other higher quality blocks to yield an

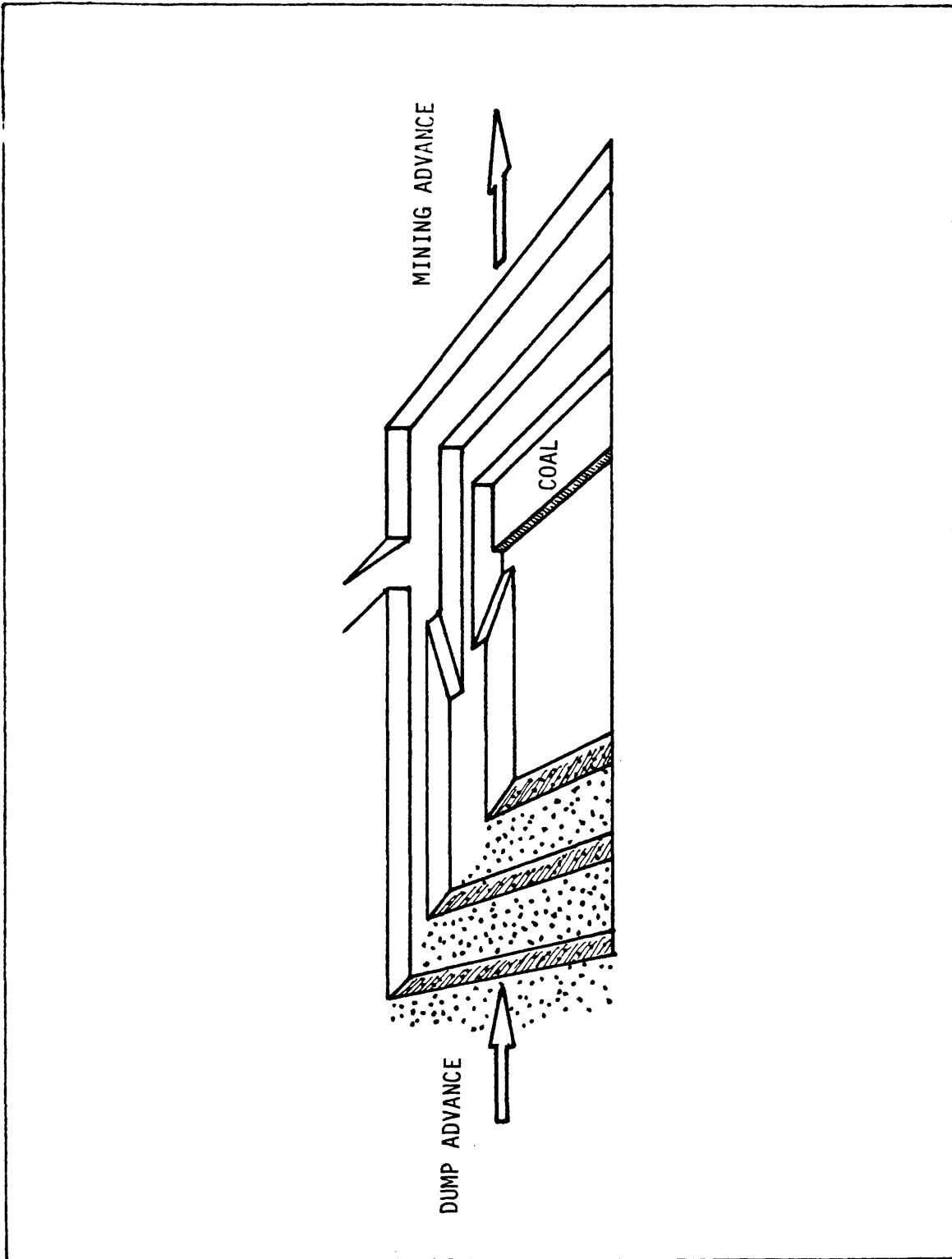


Figure 3.1. Hypothetical Layout of an Open Pit Haulback Mining Operation

acceptable coal shipment. Thus, the value of a coal block depends not only on its own quality values and tonnage, but also on that of the other blocks that can be blended with it: optimal resource utilization is obtained by a proper blending operation.

Blending occurs during the mining operation and also in out-of-pit raw coal stockpiles. However, stockpiled coal has a limited useful life. If it is left in the pile over a certain period of time, the risk of spontaneous combustion exists. Also, any stockpile has a limited capacity and not all the coal in the stockpile is accessible at one time. These factors limit the available time frame during which out-of-pit blending can be performed for a given coal block.

Similarly, in-pit blending is constrained by the mining operation. In-pit blending is done by extracting coal from several mining faces during the same mining time-period. At any given time, the mine has some uncovered coal reserves available for extraction. However, the fact that the mine dump is advancing behind the advancing coal face results in a limited time frame for the uncovered coal to be mined out. The proper blending combination must be found during this time span. Otherwise the coal from the bottom seam will be inevitably buried under the dump as it advances. Similarly, coal from the upper seams may have to be removed to make

room for the stripping of lower seams.

Therefore, the production planning problem is heavily restricted by the mining advance rate, geometry of the deposit, contract requirements, stockpiling facilities, and mining advance orientation. All of these factors affect the feasibility and optimality of a production plan, and are discussed below.

### 3.2 General Description of the Mining System

The overall system is based on a truck and shovel coal haul-back mining operation, blending stockpile, and coal treatment plant. Coal transportation from the plant to the buyer's stockpile is not included in the system, as it is not an objective in the production plan. The total system to be considered is depicted in Figure 3.2. The mining system is analyzed by breaking it into the suboperations that have some input in the planning formulation: waste removal, waste hauling, dump advance, in-situ uncovered reserves, and coal extraction. The coal network flow diagram of the overall system as it was considered in this study is illustrated in Figure 3.3. This Figure shows the possible alternatives of coal use:

The available coal from the existing uncovered reserves

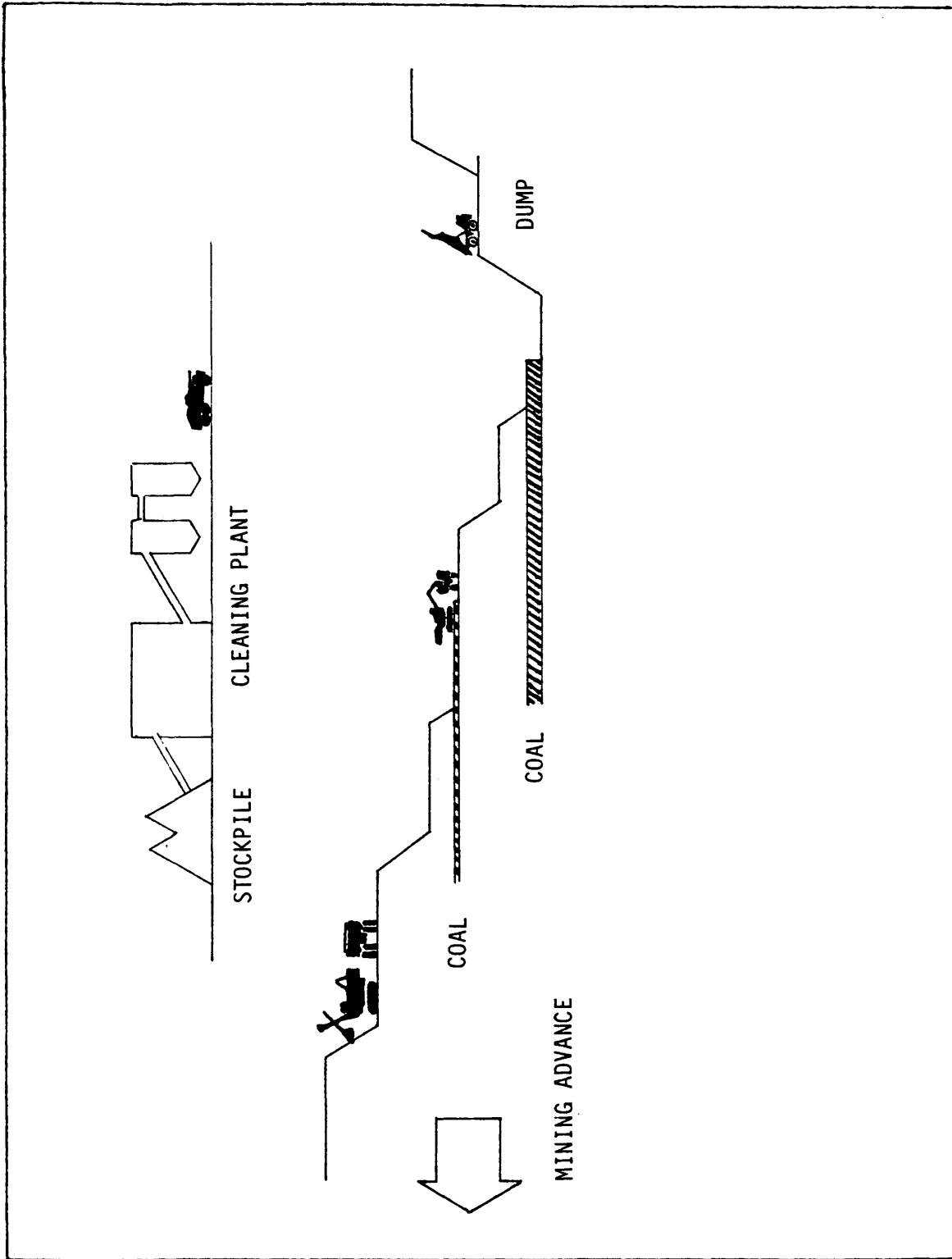


Figure 3.2. Illustration of the Suboperations of the Mining System

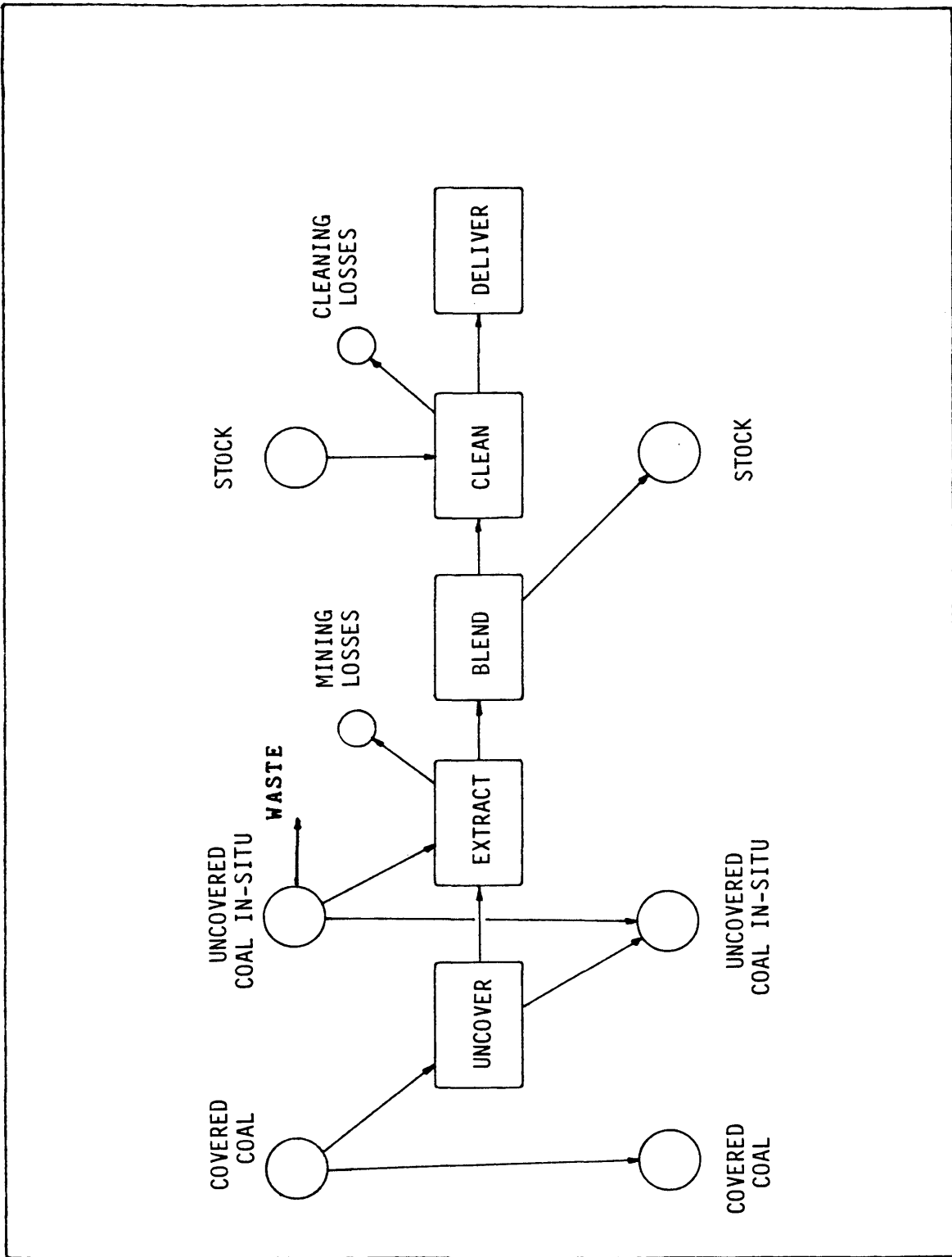


Figure 3.3. Coal Network Flow Diagram

from previous periods can then be either extracted and sent to the blending stockpile, kept as uncovered reserves for future periods, or, due to its possible low quality value, treated as waste. The model of the system accounts for mining and processing losses.

### 3.2.1 Coal Contract

Contract specifications in particular, play a major role in the extraction versus non-extraction decision for each coal block.

A typical steam coal contract includes several coal quality parameters, such as BTU/lb, ash %, sulfur %, moisture %, volatile matter %, and, in some cases, other physical tests like grindability and size distribution. A certain tonnage and delivery rate are also specified.

A bonus and penalty system is defined to force the supplier to comply with the desired specifications. This is done by applying formulae that determine the price variation from a base price, as defined by the actual tested quality of the shipment unit.

The most common penalty functions used in U.S. coal contracts are usually discontinuous linear relationships of quality versus price. However, often only one penalty

function is specified. The penalty normally concerns the B.T.U. content, while the other quality parameters are only specified as dry cut-off values that determine the acceptance or rejection of the shipment. Although in exceptional cases two or more penalty functions may be included, only one will be assumed here. While there are coal mining operations in which the coal has good quality throughout the deposit and penalties do not present a problem, the present study relates to those that require careful blending control to avoid frequent rejections.

### 3.2.2 Mining Costs

The operating costs can be allocated to the different suboperations involved in the mining operation. For the mining system of this thesis, these are:

- 1.- Drilling
- 2.- Blasting
- 3.- Overburden Loading
- 4.- Overburden Hauling to Dump
- 5.- Coal Clearing
- 6.- Coal Loading
- 7.- Coal Hauling to Stockpile
- 8.- Coal Handling and Stockpiling

9.- Coal Processing

10.- Control, General and Administrative Overhead

Out of all the mining subsystems, hauling contributes the greatest percentage to the overall cost and is more sensitive to pit geometry variations. There is another important factor in the design of the pit that has a considerable influence on the overall cost but is not numerically quantifiable. This factor is the bench layout. A good, simple mine layout that avoids winding benches improves the safety and smoothness of the operation, resulting in better operation control, higher haulage speeds, and therefore, yields higher productivity and lower haulage costs.

The cost of each mining suboperation, in turn, depends on other variables, such as production rate, haulage distances, rock properties, etc. For a given operation, the costs of some of the suboperations such as drilling, blasting, coal and waste loading, overhead, and coal processing can also be considered constant on a per cubic meter and per tonne basis. Waste hauling costs are minimized by minimizing the haul distances, and coal stockpiling costs can only be minimized by reducing the material stockpiled to the required minimum.

Finally, overburden haulage costs are a direct

function of the haul distance and vertical lift. The haul roads vary continuously as the mine progresses. Therefore, the hauling costs will directly depend on the shape of the pit, determined by the production schedule. In this thesis, waste hauling is considered to be the only cost item that depends on the extraction plan. Waste haulage costs do not directly enter into the problem formulation, but as a final result stripping guidelines are provided which will aid the planning engineer to develop minimal cost waste haulage plans.

### 3.2.3 Backfilling

As mining advances, the waste has to be dumped back into the pit. Also, the toe of the bottom coal bench must be kept beyond a minimum distance from the dump for equipment maneuverability. Since the coal extraction rate is considered fixed, the mining face advance is then only controlled by a maximum waste removal capacity.

### 3.2.4 Mining Advance Orientation

Some basic considerations should be taken in order to select the mining orientation: geometry of the deposit,

length of the generated benches, stripping ratios along the life of the mine, coal quality distribution, and dump progress. Proper mining orientation avoids wide variations in stripping requirements that would result in poor equipment utilization.

Finally, the quality of the uncovered coal that will be available for extraction will also depend directly on the chosen orientation of the cut. Thus, the production plan is directly affected by it. Selecting a mining orientation is a problem in itself (Davis, 1981). The mining advance orientation is assumed fixed in this study. This thesis provides a numerical method to evaluate the selected orientation.

### 3.2.5 Stockpiling

The stockpiling facilities also affect the production schedule, but mainly from a time standpoint. The risk of spontaneous combustion and the stockpile capacity determine the length of time that a coal unit can be safely kept in the pile. That time period is in fact what determines the production schedule term.

As the coal rejection or acceptance is determined on a shipment basis, the scheduling formulation should be

based on the delivery frequency to ensure that the quality requirements are met.

In practice the shipments are often on a daily or weekly basis, but a formulation on that basis will increase the problem size unnecessarily.

The production schedule time period unit should be small enough to guarantee a feasible blending output but as long as possible to minimize the problem size. The period used in this thesis is defined by the capacity of the blending stockpile, as it represents the maximum available coal of guaranteed marketable quality.

### 3.2.6 Coal Processing Plant

Very often, coal must be submitted to some sort of processing prior to its delivery. Coal processing might be as simple as primary crushing or as complex as a full scale washing process in which crushing, screening, milling, washing, dewatering, and drying are involved. In the proposed model the coal processing plant efficiency and coal losses are taken into account for a simple operation. This operation involves crushing, hand picking, milling, and screening. The efficiency rate is assumed to be a linear function of the quantities of coal

and parting on the raw coal feed.

### 3.3 Summary

The mining system to be modeled involves the mining operation and the coal cleaning plant. The mining operation is modeled including the following sub-operations: waste stripping, exposed coal inventory, coal extraction, and dump advance. The mine layout and advance orientation are assumed fixed in this thesis. The coal cleaning plant includes the utilization of a raw coal blending stockpile and a coal crushing and screening operation. Coal contract requirements are taken into account as dry cut-off values that determine the acceptance or rejection of the shipment, and operating costs are assumed to be directly dependent on the waste haulage costs.

## CHAPTER 4

## MATHEMATICAL APPROACH TO THE SCHEDULING PROBLEM

## 4.1 Production Plan Objectives and Considerations

The objectives to be met by solving the Linear Programming model proposed in this thesis are as follows.

1.- Must provide a practically feasible plan that ensures compliance with the contract requirements on a shipment basis and maximizes the coal reserve utilization.

2.- Must account for all the mining operational constraints to guarantee the plan's practical feasibility.

3.- Must provide a reliable estimation of marketable coal reserves.

4.- Must provide a quantifiable means for evaluation of the predetermined mining advance orientation.

5.- Must provide a basis for estimating the mining equipment necessary for the fulfillment of the mining plan.

These objectives require that the production schedule be on a short term basis. Any plan based on medium or long term averages can not guarantee that the quality value fluctuations on the short term do not include shipment

rejections. The quality of marketable coal for a given deposit and mining orientation depends on three variables: the blending facility capabilities, the coal processing plant performance, and the extraction schedule. While the first two variables are beyond the scope of this work, but the third is the objective.

The two major problems to be solved here are, thus, the optimal in-pit operational blending of coal along with secondary blending in stockpile if required, and the time allocation of waste removal operations so that the stripping capacity required is maintained within a certain level of variability. The applicability of the approach developed here is specially oriented to low-quality, highly geologically disturbed multi-seam coal deposits. Hence, the technique is more applicable where planning is most needed.

#### 4.2 The Philosophy Behind the Solution Technique

In developing the present approach to the planning problem, two important factors must be considered: the practicality of the technique from an operational point of view, and the cost efficiency of the computing techniques to be used.

Preparing a short range production plan, even for a

medium size mining operation, is a very tedious and time consuming task. The planning engineer is usually confronted with a large problem with many inter-related variables and, due to the short time available to solve it, many short cuts are often used. Usually a feasible solution is quickly accepted without questioning its possible improvement.

On the other hand, the mathematical techniques available to solve the problem require the use of digital computers, and these have limited capabilities, both in the size of the problem they can handle and the accuracy of systems modeling. The short range production planning problem, unsolved successfully to date, is often too complex to be solved inexpensively with a reasonable degree of accuracy by techniques that yield guaranteed true optimal solutions. More flexible methods may be required if a more accurate representation of the system is desired. The price to be paid is the loss of optimality of the solution obtained by the alternative methods. A fast, inexpensive technique approaching the optimum that takes into account the major subproblems should be the result of this trade-off situation.

The approach developed here is based on the use of a truly optimizing technique (Linear Programming). The solution technique is developed by analyzing the formulation

of the problem as constrained by the practical implementation of the Linear Programming code available. It incorporates the characteristics below:

- \* Easy to Understand
- \* Easy to Implement
- \* Uses Well Documented Mathematical Techniques
- \* Relatively Inexpensive to Run
- \* Flexible to Changes in Mining Conditions
- \* Practical in its Results

#### 4.3 Assumptions and Applicability of the Solution Technique

The approach has been based on truck-and-shovel multi-seam coal haul-back mining operations. It has been developed for a mining system that includes the mining operation, crushing plant and stockpiling system. Nevertheless, not all the factors mentioned previously in subsection 3.2 will be included in the mathematical formulation as variables.

The operational considerations that are analyzed when formulating the model are the following:

1. Haulage Costs
2. Dump Geometry

3. Outside-Pit Dumping Areas
4. Quantity and Quality of Uncovered Reserves
5. Quantity and Quality of Delivered Coal
6. Pit Slopes
7. Coal Crushing Plant Efficiency
8. Quantity and Quality of Mined Coal
9. Quantity and Quality of Stockpiled Raw Coal
10. Coal Contract Penalty Functions
11. Waste Bench Geometry
12. Mining Losses
13. Equipment Operating Room
14. Preproduction Stripping
15. Mine Advance Orientation
16. Equipment Capacity

Each of these items is included in the solution algorithm at different stages, as required for their accurate modeling, as explained below. The block model, as it has been developed in Chapter 2, is based on a predefined mining orientation (item 15), and it incorporates the proper bench berm and bench height to represent the current mining practices and equipment operating room (item 13). Also, the pit slopes (item 6) can be generated with block volume data manipulation. The mining and processing losses (items 7 and 12) can be modeled through numerical data manipulation of

the coal data files.

The planning problem consists of finding which coal blocks have to be uncovered, delivered, stockpiled, or treated as waste, in every time period. Logically, the variables should express the percentage of a coal block that is extracted ( $x_{ij}$ ), uncovered ( $y_{ij}$ ), stockpiled ( $v_{ij}$ ), or treated as waste ( $z_{ij}$ ) by the end of the period  $j$ .

Based on this variable definition, the considerations 4, 5, 8, 9 and 16 listed on page 38 can be easily formulated as linear equations of these variables. The contract penalty functions and haulage costs are included indirectly in the formulation by certain assumptions.

Finally, the dump advance geometry, outside dump area requirements, preproduction stripping, and waste bench geometry require a more versatile model achieved by a computer simulation program.

Notice that some important assumptions are implied in the proposed solution technique.

a) All the coal in the deposit considered in the model is assumed to be profitable. The only reason for its rejection is possible low quality. It is always beneficial to extract more coal at a lower average quality rather than restrict the production of higher quality that sells without penalties.

b) The contract has a long term life. It is, therefore, assumed fixed for the life of the mine. Nevertheless, the approach allows variable production rates.

c) The coal contract includes only one quality parameter in the penalty function. Other quality parameters can be included in the contract cut-offs that determine the possible rejection of a shipment.

d) The mining method layout, stripping equipment size, and mining orientation have been previously determined and are fixed.

e) The crushing plant efficiency is expressed as a flat percentage of the quantity and quality of the coal feed.

f) There is no notable difference in stripping costs for the various overburden rock types.

g) Only the waste haulage cost depends clearly on the production plan. All other mining suboperations, such as drilling, blasting, loading and overhead, have fixed costs on a per waste volume or a per coal tonne basis.

h) The ultimate objective used in the development of the approach as an example is defined as to maximize the marketable coal resource extraction. Once this objective is achieved, the waste stripping is scheduled to minimize costs.

#### 4.4 Application of Operations Research Techniques

The mathematical approach developed in this thesis is based on the recognition of two separable subproblems within the overall planning problem. This is due to the fact that the constraints involved are of two very different natures. First are the production requirements that constitute basically a blending problem. They are easy to formulate as part of a Linear Programming problem and are solved for the mathematical optimum.

A special case is the Mining Sequence constraints. They can be mathematically modelled as a set of linear equations but they require an integer solution to be feasible from a practical standpoint. Note that this integer solution is not always guaranteed by Linear Programming solution techniques. In case of infeasibility, automatic or manual modification of the solution can be performed.

In some cases, Integer Programming (I.P.) could be used instead of Linear Programming, provided that the number of integer variables does not exceed 100. Over that number the problem becomes too large and the computer C.P.U. time requirements are unjustifiable.

Second, mining advance, dump development and other operational constraints that, due to their complexity or non-linear character, can not be solved simultaneously with the blending problem using linear programming. Hence, Linear Programming is not, by itself, a suitable technique and mathematical simulation will be used to complement it. Linear Programming has been successfully used in mine planning by many authors ( Kim, 1967; Johnson, 1969; Wilke and Reimer, 1979), and it is a well known technique with readily available computer codes.

#### 4.5 The Solution Procedure

Based on the above statements, the planning problem is solved in two stages: the blending and sequencing problem, and the waste stripping and dump advance problem.

First, the blending-sequencing problem will be formulated as a Linear Programming problem and solved with the use of the Revised Simplex algorithm. This Linear Programming problem optimizes the resource extraction by maximizing the mine coal output with lowest quality within the contract bounds. The linear programming model includes constraints concerning coal extraction sequence, coal uncovering sequence, block capacities, coal production

demand, stockpile capacity, stockpiled coal quality requirements, and contract coal quality bounds.

The Linear Programming model is formulated so that its solution develops a monthly production schedule and considers a limited number of periods simultaneously. This short term planning guarantees the practical feasibility of the short term blending process. Since the plan does not consider all the periods simultaneously, it yields a sub-optimal solution to the overall problem. Yet, breaking the total problem into smaller subproblems that analyze the mining plan by independent shorter terms is a valid simplification in this situation. This results because the mining advance is highly constrained and the mining method lacks flexibility in its progress.

After each Linear Programming run, a validating computer program is run. This program examines the solution, generates displays and reports, and updates the mining progress data files. This procedure is repeated until the area of interest within the deposit is considered or a given time horizon is reached. Then, after all the periods of interest have been solved for optimal blending, the mining plan is used for calculating the waste and dump advances at the end of each period. This can be done by a computer program, referred to as the mining simulator, that

calculates the upper and lower bounds of required waste removal capacity and an upper bound on dump space for each mining period. This process can be performed for the various types of stripping equipment involved. Finally, the output from the mining simulator is used in a subsequent Linear Programming model that allocates the stripping requirements for each period. The objective of this final problem is to minimize costs by minimizing the stripping requirement fluctuations along the life of the operation. The whole life of the mine is taken into account simultaneously in this phase. The solution of this L.P. problem also provides information for the estimation of outside dump areas, required stripping fleet size, and equipment replacement schedule.

A flow chart of the solution procedure is depicted in Figure 4.1. The development of the approach starts with an attempt to formulate and solve the overall problem as a single L.P. problem. An analysis of the practical feasibility of that formulation from a computer code execution standpoint leads to the partitioning of the problem into the steps mentioned above. The blending and sequencing problem and the dump advance and stripping allocation problem are formulated in the next Chapter.

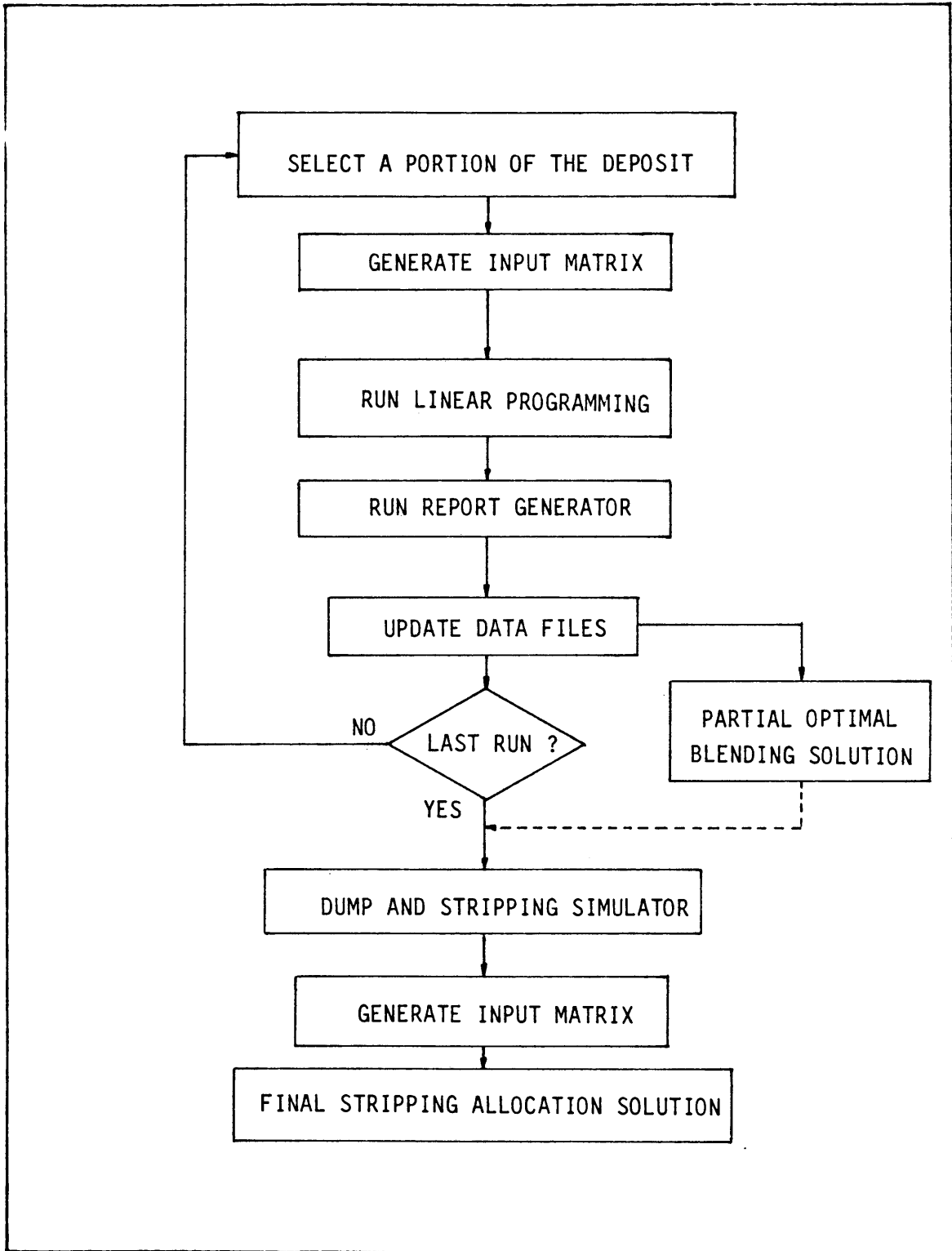


Figure 4.1. Flow Chart of the Solution Procedure

## CHAPTER 5

## ANALYSIS AND FORMULATION OF THE PROBLEM

## 5.1 Linear Programming Formulation Considerations

In mathematical systems modelling, to formulate the problem properly using a specific technique is not enough. Practical execution of the solution algorithm using available computer codes has to be possible. In short term planning, the formulated problem often becomes too large and unsolvable with the available computer codes.

The problem size becomes very important when considering the computer C.P.U. time required to solve it. This fact has been addressed by many authors (Taha, 1976; Gershon, 1982).

The most important factor affecting the required computational time is the number of constraints. In developing an economically feasible solving technique, however, special care should be taken in order to reduce the size of the problem as much as possible without jeopardizing the accuracy of the formulation.

The most powerful commercially available L. P. computer codes can solve problems of up to 4,000 equations and many

more variables. Yet, in general, any problem with over 200 equations can be considered large (Luenberger, 1973).

It is easy to realize that even with a small deposit block model, as the number of periods will be large due to the short term basis required by the blending process, the size of the L.P. can become unmanageable rapidly. The present work is developed with a maximum solvable problem size of the order of 500 equations and 1000 variables, as constrained by the available L.P. computer code.

## 5.2 General Problem Formulation

### 5.2.1 Variable Definition

Following the mining practices for a multiple seam operation, a coal bearing block from the generated block model is extracted as composed of up to three independent blocks. An upper block that contains waste above the coal seam, a middle block that contains the coal seam and a possible lower block that contains only waste underneath the coal seam. First, the upper block is removed to uncover the seam; then, the coal is extracted, and, last, the lower part, if it exists, is extracted only if underlying coal blocks are to be uncovered.

The decision process relative to a coal block for the coal mining system of this thesis can be expressed as a decision tree as shown in Figure 5.1. Each decision corresponds to a variable in the formulation. The variables have been defined as follows:

$X_{ij}$  = % of a coal block  $i$  extracted, blended, cleaned and delivered during period  $j$

$Y_{ij}$  = % of waste above coal in a coal block  $i$  removed during period  $j$  (equivalent to the % of coal uncovered from the block  $i$  during period  $j$ )

$Z_{ij}$  = % of coal from a coal block  $i$  treated as waste during period  $j$

$V_{ij}$  = % of coal from a coal block  $i$  extracted and sent to the stockpile for the next period  $j+1$  in period  $j$

$R_{ij}$  = % of waste from a waste block  $i$  or % of waste underlaying coal in a coal bearing block  $i$  extracted in period  $j$

Initially, all the blocks in the P.B.M. are included in the formulation. Hence, a coal bearing block may have all the above variables associated with it, whereas only the "R" variable is assigned to waste blocks. Note that, for L.P. formulation purposes, only two types of blocks are

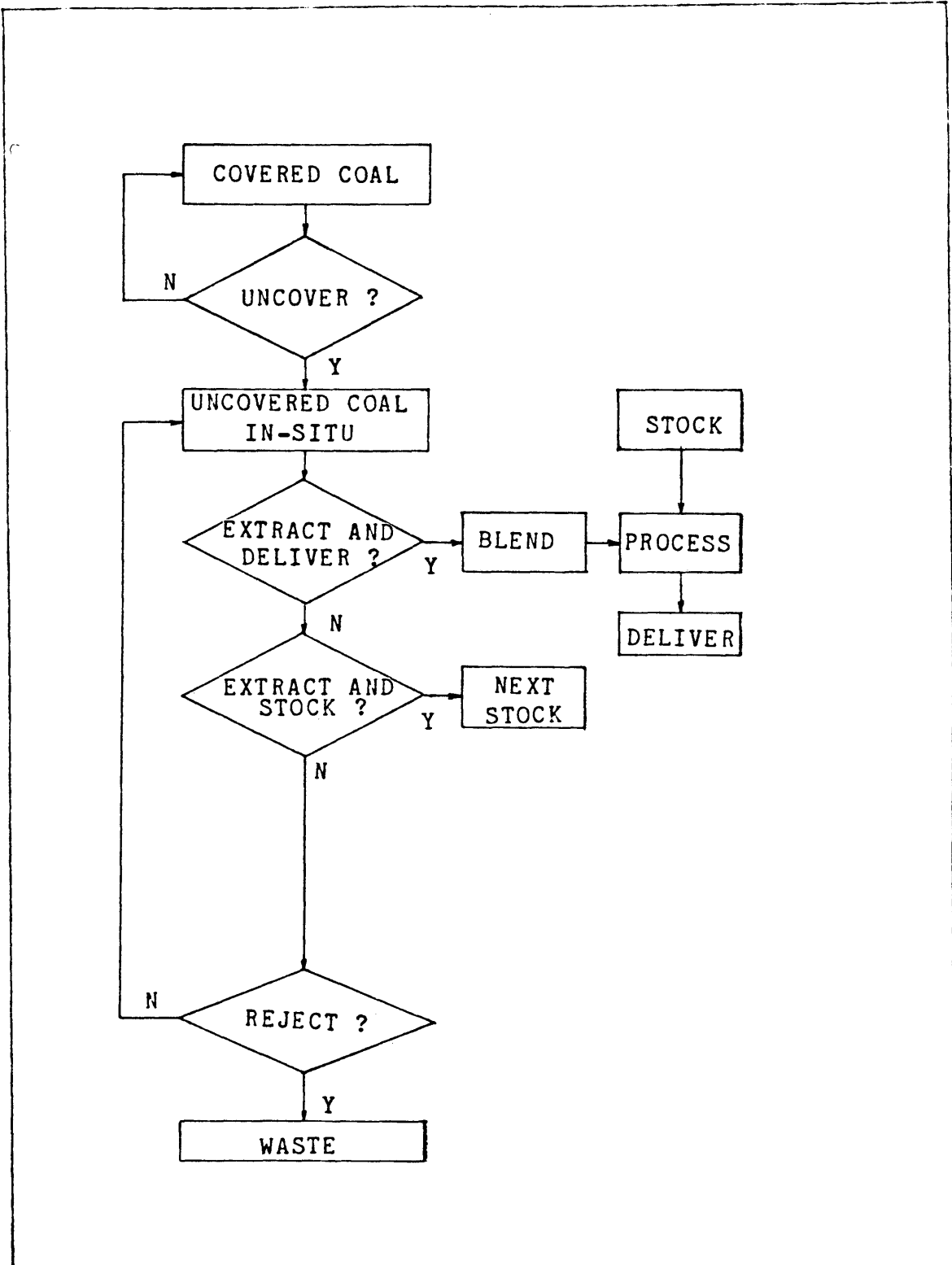


Figure 5.1. Diagram of the System's Decision Tree

considered: coal-bearing blocks, or "coal blocks", and blocks that contain waste but no coal. These variables are expressed on a range of values from 0 to 1. Note also that for coal blocks the following bounds apply:

$$0 \leq \sum_{i=1}^T Y_{ij} \leq 1$$

$$0 \leq \sum_{i=1}^T (X_{ij} + V_{ij} + Z_{ij}) \leq 1$$

$$0 \leq \sum_{i=1}^T R_{ij} \leq 1$$

where T is the total number of periods,  
and for waste blocks only the last equation is applicable.  
The physical meaning of the variables is illustrated in  
Figure 5.2.

### 5.2.2 Parameter Definition

The following parameters are included in the  
formulation:

$C_i$  = tonnage of coal in-situ in block i

$C'_i$  = tonnage of coal, after mining losses, block i

$C''_i$  = tonnage of coal, after mining and crushing losses,  
in block i

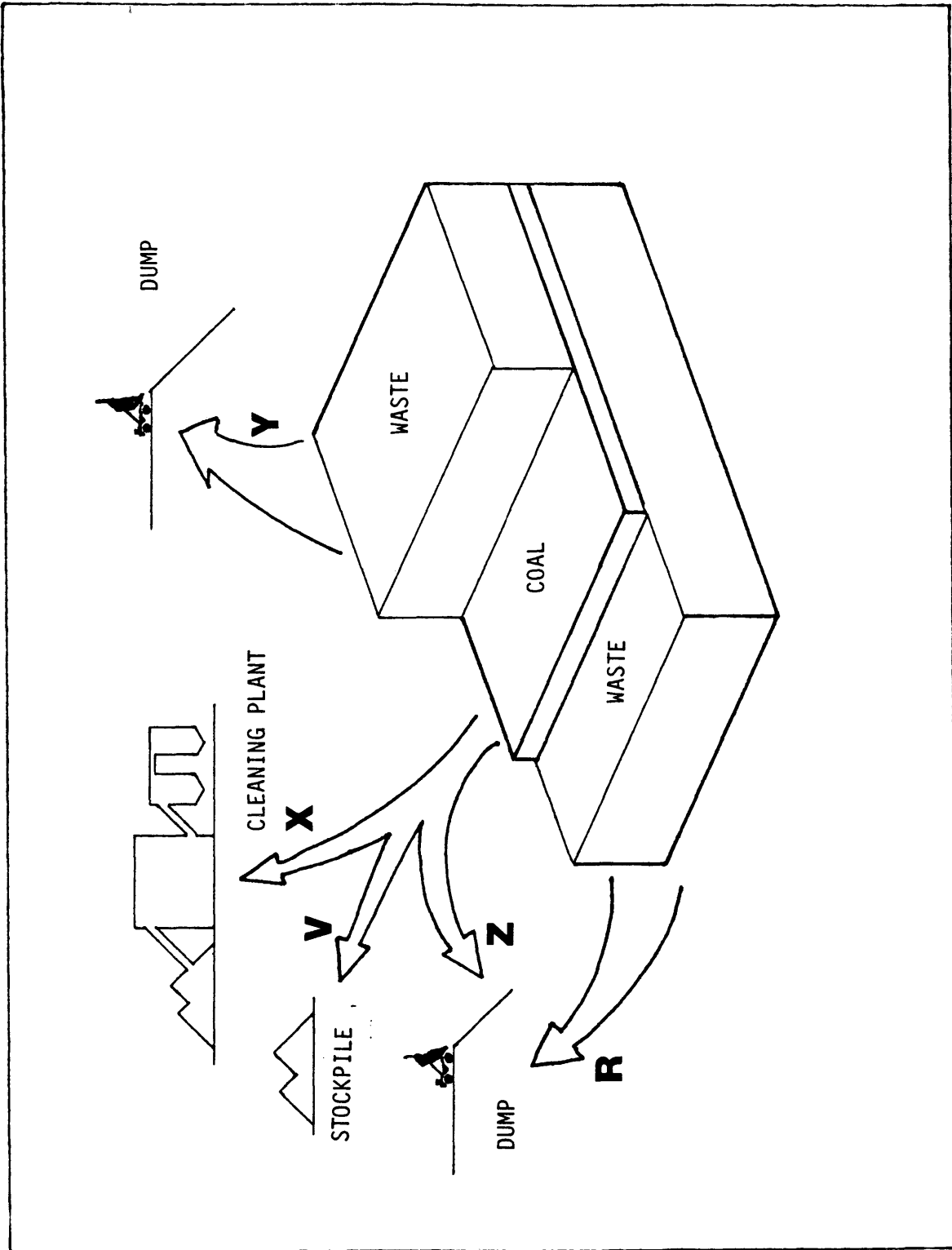


Figure 5.2. Definition of Variable Names

$A'_i$  = ash content, after mining losses, of block i

$A''_i$  = ash content, after mining and crushing losses,  
of block i

T = total number of time periods

P = required production (tonnes of clean delivered coal)

$W_i$  = volume of waste in block i (m<sup>3</sup>)

$W_{iy}$  = volume of waste overlaying coal in coal bearing  
block i

$W_{ir}$  = volume of waste underlaying coal in coal bearing  
block i

AMAX = maximum ash level allowed in the shipment

CMAX = maximum extraction capacity of coal mining equipment

WMAX = maximum waste removal capacity

UMAX = maximum limit of uncovered reserves

UMIN = minimum limit of uncovered reserves

PMAX = maximum treatment capacity of the coal  
crushing plant

STMAX = maximum stockpile capacity

STMIN = minimum stockpile reserves requirement

SW = waste swell factor

SC = coal swell factor

$d_i$  = coal density of block i (Tm/m<sup>3</sup>)

c = number of coal blocks

k = number of coal blocks not located at

the bottom of the deposit

l=number of coal blocks located at the  
bottom of the deposit

w=number of waste blocks

Note that, for each coal bearing block,  $W_i = W_{iy} + W_{ir}$

### 5.2.3 Formulation of the Constraints

Following the system's network as depicted in Figure 3.3, the constraints can be grouped into different categories:

- a) Production Demand
- b) Quality Requirements
- c) Equipment Capacities
- d) Crushing Plant Capacity
- e) Dump Progress
- f) Stockpile Capacity
- g) Uncovered Reserves
- h) Block Mining Sequencing
- i) Block Stripping Sequencing
- j) Block Capacity

each of them is formulated below:

#### a) Production Demand

The coal to be delivered in a time period  $t$  is the

tonnage of the coal extracted, blended and crushed during that period, plus the existing raw coal stockpiled from the previous period  $t-1$ , adjusted for mining and processing losses.

$$\sum_{i=1}^n X_{it} C_i'' + \sum_{i=1}^n V_{it} C_i'' = P \quad t=1, T$$

where  $n$  is the total number of blocks involved in the formulation.

Note: stockpiled coal can only be held for one period.

#### b) Quality Requirements

The quality requirements apply to the extracted coal during a given period, regardless of whether it is to be kept in the stockpile for the next period or shipped in the period considered. The actual form of these constraints depend on the contractual quality restrictions. As an example, an upper bound on the ash content of the delivered coal is written below:

$$\sum_{i=1}^n X_{it} C_i'' (A_i'' - A_{MAX}) \leq 0 \quad t=1, T$$

$$\sum_{i=1}^n V_{it} C_i'' (A_i'' - A_{MAX}) \leq 0 \quad t=1, T-1$$

Note that a separate equation requires the stockpiled coal to comply with the contract quality demand. This formulation is adopted to ensure that the stockpiled coal is always ready to be fed into the cleaning plant and yield a marketable product. Hence, the stockpile acts as a buffer that provides the mining operation some slack time in case of major equipment failures that would compromise the coal delivery.

c) Equipment Capacities

There are as many constraint equations as there are types of equipment:

Coal Removal

These equations apply to coal extracted during the period  $t$ . Tonnages are reduced by the mining losses:

$$\sum_{i=1}^n (X_{it} + V_{it}) C'_i \leq CMAX \quad t=1, T$$

Waste Stripping

Stripping equipment removes waste as well as rejected coal. The capacity of the equipment is measured in bench volume; therefore, no correction for any losses are necessary here.

$$\sum_{i=1}^W R_{it} W_i + \sum_{i=1}^C W_{ir} R_{it} + \sum_{i=1}^C Y_{it} W_{iy} + \sum_{i=1}^k Z_{it} C_i / d_i \leq WMAX \quad t=1, T$$

where k is the number of coal blocks that include the "Z" variable and are not located at the bottom of the pit.

d) Crushing Plant Capacity

These equations apply to mined coal, after mining losses have been considered.

$$\sum_{i=1}^C X_{it} C'_i + \sum_{i=1}^C V_{it-1} C'_i \leq Pmax \quad t=1, T$$

e) Dump Progress

The volume of material to be spoiled is that of rejected coal and of removed waste, both affected by their swell factor.

$$D + \sum_{p=1}^t \left[ \sum_{i=1}^1 (X_{ip} + V_{ip} + Z_{ip}) DI_i - SW \left( \sum_{i=1}^C Y_{ip} W_{ip} + R_{ip} W_{iy} \right) + \sum_{i=1}^W R_{ip} W_i - \sum_{i=1}^k Z_{ip} C_i / d_i \right] \geq 0.0$$

for t=1, T

where k is defined as above, and l is the number of blocks at the bottom of the pit. D is the initial dump space available after the preproduction period.

Note that only the blocks at the bottom of the pit increase the spoil room when they are extracted or left in situ, rejected. The values  $DI_i$  represent the dump room increment that results from the extraction of those blocks. The calculations of  $DI_i$  is done on a two dimensional basis, as depicted in Figure 5.3. This value is adjusted by the last term in the equation  $(-CW \sum_{i=1}^k Z_{ip} C_i / d_i)$  in case that a portion of the block is left in situ.

f) Stockpile Capacity

Upper and lower bounds on the raw coal stockpile reserves are specified. The amount of coal is measured after mining losses.

$$\sum_{i=1}^n V_i C'_i \leq STMAX \quad t=1, T$$

$$\sum_{i=1}^n V_i C'_i \geq STMIN \quad t=1, T$$

g) Uncovered Reserves

The uncovered reserves also have upper and lower limits. The reserves can be expressed in terms of cleaned coal, accounting for mining and cleaning losses.

$$U + \sum_{p=1}^t \left( \sum_{i=1}^c (Y_{ip} - X_{ip} - V_{ip} - Z_{ip}) C''_i \right) \leq UMAX \quad t=1, T$$

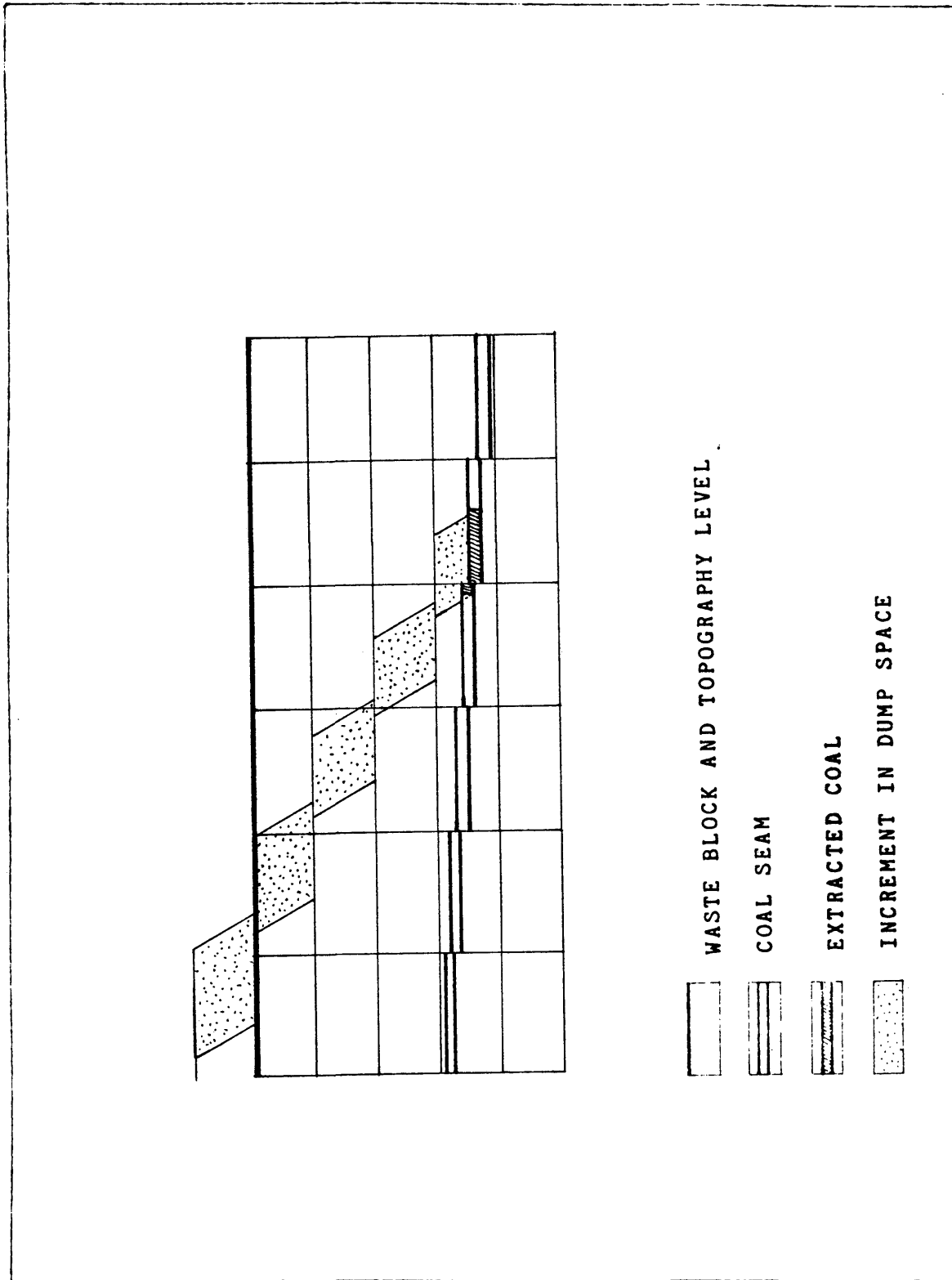


Figure 5.3. Dump Space Increment by Extracting a Coal Block from the Bottom of the Pit

$$U + \sum_{p=1}^t \left( \sum_{i=1}^c (Y_{ip} - X_{ip} - V_{ip} - Z_{ip}) C_i^n \right) \geq U_{MIN} \quad t=1, T$$

Where  $U$  represents the available uncovered reserves at the end of the pre-production period.

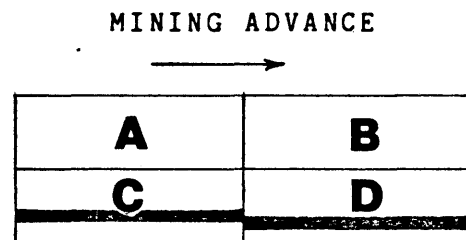


Figure 5.4. Two-Dimensional Representation of the Blocks Stripping Sequence

#### h) Stripping Sequencing

The mining process advances in a horizontal manner, mining the deposit in one pass. This fact determines a basic stripping sequence as pictured in Figure 5.4, on a 2-D basis, on a vertical plan parallel to the mining advance orientation. In this Figure, waste blocks A and B have to be fully extracted to uncover coal from block D. Also, coal

from block C has to be previously uncovered - not necessarily extracted - before exposing coal from block D.

This sequence can be approximated by a set of linear equations as follows.

1) for the sequence between same level blocks:

$$\sum_{p=1}^t Y_{jp} - \sum_{p=1}^t Y_{ip} \geq 0 \quad t=1, T$$

Where j is a block previous in sequence to i

2) for different level blocks:

If j is a waste block, then

$$\sum_{p=1}^t R_{jp} - \sum_{p=1}^t R_{ip} \geq 0 \quad t=1, T$$

If j is a coal block, then

$$\sum_{p=1}^t (X_{jp} + V_{jp} + Z_{jp}) - \sum_{p=1}^t R_{ip} \geq 0 \quad t=1, T$$

Where j is a block previous in sequence to i.

1) Mining Sequence

This concept involves two sequences: an extraction sequence within each coal block, or "block sequence", and an extraction sequence between consecutive blocks, or "mining

extraction sequence".

1) block sequence

A block has to be fully uncovered before it is extracted:

$$\sum_{p=1}^t (X_{ip} + V_{ip} + Z_{ip} - Y_{ip}) < 0 \quad t=1, T$$

and also:

$$\sum_{p=1}^t (X_{jp} + V_{jp} + Z_{jp}) - \sum_{p=1}^t R_{ip} \geq 0 \quad t=1, T$$

2) mining extraction sequence

A coal block has to be fully used -extracted and/or rejected- in order to let subsequent blocks to be used.

This requirement is approximated by:

$$\sum_{t=t_1}^{t_2} (X_{jt} + V_{jt} + Z_{jt}) - \sum_{t=t_1}^{t_2} (X_{it} + V_{it} + Z_{it}) \geq 0 \quad t=1, T$$

j) Block Capacity

Only 100% of a block can be extracted.

$$\sum_{t=1}^T R_{it} < 1$$

$$\sum_{p=1}^t Y_{it} < 1$$

$$\sum_{t=1}^T (X_{it} + V_{it} + Z_{it}) < 1$$

Where T is the total number of periods

#### 5.2.4 Formulation of the Objective Function

The objective function of this model is to maximize the resource extraction. This is achieved by optimizing the blending of high and low quality coal blocks from the various seams of the deposit. This is expressed in terms of maximizing the coal that complies with the required quality bounds.

The Objective Function can be written as :

$$\text{Max } Z = \sum_{i=1}^n \sum_{t=1}^T C^i (X_{it} + V_{it})$$

#### 5.2.5 Problem Size Determination

The size of the problem, as formulated above, is now estimated to evaluate its solution cost and assess its computing feasibility.

The total number of variables can be estimated as:

$$V = (3.25N + M)T \text{ variables, where } N \text{ is the number of}$$

coal blocks,  $M$  is the number of waste blocks and  $T$  is the number of time periods considered in the formulation. Note that, as an initial estimate, only 25% of the coal blocks are assumed to have quality values below rejection and require the variable  $Z$ .

Also, the number of constraints is closely related to that of the variables and it can be estimated by:

Type of constraint	number
a) Maximum capacity of processing plant	(T)
b) Maximum capacity of overburden removal	(T)
c) Bounds in quality of stockpiled coal	(2QxT)
d) Bounds in quality of delivered coal	(2QxT)
e) Dump progress	(T)
f) Sequence of extracting a waste block	(2MxT)
g) Sequence of uncovering a coal block	(2NxT)
h) Sequence of extracting a coal block	((N+2N)T)
i) Coal block capacity	(N)
j) Waste block capacity	(M)
k) Maximum capacity of coal removal equipment	(T)
l) Bounds in quantity of produced coal	(2T)
m) Bounds in quantity of uncovered coal	(2T)

where  $Q$  is the number of quality parameters included in the constraints.

Therefore, the total number of constraints is:

$$C = 8T + 4Q \times T + N + M + 2M \times T + 5N \times T$$

A quick estimate of the proposed scheduling problem can now be made for a medium-size coal deposit. Assuming that the block model includes 3,000 coal blocks and 15,000 waste blocks, the mining operation has an expected life of 10 years, and that only one quality parameter is included in the formulation, then:

$$T = 12 \times 10 = 120$$

$C = (8 \times 120 + 4 \times 120 + 3,000 + 15,000 + 2 \times 15,000 \times 120 + 5 \times 3,000 \times 120 =$   
5,419,440 constraints and

$$V = 120 \times (3.25 \times 3,000 + 15,000) = 2,790,000 \text{ variables.}$$

This problem is unsolvable as it is. There are several procedures to reduce the size of the problem. Some sophisticated mathematical techniques, such as Dantzig-Wolfe Decomposition, may be used to subdivide large problems into smaller ones so that they can be handled separately without affecting the optimality of the original problem (Lasdon, 1970). However, these techniques are not discussed here as they require high limits of both time, effort, and economic resources.

Other procedures are based on increasing the block size, or aggregating blocks. However, a disadvantage of aggregating blocks resides in the fact that less blocks will

be included in the solution. If the number of blocks scheduled for each period is small, the solution technique loses flexibility, the marketable reserves calculation loses accuracy, and the modelled mining operation does not reflect the selectivity that is realized in practice. In addition to that shortcoming, the model data base becomes less accurate since block values are averaged. This presents considerable inaccuracies, particularly in the case of blocks near faults or boundaries. Not all the blocks have to be aggregated, however. In some aggregation approaches, all the mining periods are run simultaneously, but the initial periods are short, and the rest of them are much larger. By doing so, the L.P. yields a short term solution for the initial mining periods, and long term solution for the rest of the deposit. This process allows increasing the size of the blocks that are included in the formulation for the long term solution, by aggregation of smaller blocks.

In order to obtain a short term mining schedule throughout the life of the mine, the data files are updated after the run by eliminating the blocks that are included in the short term schedule, and rerunning the problem for the rest of the deposit in a similar fashion.

In this way, the problem size is largely reduced. This

technique, however, presents the following drawbacks:

1) The representation of actual tonnages and quality values of the long term, aggregated blocks is less accurate, as in the previous approach.

2) In order to reduce the problem size, the long term part of the plan has larger periods, on the order of years. This is required to attain a considerable size reduction. This could result in requiring the blending of blocks that may not be reachable simultaneously. With this pitfall the validity of the obtained optimal solution for the overall operation is seriously questioned.

As an alternative to these aggregating techniques, the author suggests the following steps to reduce the problem size by analyzing the formulation: a) eliminate the waste blocks from the formulation, b) reduce the number of coal blocks that can be allocated to any time period, c) reduce the time periods that are solved simultaneously, and d) eliminate the superfluous and inefficient constraints. These measures are discussed and justified in the following discussion.

### 5.3 Eliminating the Waste Blocks

Waste blocks appear in the formulation in the waste

stripping, dump progress, stripping sequence, mining sequence, and block capacity constraints. In the example of subsection 5.2.5, they contribute 3,615,000 equations, or 66.7% of all the equations of the formulation. Hence, their inclusion in the formulation deserves further analysis.

The mining process involves some strict restrictions concerning the block extracting sequence. These restrictions refer to the mining method, local mining practices, and slope angles. The way the extraction sequence is approximated by an L.P. formulation is:

$$X_j > X_i \quad \text{for all } X_j \text{ directly above } X_i$$

Including the waste blocks into the formulation allows direct waste removal accounting and a more accurate pit geometry output in the L.P. solution. It is the author's viewpoint, however, that the price to be paid for this is too high, considering that even more accurate calculations and control of waste removal and spoil advance can be done by a subsequent simulation model. This simulation model calculates the stripping requirements throughout the life of the mine and generates stripping and dump benches as the mining progresses, as explained in subsection 4.5.

The formulation developed herein eliminates the waste

blocks. The sequencing equations refer exclusively to coal blocks that are to be uncovered or extracted prior to removing any coal block below. In Figure 5.5 the sequence

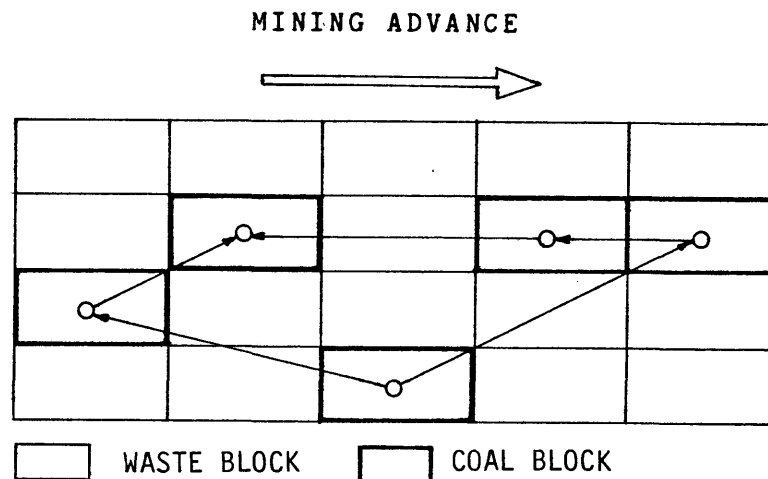


Figure 5.5. Example of Two-Dimensional Stripping Relations Between Coal Blocks

relations are shown as arrows. Notice that for simplification, the sequence equations have been formulated only in two dimensions, on a vertical plan parallel to the direction of advance. By doing so, the extracting sequence is less restricted and the solution gains flexibility. The only disadvantage with this method is that several complex search subroutines have to be used in the matrix generation program, thus increasing its computational cost.

The elimination of waste blocks from the formulation

removes the block capacity and stripping sequence constraints related to waste blocks. The waste stripping capacity and dump progress constraints require some estimate of the waste to be stripped and dumped. It will be assumed here that the waste stripping capacity is adequate to handle what is required in the optimal plan. In most surface coal mines the stripping equipment is selected so that it is capable of uncovering sufficient coal to meet the desired production rate.

A similar situation is found with the dump advance constraints. Since these constraints use the allocated waste volumes referred to above they may also be dropped from the formulation.

Since the uncovered reserves constraints are no longer included in the formulation, the Y variable is no longer needed. The good-quality coal blocks - those in the ready acceptance quality range - remain with the variables X and V, and the poor-quality blocks - rejectable unless properly blended -, have the variables X, V, and Z.

Hence, by eliminating the waste blocks from the formulation, the problem size is considerably reduced. Not only is the number of variables is reduced, but also the number of constraints associated with them.

#### 5.4 Reducing the Number of Coal Blocks to be Allocated to Any Time Period.

Due to the continuous advance of the mining face, some time limits can be presumed for the extraction of each coal block. The idea is to find which blocks can be allocated to a given time frame for mining, from a practical standpoint.

This time frame allocation is performed during the L.P. matrix generation, taking into consideration the average tonnage of a coal block, the production requirements, and the mining advance procedures. Thus, the size of the problem is again considerably reduced, since each coal block now generates only a small number of original variables.

#### 5.5 Reducing the number of Periods Solved Simultaneously

As it has been shown above, the problem size is greatly increased by  $T$ , the number of periods in the mine life. This number is necessarily large because of the short term schedule needed. The question that arises is: Is it absolutely necessary to solve for all of them simultaneously?

Initially the general answer is affirmative, as

selecting a set of blocks to be uncovered or mined in a given time period may have a significant effect upon the plans of future mining periods. However, in haulback coal mining operations, the time frame during which a coal block may be extracted is severely restricted by the advance of the waste dump. This limits considerably the effect of whatever is extracted during a given period and what is extracted few periods later, even when the periods are on the order of weeks.

Thus, the overall planning problem is broken into several L.P. smaller problems that concern only a limited time span and a limited section of the deposit. The portion of the deposit considered should include more coal reserves than those that are attempted to be extracted. In order to recognize how much coal is available from each block to the next run, a parameter is introduced. This parameter is updated after each L.P. run and it serves as a link between consecutive L.P. runs. This parameter,  $a_i$ , represents the amount of coal from block  $i$  that has been extracted by the end of the L.P. run.

The block capacity constraints become

$$\sum_{t=t_1}^t (X_{it} + V_{it} + Z_{it}) \leq 1 - a_i \quad \text{for all } i$$

where the variable  $Z$  is only included for poor coal blocks and  $t_1$  and  $t_2$  represent the time period limits considered in the formulation. Along with these parameters, the existing stockpile reserves must be calculated at the end of each run, to use them as input for the next run.

However, a suboptimal solution may occur in which some coal is rejected because of the excess of better coal present. To avoid this situation, the last period of the run is not constrained for production. Coal from this run will be fed into the next run. Thus, an overlapping portion of the deposit is established between runs.

This approach also forces a change in the objective function formulation. As the production of each period is restricted and more coal than needed is present in the portion of the deposit being considered, to express the objective function as to maximize resource utilization as in 5.2.4 becomes meaningless. If such formulation is maintained, the L.P. algorithm will tend towards the extraction of coal blocks based on the tonnages they have, with no consideration in maximizing the usage of poor-quality blocks. If the objective function is expressed in terms of maximizing the tonnage of only poor-quality blocks, a similar situation is encountered: poor blocks may be treated as waste and even poorer blocks may be included

in the solution just because they contain more tonnage. The objective should be expressed exclusively in terms of quality. Furthermore, some preference should be given to any block with respect to lower-quality blocks, so that the wasted coal is guaranteed to be the worst in quality. This is accomplished by assigning priority coefficients to the different variables of each block. The priority values given are a function of the location of the block and its quality. The rank of priorities assigned to the blocks are as follows:

- 1) Extraction of good quality blocks (variables X,V)
- 2) Extraction of poor quality blocks (variables X,V)
- 3) Rejection of poor quality blocks (variable Z)
- 4) Rejection of good quality blocks (variable Y)

Within each category, a slightly higher priority is assigned to blocks toward the center of the seam, so that if a block is rejected it is better if it is located at the seam boundary.

The categories 1 and 2 are assigned positive priorities (bonuses), whereas the categories 3 and 4 have negative priorities (penalties). There are three orders of magnitude difference between 1 and 2, and 3 and 4 respectively, to ensure that no good quality block is rejected. All good quality blocks have the same priority coefficient, while

poor quality blocks priorities vary within two orders of magnitude with respect to each other. This variation depends on the coal quality (two orders of magnitude) and the block location (one order of magnitude). An example of this coefficient allocation is included below.

First, a reference quality value is established. This value,  $Q$ , is selected so that the difference in absolute value  $(Q - q_i)$  increases with the quality value of a coal block. If the coal economic value increases as the parameter decreases (case of ash content),  $Q$  is selected larger than any possible value of the parameter, and the difference is calculated as  $(Q - q_i)$ . On the contrary, if the quality increases with the value of the parameter (as in BTU content),  $Q$  is selected lower than any possible value of the parameter, and the difference corresponds to  $(q_i - Q)$ .

Second, a deposit centerline is determined. This is expressed as a column number  $-CL_i-$  of the block model, on plan view, as shown in Figure 5.6.

If "i" is a poor quality coal block, it enters the objective function with a priority coefficient as

$$(B(Q - q_i) - (CL_i - C_i))(X_i + V_i - Z_i)$$

where  $q_i$  is the quality of the block and  $C_i$  is the column

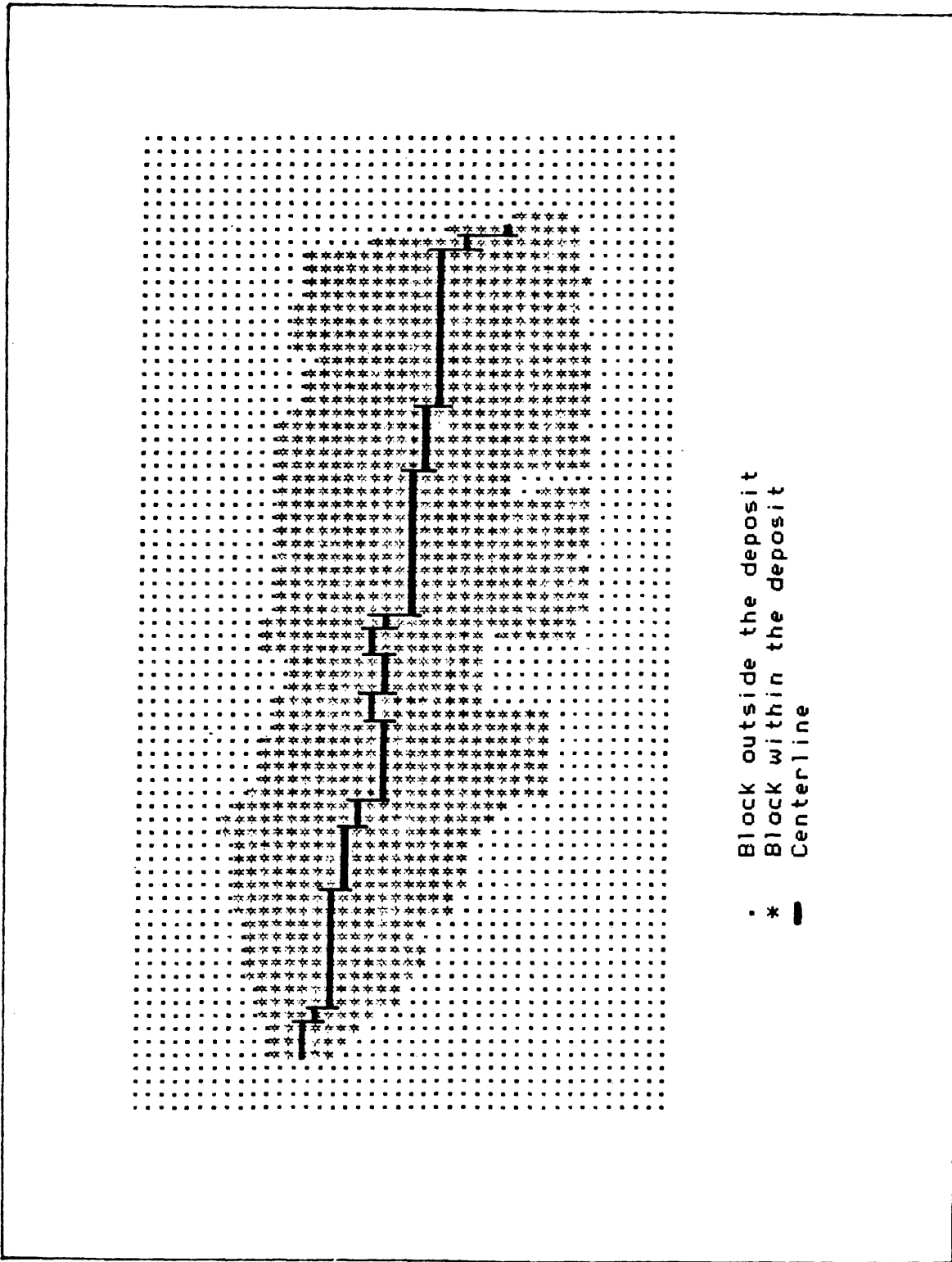


Figure 5.6. Illustration of the Block Model Centerline

number that expresses its location within the deposit. Both subtractions  $(Q-q_i)$  and  $(Cl-C_i)$  are expressed in absolute values.

If "i" is a good quality coal block, its objective function coefficients are

$$A(X_i + V_i + Z_i)$$

where A is a large number, equal for all good quality blocks. The parameters A and B are selected such that there are at least three orders of magnitude between the coefficients of good and poor coal blocks, and one between  $B(Q-q_i)$  and  $(Cl-C_i)$ . The objective function now may be expressed in terms of maximizing the total priorities.

$$\text{Max } F = \sum_{i=1}^c \sum_{t=1}^T \text{Priority}(X_{it} + V_{it} + Z_{it})$$

With this formulation the better quality coal blocks have preference over lower quality coal blocks, as it would be in practice.

## 5.6 Eliminating Superfluous and Inefficient Constraints

Finally, one more way that the system of equations can be simplified is by the elimination of redundant

constraints. These are equations that are linear combinations of others or equations that do not effectively define the set of possible feasible solutions.

The elimination is done by a search algorithm included in the matrix generator.

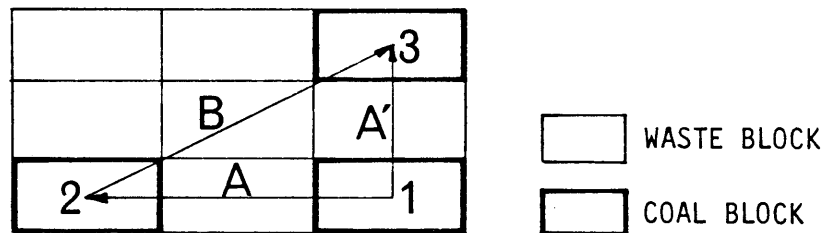


Figure 5.7. Example of Redundant Sequence Constraints

An example is illustrated in Figure 5.7: The mining sequence constraints are represented by arrows. The arrows A and A' apply to block 1, but, in fact, A' can be dropped from the formulation since it is already implied by B.

Some of the capacity constraints, as formulated above, become redundant and they may be eliminated from the

formulation: The sequence constraints are expressed as:

$$(1) \sum_{t=t_1}^t (X_{jt} + V_{jt} + Z_{jt}) + a_j \cong \sum_{t=t_1}^t (X_{it} + V_{it} + Z_{it}) + a_i$$

and the block capacity constraints are

$$(2) \sum_{t=t_1}^t (X_{it} + V_{it} + Z_{it}) \leq 1 - a_i$$

Therefore, the expression (2) applicable to the block  $i$  may be eliminated, as it is implied by (1) and the capacity constraint for block  $j$ .

This procedure classifies the blocks into those that need the block capacity constraints - independent blocks - , and those that do not - dependent blocks-. Physically, an independent block is that block which is directly accessible without the need to uncover or remove any other coal blocks. In practice , this classification procedure is performed on a 2-D basis, on the same plan that the sequence relationships are defined.

This classification is done in a subroutine of the matrix generator program, and eliminates a considerable number of constraints, thus improving the efficiency of solving the L.P.

### 5.7 The Non-integral Problem

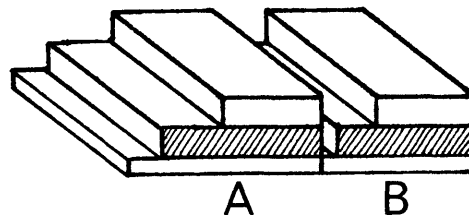
Among the constraints included in the L.P. formulation, the sequencing constraints become crucial in the feasibility of the solution obtained. This set of equations sets up a sequential extraction of the blocks, as formulated in subsection 5.2.3. The practical feasibility of the constraints demands integer solutions in some cases. Let us consider a two-dimensional block model and let  $X_i$  be the % of block  $i$  being extracted. The linear equation that approximates the sequence condition is:

$$\sum_{p=1}^T X_{jp} \cong \sum_{p=1}^T X_{ip}$$

where  $X_j$  is any block that has to be mined directly before  $X_i$ . The Figure 5.5 on page 48 shows the sequence pattern. The arrows show the block mining relationships: the head end of an arrow is at a block that has to be extracted prior to the block at the tail of the arrow.

The solution depicted below, in Figure 5.8, represents a mathematically feasible solution, but it is not feasible from a practical standpoint.

This problem of practical infeasibility has been addressed often in the literature (Johnson, 1969; Gershon, 1982). In some cases, special formulation structures show a



	uncovered	extracted
A	50%	20%
B	30%	10%

Figure 5.8. Example of a Mathematical Feasible  
Solution Impractical in its Implementation

particular property called unimodularity. This property is derived from the structure of the L.P. matrix and the problem always yields an integer solution. Unfortunately, this situation does not apply to the formulation of the problem discussed here. Thus, the risk of practical infeasibility exists.

One way of eliminating this infeasibility in the formulation is to constrain some variables to be integers. The problem becomes of mixed-integer character, with the unwanted disadvantages explained in subsection 4.4.

Another procedure is by computer checking on infeasibilities and subsequent modifications, if required,

of the L.P. solution. This is performed by a computer program that is run after each L.P. execution. The program makes the sum  $(X+V+Z)$  that is associated with each block equal to zero or one, with the exception of the blocks that form the final mining face of each mining period. The program also checks that the quality requirements are met. The changes in the L.P. solution are performed following engineering guidelines and criteria, such as bench geometry and equipment operating room. Such a procedure is feasible, but its heuristics may affect the optimality of the overall solution. Also, it is required to check every time period, and that becomes cumbersome. A third approach to this problem is based on a different formulation of some constraints.

The non-integral problem is approached based on the assumption that any block that is considered in the formulation is fully utilized. This means that, if a poor quality block can not be fully blended within the time frame considered in the formulation, whatever is left from blending is rejected. This assumption agrees with reality, and it is taken except for the last period of the run. In this period, if any block is not fully mined and it is accesible at the mining face, it can be used in the next run.

If the sum of all the variables of each blocks is forced to take the value of 1, the solution becomes integer. To make the sum of all variables equal to one it is not necessary to add a constraint for each block that explicitly says that. The blocks that are the last ones to be at least partially mined are called "tail blocks". To make the sum of all the variables of each block equal to one only requires the sum of the variables assigned to the tail blocks to be one. Therefore, the following constraints are added:

$$\sum_{t=t_1}^t (X_{it} + V_{it} + Z_{it}) = 1 \quad \text{for all tail blocks}$$

This way, the non-integer problem is solved at the L.P. stage, without requiring further manipulation of the L.P. solution. This solution, however is not obtained on a monthly basis, but on the basis of the total time frame allocated to each block. Nevertheless, several considerations lessen the risk of infeasibility. First, the risk of obtaining a non-integral solution increases with the number of periods assigned to each block (block time frame). In the approach discussed in this thesis only a few periods are assigned to each block (typically three or less), thus the probability of obtaining a non integral solution is

relatively low. Second, some non-integer solutions do not represent practical infeasibility, as the examples depicted in Figure 5.9. In this Figure, coal blocks show the percentage of extraction. The solution depicted here is not integer, but as the non-integer blocks are found next to the pit wall at the time of extraction, it is an operational feasible outcome. In addition to that fact, the relatively big difference, on the orders of magnitude of the coefficients of the variables included in the objective function, aids in achieving the result of an integer solution. Also, due to the flexibility of the coal extraction equipment, non integer solutions that involve blocks on the same bench may not be practically infeasible. An initial trial was performed in the case study to check the need for developing a computer program to modify the proposed Linear Programming solution in case of practical infeasibility, but that case was not encountered or could be solved by reassigning some of the block time frames. In any case, this approach will reduce the probability of encountering the non integral infeasible problem and it could always be used as a guideline for the short term production plan.

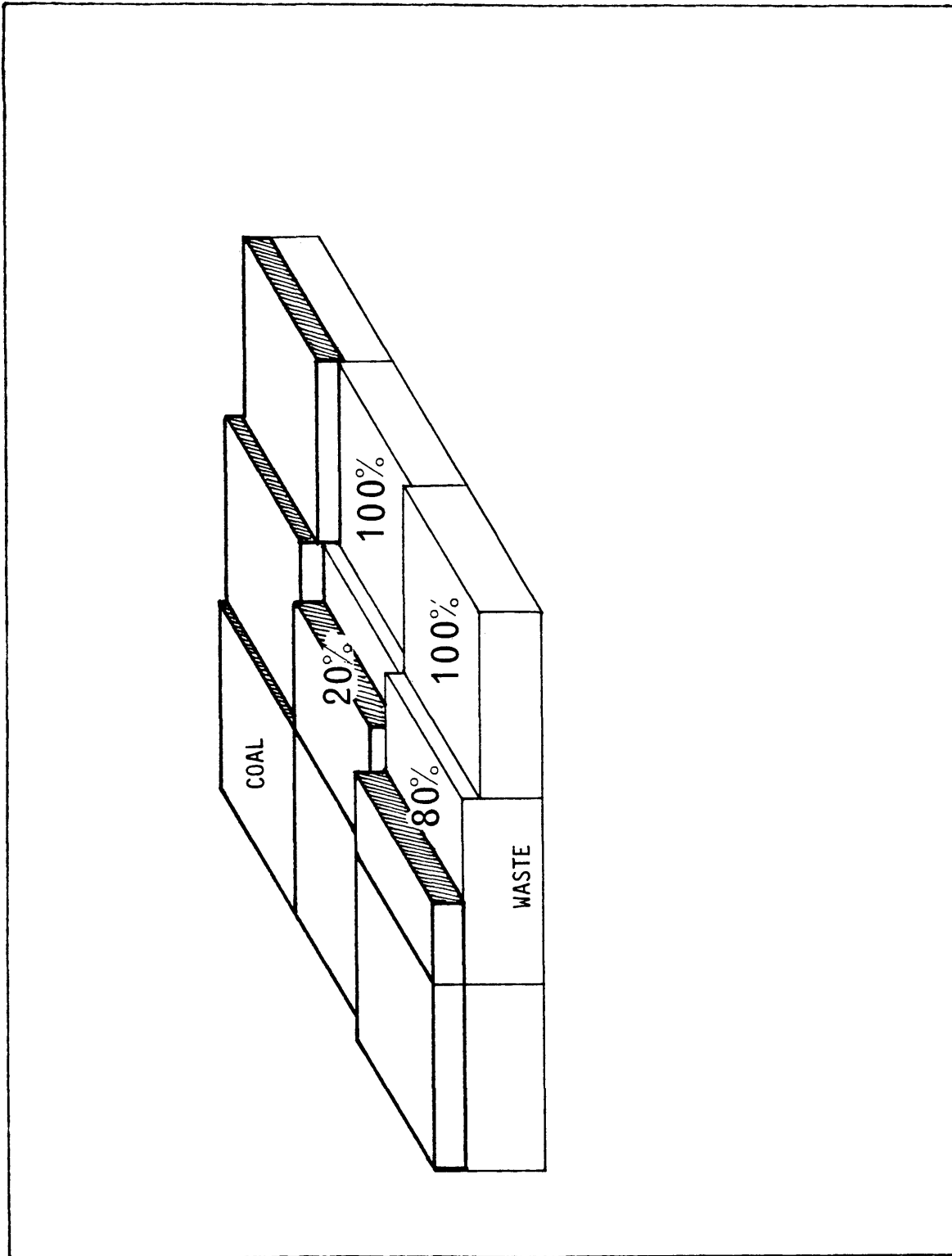


Figure 5.9. Example of a Non-Integral Solution That Is Practically Feasible

### 5.8 Final Formulation of the Blending Problem

After all the above considerations, the L.P. formulation is reduced to the following set of equations:

$$\text{Max } F = \sum_{i=1}^c \sum_{t=1}^T \text{Priority}(X_{it} + V_{it} + Z_{it})$$

subject to:

a) Production demand

$$\sum_{i=1}^n X_{it} C_i'' + V_{it} C_i'' = P \quad t=1, T$$

b) Production Quality Requirements

$$\sum_{i=1}^n X_{it} C_i'' (A_i'' - A_{\max}) \leq 0 \quad t=1, T$$

c) Mining Sequence

$$\sum_{p=1}^t [(X_{ip} + V_{ip} + Z_{ip}) - X_{ip} - V_{ip} - Z_{ip}] \geq a_i - a_j \quad t=1, T$$

for j before i.

d) Block Capacity

$$\sum_{i=1}^n (X_{it} + V_{it} + Z_{it}) = 1$$

for all  $i$  that are tail blocks

$$\sum_{t=1}^{t_2} (X_{it} + V_{it} + Z_{it}) \leq (1 - a_i)$$

for all independent  $i$

e) Raw Coal Stockpile Requirements

$$\sum_{i=1}^n V_{it} C'_i \geq \text{STMIN} \quad t=1, T$$

for all  $i$

$$\sum_{i=1}^n V_{it} C'_i \leq \text{STMAX} \quad t=1, T$$

for all  $i$

$$\sum_{i=1}^n V_{it} C''_i (A''_i - \text{AMAX}) \leq 0 \quad t=1, T$$

for all  $i$

## 5.9 Matrix Generator

The practical implementation of a large set of L.P. runs resides in the creation of a computerized L.P. matrix generator. The program LP.XF4, written by the author in FORTRAN IV, generates the data files for the formulated problem. It is partially interactive. The user supplies information about the bounds of the deposit that delimit the area of interest, and initializes variables as production

rate, number of periods to be run simultaneously, and existing stockpile reserves.

The program performs the following operations:

- 1) loads data from data files
- 2) selects the coal blocks within the area of interest
- 3) displays statistics concerning tonnages and quality of the selected coal blocks
- 4) searches for block sequence relationships
- 5) determines the independent blocks
- 6) determines the tail blocks
- 7) assigns a time frame to each block
- 8) writes the headings of the output files
- 9) calculates and writes the coefficients of the equations of the first tableau
- 10) calculates and writes the coefficients of the objective function

Finally, the program provides the user with the number of equations, number of constraints, and number of non-zero elements in the formulation, as these data are needed for executing the L.P. run with the available package (MINOS, of COMPUERVE. Inc).

The output data is written in six separate files simultaneously. These files have to be merged together in a

certain order to be read by MINOS. The output is written in Mathematical Programming System (MPS) standard format. The program listing is included in Appendix 3.

#### 5.10 Report Generator

After each L.P. run has been performed, an updating program is executed. This program is referred to as the Report Generator, and it performs the following tasks:

- 1) reads the L.P. solution.
- 2) generates a report that includes statistics on tonnages and quality of delivered, stockpiled, and rejected coal.
- 3) generates, by user request, a printer plot, by bench and by period, showing the mining advance and approximate percentage of each block that is either rejected or extracted, or both.
- 4) analyzes the solution, selecting the blocks that are accessible at the mining face at the end of the previous-to-last mining period.
- 5) updates the deposit status file, where the status of each block (totally mined or with some coal available). and an identification code by seam are recorded.
- 6) updates the coal availability file, where the actual

available tonnages of each block are stored.

7) stores the values of the non zero variables of the solution in a history file that records the mining advance and utilization of reserves by the end of each period.

The program ,REPORT.XF4 has been written by the author in FORTRAN IV and its listing is included in Appendix 5, and a sample run is included in Appendix 6.

#### 5.11 Solution Technique for the Dump Advance and Stripping Allocation Problem

Three major subproblems are approached here. First, coal blocks to be uncovered by the end of each period have to be determined. These coal blocks represent the equivalent to two to three months of production, or as required by the company's policy. Second, the stripping advance by bench is calculated so that the variations of equipment requirements period by period are minimized. Third, the subproblems above have to be coordinated with the dump advance rate. This means that the volume of waste removed must fit in the available spoil room as calculated under the current mining practices and law requirements. This is a desirable objective to be met whenever possible to avoid rehandling, although outside dumping may be practiced

in some instances.

The data base used to solve this problem is the history file as defined above. This file stores the short term production plan that maximizes the utilization of reserves. Therefore, the blocks that constitute the marketable reserves are known. From these data, the model of the deposit is reconstructed, reclassifying coal blocks as waste if they are not part of the marketable reserves. Then, the pit is generated again based only on the marketable reserves. The pit defined now is the final pit for the proposed plan.

As the mining face of each seam is known at the end of each period, an allocation of coal blocks to be left exposed at the end of the period can be done. This allocation can be performed by a computer program that simulates the stripping advance from the mining face following the required operating slopes and uncovers the lower and upper bounds of the uncovered reserves. The algorithm gives high priority to uncovering coal from lower benches whenever possible, as it minimizes the haulage distances by making a more compact opening. Also, bench geometry is kept as straight as possible to maximize the equipment productivity. Note that, for the preproduction period the minimum reserves will be uncovered as an early production start will maximize

the net present value of the operation.

Once these coal block allocations are made, the required waste volume to be stripped is calculated. Consequently, the volumes calculated represent the lower bound of waste removal that provide the minimum exposed coal reserves. Let  $W_t$  be the value obtained for period  $t$ .

A similar process is carried out to calculate the maximum available dump space at the end of each period. From the short term plan, the mining face at the end of each period is known. With this data, the dump space at the end of each period can be calculated. The calculations of the dump advance must be done observing the local mining practices and rock conditions, such as dump bench berm and height, waste angle of repose, minimum equipment operating room at the toe of the dump and maximum allowed dump elevation over the original topography. Let  $D_t$  be the dump advance volume as defined above for the period  $t$ .

With these data, the problem can be solved using Linear Programming techniques.

Let  $X_t$  be the stripping volume to be allocated to the period  $t$ , and  $T$  the total number of periods. The objective is to minimize the deviation of the stripping requirements of one period,  $X_t$ , from the next  $X_{t+1}$ . Two variables are added per each original variable,  $X$ . These new variables are such

that

$$X_t - X_{t+1} + X'_t + X''_t = 0.0$$

and they represent the deviation of the variable  $X_t$  from  $X_{t+1}$ .

Then the problem can be formulated as:

$$\text{Minimize } Z = \sum_{t=1}^T (X'_t + X''_t)$$

subject to:

$$X_t - X_{t+1} + X'_t - X''_t = 0.0$$

$$\sum_{p=1}^t X_p \cong \sum_{p=1}^t W_p \quad t=1, T$$

$$s \sum_{p=1}^t X_p \cong \sum_{p=1}^t D_p \quad t=1, T$$

where  $s$  is the swell factor.

The solution of this problem is the base for calculating the stripping equipment fleet. Short periods of peak requirements may call for leasing or contracting more equipment, whereas longer periods of high equipment demand may justify the purchase of additional pieces of equipment.

## CHAPTER 6

## A CASE STUDY

## 6.1 Objectives and Problem Definition

In this case study, data from a real mining operation is used for testing the solution technique for application to a practical problem. The mining operation exploits a two seam coal deposit by a truck and shovel stripping method. Several major faults of up to 35 meters of vertical displacement break the continuity of the seams and result in sudden changes of the stripping ratio. High ash content of the coal requires careful blending to meet the contract specifications. The key items included in the contract are a required monthly delivery of 45,000 to 55,000 metric tonnes with a maximum of 36% ash content. These facts show the need of a comprehensive short term production planning system. The planning system should be able to aid the planning engineer to estimate the maximum marketable coal reserves, to predict its quality variations, and to schedule the mining advance to minimize the stripping equipment demand variations for any pre-established planning horizon. This planning horizon can be defined as a time length or a

specific portion of the deposit. For the present case study, a planning horizon of four and a half years is set. This term provides a good insight to the approach and is adequate for the objective of the case study.

## 6.2 Description of the Deposit and Mining System

The data used in this case study is from a real mining operation. However, due to lack of some information, some specific data were estimated and may not be very accurate for the particular deposit. Nevertheless, the lack of accuracy in the estimation of some parameters does not detract from the objective of this case study.

The coal deposit is located near Puertollano, in Central Spain (Figure 6.1). The Puertollano coal system includes five major seams. A zone of the deposit separated from the main body by a fault of 46 m. of vertical displacement was assessed to contain seams #2 and #3 over an area of 1,000 m.x2,275 m. An initial estimate yielded 13,533,470 metric tonnes of recoverable coal. This portion of the deposit is the object of study. It approximates an ellipse in shape, truncated on one end by a straight fault (Figure 6.1). The average elevation is 685 m. above sea level, and the topographic surface is relatively smooth.

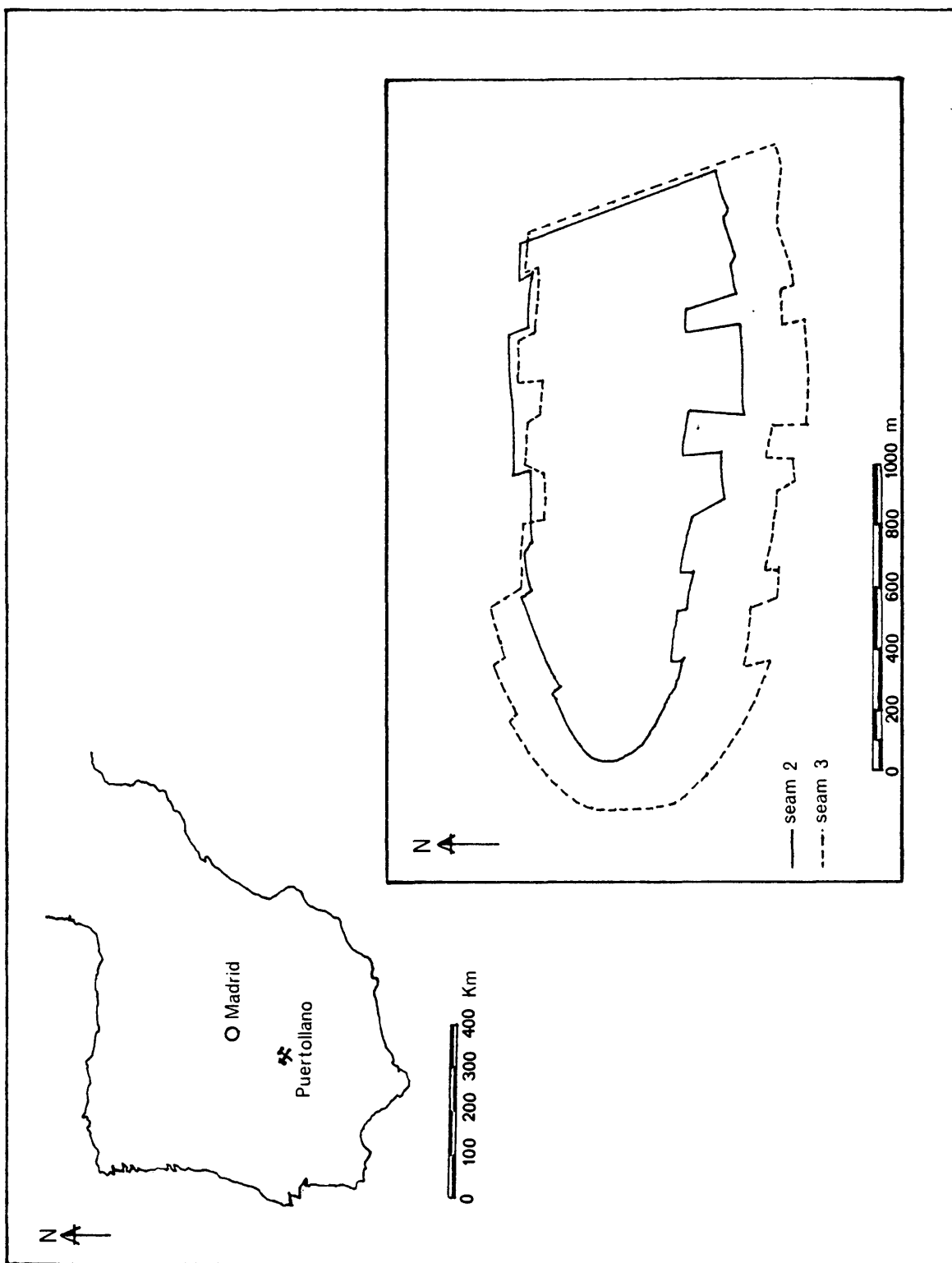


Figure 6.1. Location of the Deposit and Plan View of the Coal Seam Boundaries

The coal seams follow a syncline structure and are heavily faulted on a direction consistently perpendicular to that of the trough. This results in a highly variable stripping ratio, from 8.6:1 to 10.5:1. The coal seams dip a maximum of 12 degrees near the subcrops, as shown in two representative cross sections included in Figure 6.2. The coal is classified as sub-bituminous and averages 10,050 BTU/Lb. It is very low in sulfur, but the inclusion of thin partings result in a very high ash content, averaging 39.95%. The average thicknesses of the seams are 3.99 m. and 2.27 m. for seam #2 and #3 respectively. The upper seam, #2 seam, averages 36.46% ash in situ, and the lower seam, #3 seam, averages 44.3% ash. Coal density average 1.534 Ton/m for #2 seam, and 1.6 Ton/m for #3 seam.

The overburden is principally shales and sandstones, with some inclusions of clay. The partings are mainly shale and volcanic ash.

A truck and shovel stripping method was chosen as it seemed most adaptable to the geological structure of the coal seams. The mining orientation was selected to yield an early production, starting stripping at the subcrop closest to surface and moving eastward. This orientation results in 1,200 m. long benches, and a relatively easy operational control. However, high stripping variations are encountered

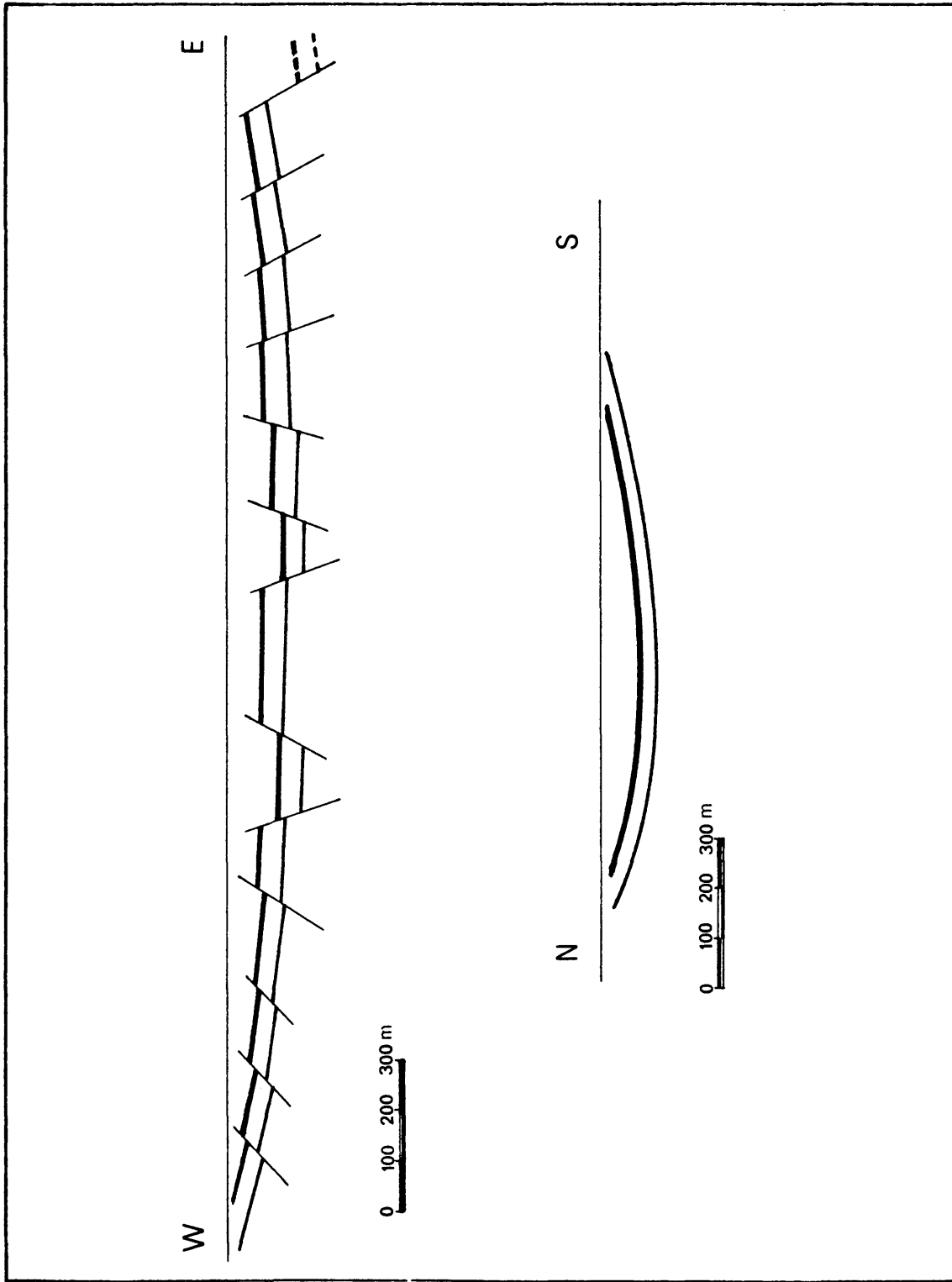


Figure 6.2. Representative Vertical Cross Sections of the Deposit

as the benches are consistently parallel to the fault strikes.

Stripping is done in three ways: First, top soil is cleared by dozers and stockpiled for later land reclamation. Second, two Marion 191-M shovels fitted with 11.5 m. dippers, strip waste on benches having an average height of 10 m. Third, front-end-loaders remove waste from the edges where the coal seam is too steep for the shovels or benches which are below 6 m in height (Figure 6.3). Strip benches are 32 m. wide and their height varies from 6 to 12 m.

Coal is extracted by front-end-loaders and backhoes. Mined coal is sent to a blending facility that feeds a cleaning and crushing plant located at the mine mouth. The blending stockpile has a maximum capacity of 10,000 tonnes and a minimum of 6,000 tonnes is required. Stockpiled coal may be sent directly to the plant, and its quality must be such that it complies with the contract requirements after cleaning. The cleaning process is based on a handpicking operation previous to a secondary crushing and screening circuit. Treated coal must have less than 36 % ash content, and be reduced to a minus 2 cm. size. Coal is sold to a 220 Mw. power plant located 6 Km. from the mine.

Dump benches are 10 m. high and 20 m. wide. The dump height is limited by law to a maximum elevation of 10 m.

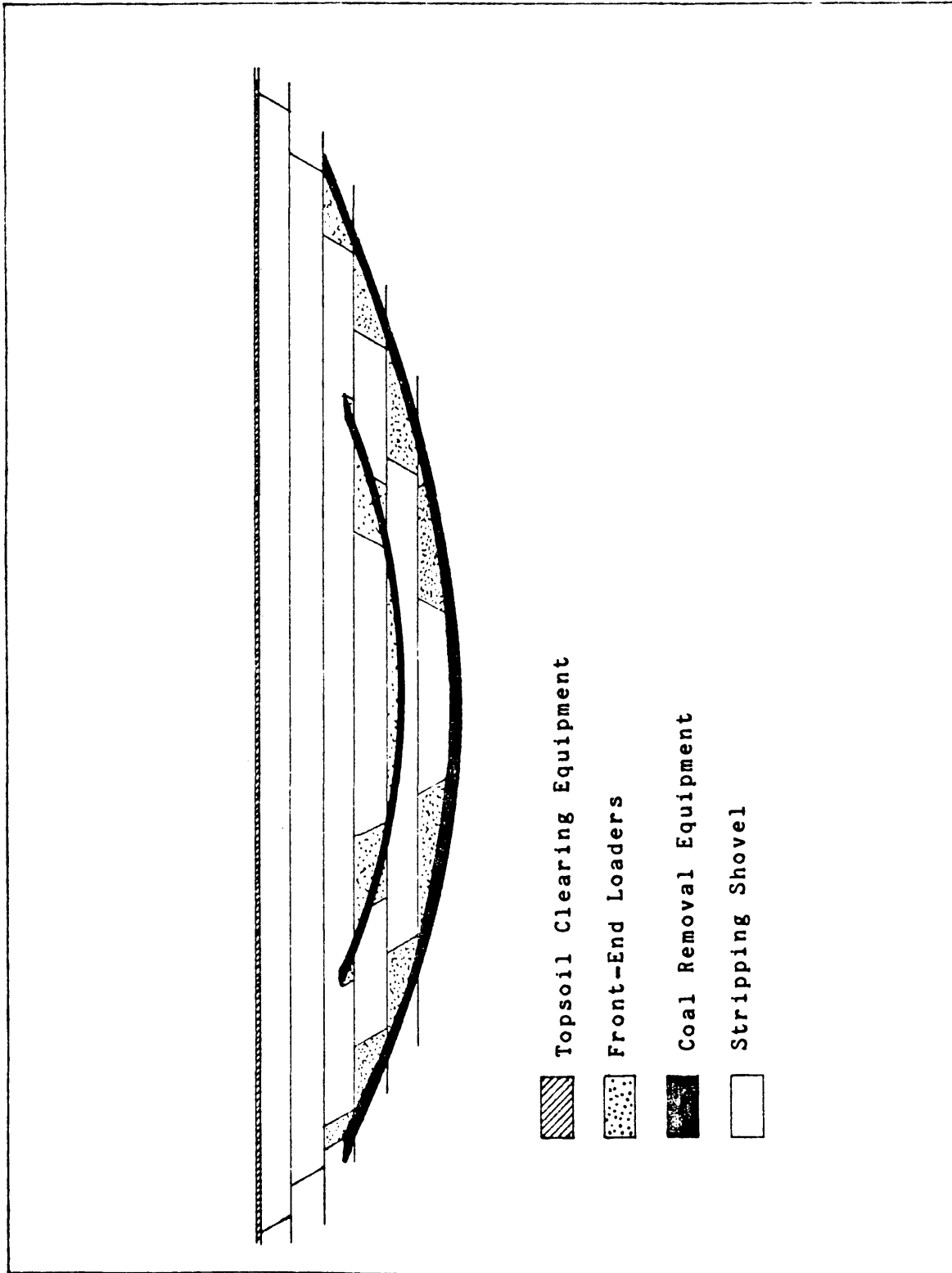


Figure 6.3. Material Removal Allocation by type of Equipment

over the original topographic surface. Also, a minimum space of 8 m. between the dump toe and the coal face, at the bottom of the pit is required for equipment maneuverability. Mining losses are calculated as 6 cm. of the top of the seam and 6 cm. from the bottom of the seam. The cleaning and processing losses are estimated as 80% of the partings and 2% of the coal.

### 6.3 Development of the Planning Block Model

Data for building the Mineral Inventory Model and later the Planning Block Model was available from drill hole data and hand interpreted maps of the topseam structures. Maps include the seam boundaries and fault traces. Also, operation maps were available. Topstructure maps were digitized, recording fault traces, seam boundaries, and the coal top seam elevation in contour interval of 10 m. (Figure 6.4). Drill hole data included drill hole collar elevation, seam thickness, and ash content. A total of 69 drill holes intersecting seam #2 and 96 holes intersecting seam #3 were available. Drill holes were located on the maps and their coordinates digitized. The digitized data files were edited, checked, and plotted for verification. To align the blocks with the benches as defined by the selected mining

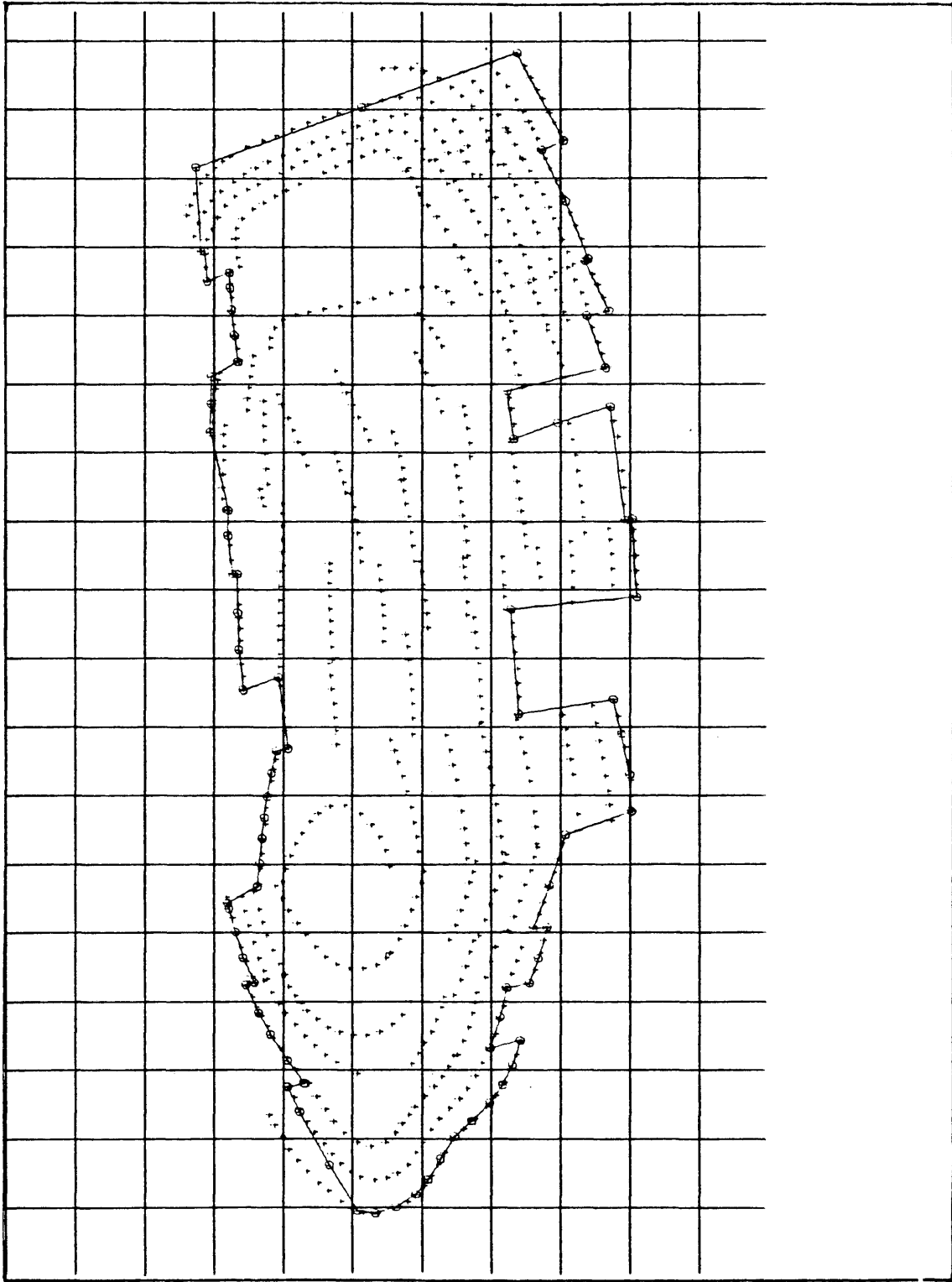


Figure 6.4. Digitized Topstructure Elevation Map of Coal Seam 2

orientation, the coordinates of the digitized points were changed with the program TILTER.FOR. The surface of the coal topstructure and topographic surface were modelled by interpolating the digitized data. Preliminary geostatistical analysis was performed on drill-hole data concerning ash content and thickness. The generated variograms (Figures 6.5 and 6.6) do not show a clear model, and, taking into consideration the limited amount of data available, it was decided to use the inverse squared distance interpolation method for these parameters. The interpolation was performed using the CPS-1 computer package, as it was the only gridding package available that includes fault handling capabilities. Different gridding algorithms were used for the various parameters to be interpolated. The drill hole collar elevation data were interpolated linearly to model the topographic surface. Inverse squared distance was used to interpolate the coal quality and thickness, disregarding the faults. The seam topstructure was modelled using linear interpolation, taking into account the fault traces, so that points located on one side of the fault do not affect the values of the points on the other side. Several tests were performed to attain the closest results to the hand interpreted maps. The final CPS-1 control data files for the interpolations are included

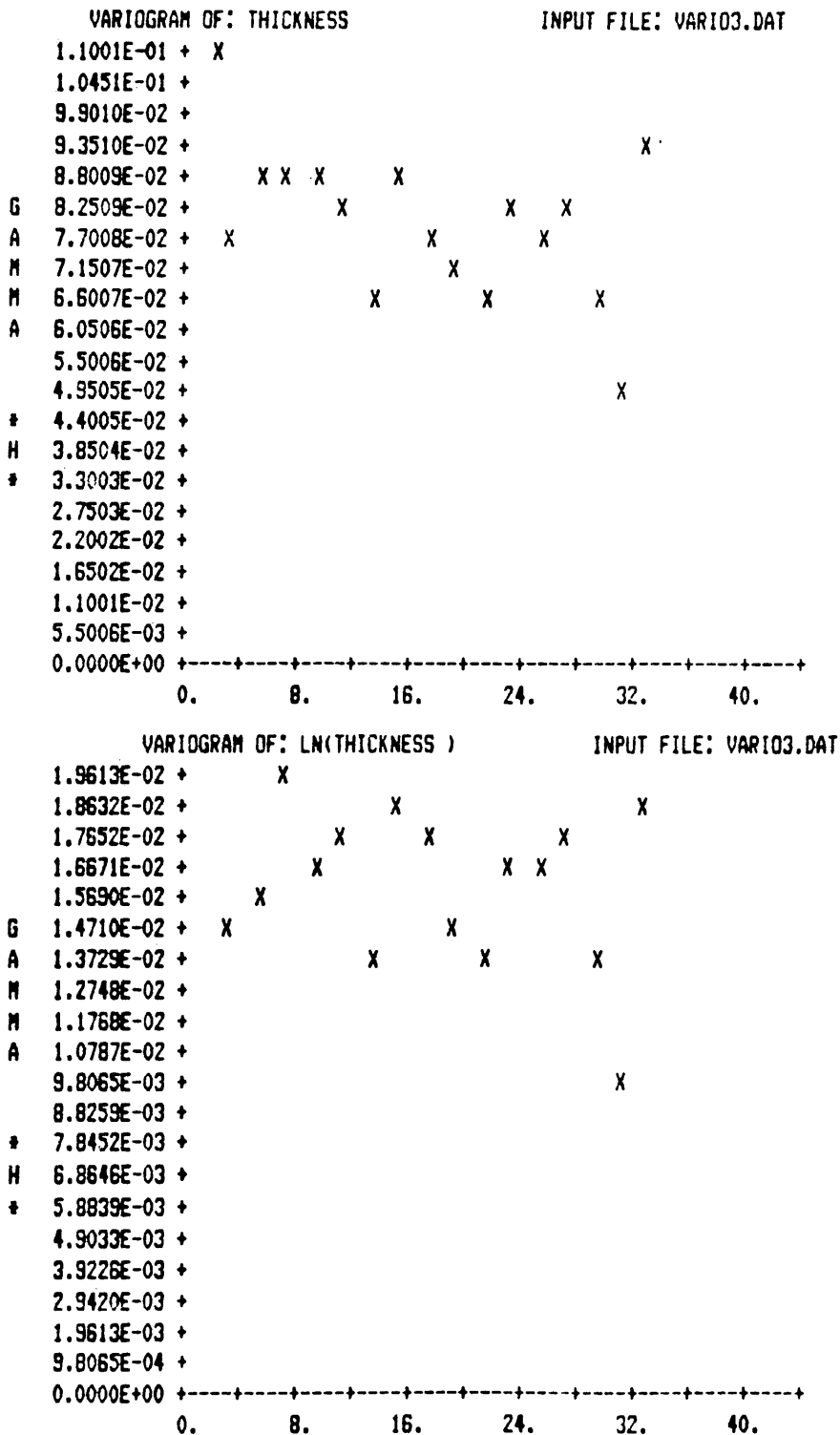


Figure 6.5. Variograms of Thickness and Logarithm of Thickness of Coal from Seam 3

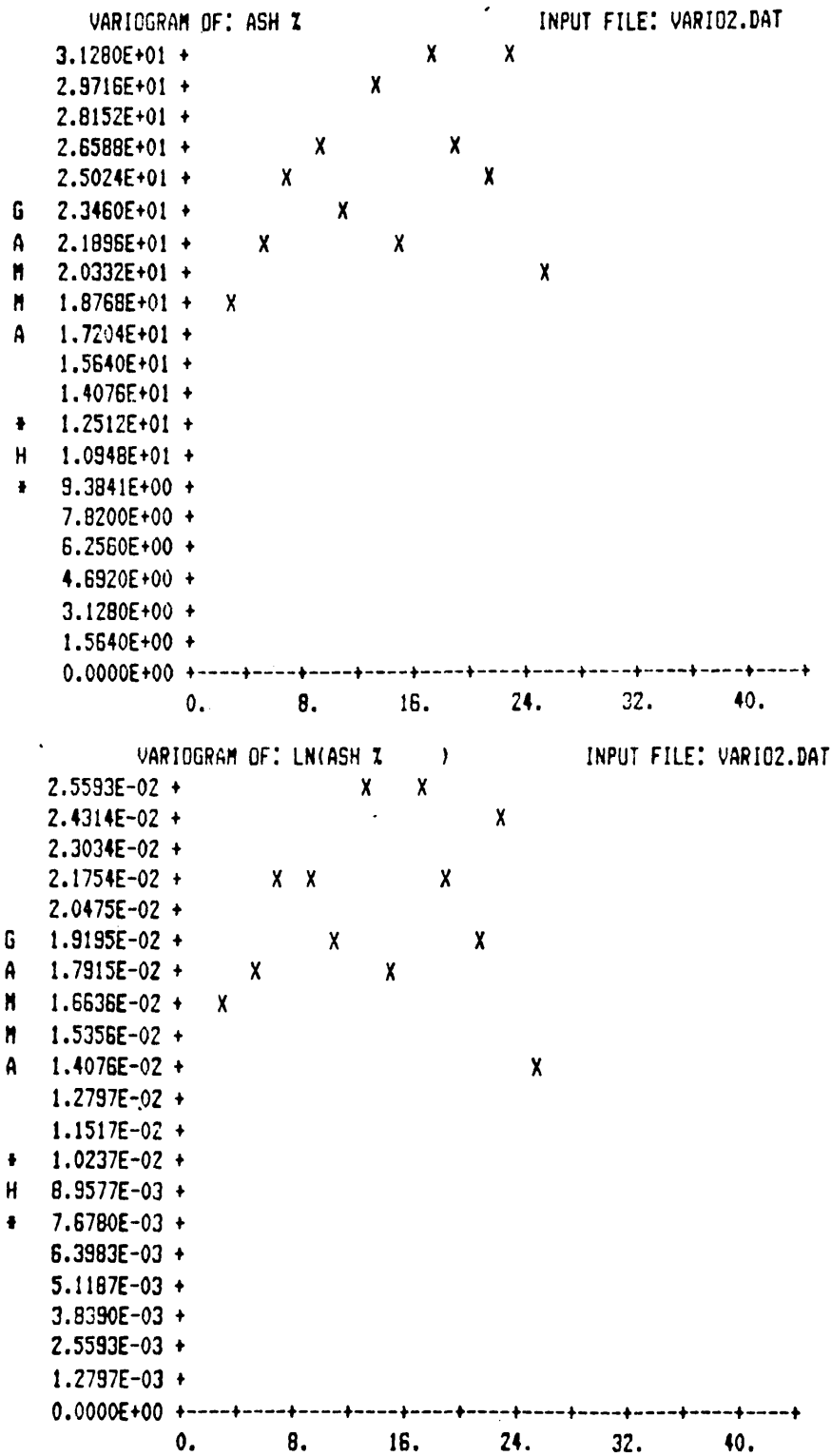


Figure 6.6. Variograms of Ash% and Logarithm of Ash% of Coal from Seam 2

in Appendix 1. After the gridding was done, the generated cells were 16 m. x 16 m. The program GROUP.FOR was executed to aggregate the cells to form bigger blocks of 32 m.x32 m., that correspond to the mining bench width. Seven grids were generated that contain the topography, the topseam elevation, ash content, and thickness of both seams. These files were plotted for further validation and checking. Some examples are shown in Figures 6.7 through 6.12. Utility programs to generate cross sections on the direction of both axis were written and run.

All these grid files were input in MODGEN.FOR, a program that generates the three-dimensional block model. This block model is defined by a standard block of 32x32x10 m. However, the coal blocks and waste blocks located directly above or below the coal blocks may be modified in height so that the generated blocks have the bench height that follows the mining procedures. A log file that stores the locations of each block is created. In this file, each block is represented by one single digit: (0) represents air, (1) represents an only waste block, (2) is a seam 2 coal bearing block, (3) is a seam 3 coal bearing block, and (4) represents a waste block that includes the topography.

After MODGEN.FOR is run, the data files are organized in two different ways. First, the location of each block

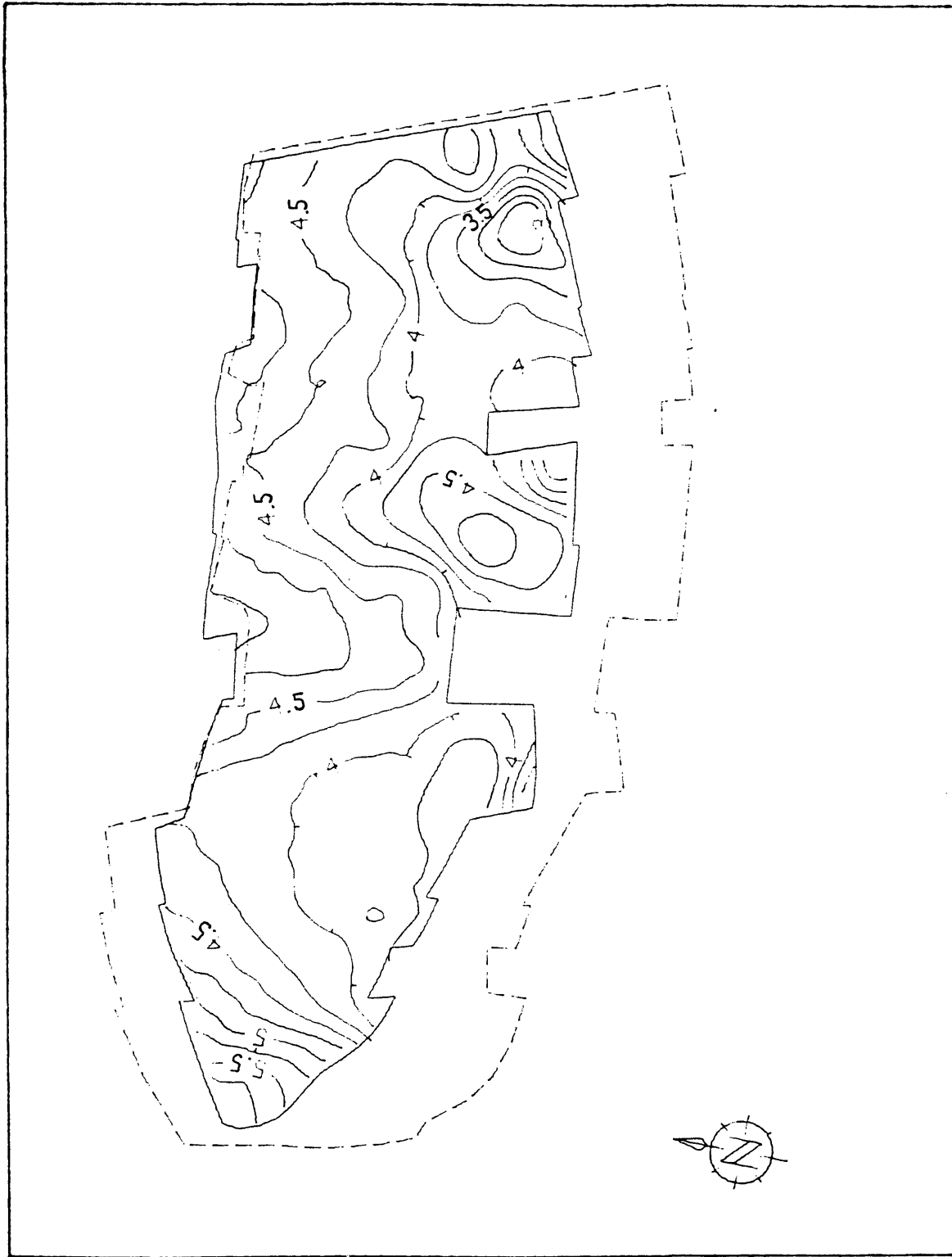


Figure 6.7. Plot of Seam 2 Isopachs. Scale 1.11,000



Figure 6.8. Plot of Seam 3 Isopachs. Scale 1.11,000

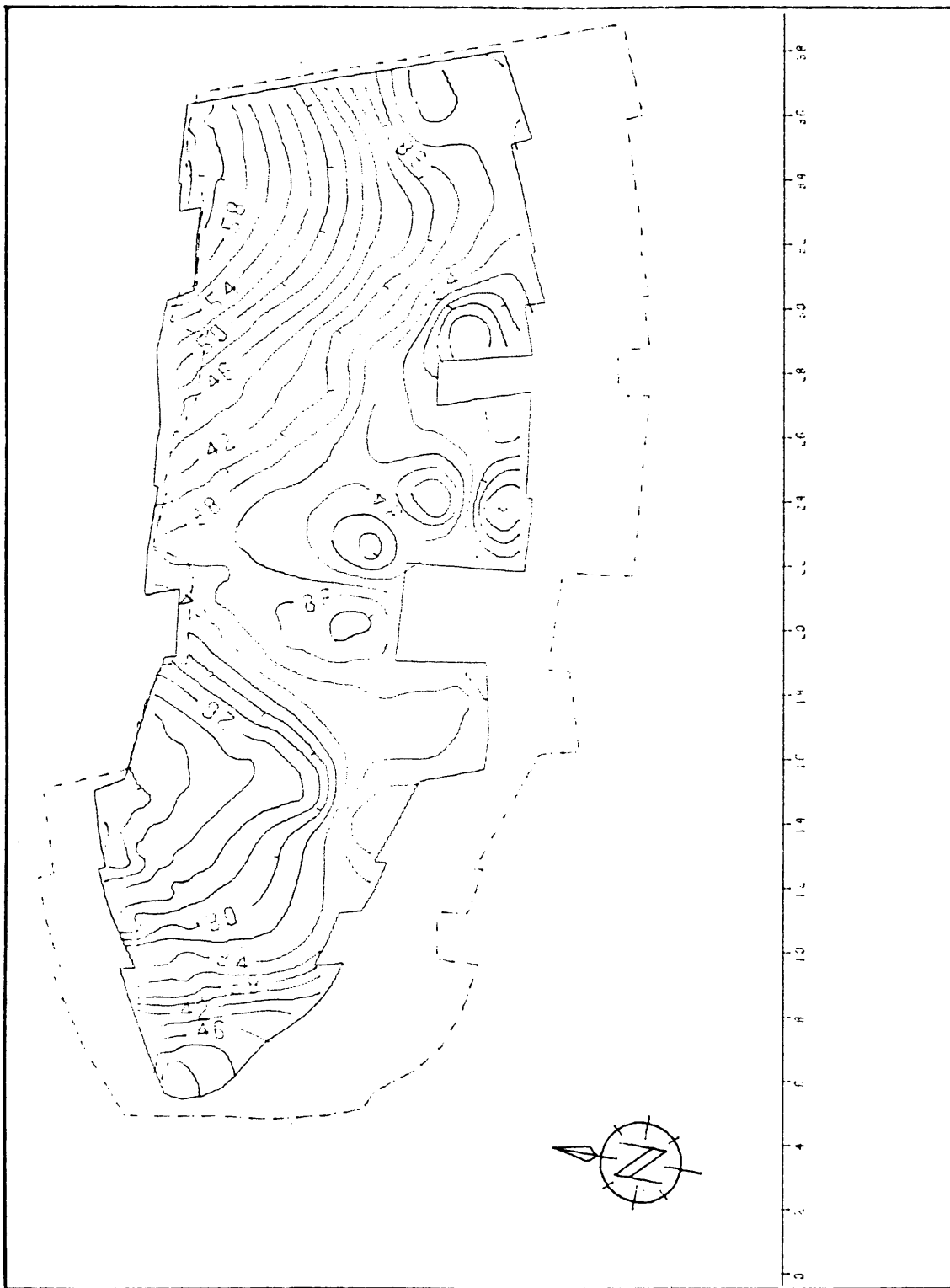


Figure 6.9. Plot of Seam 2 Isoash Lines. Scale 1:11,000

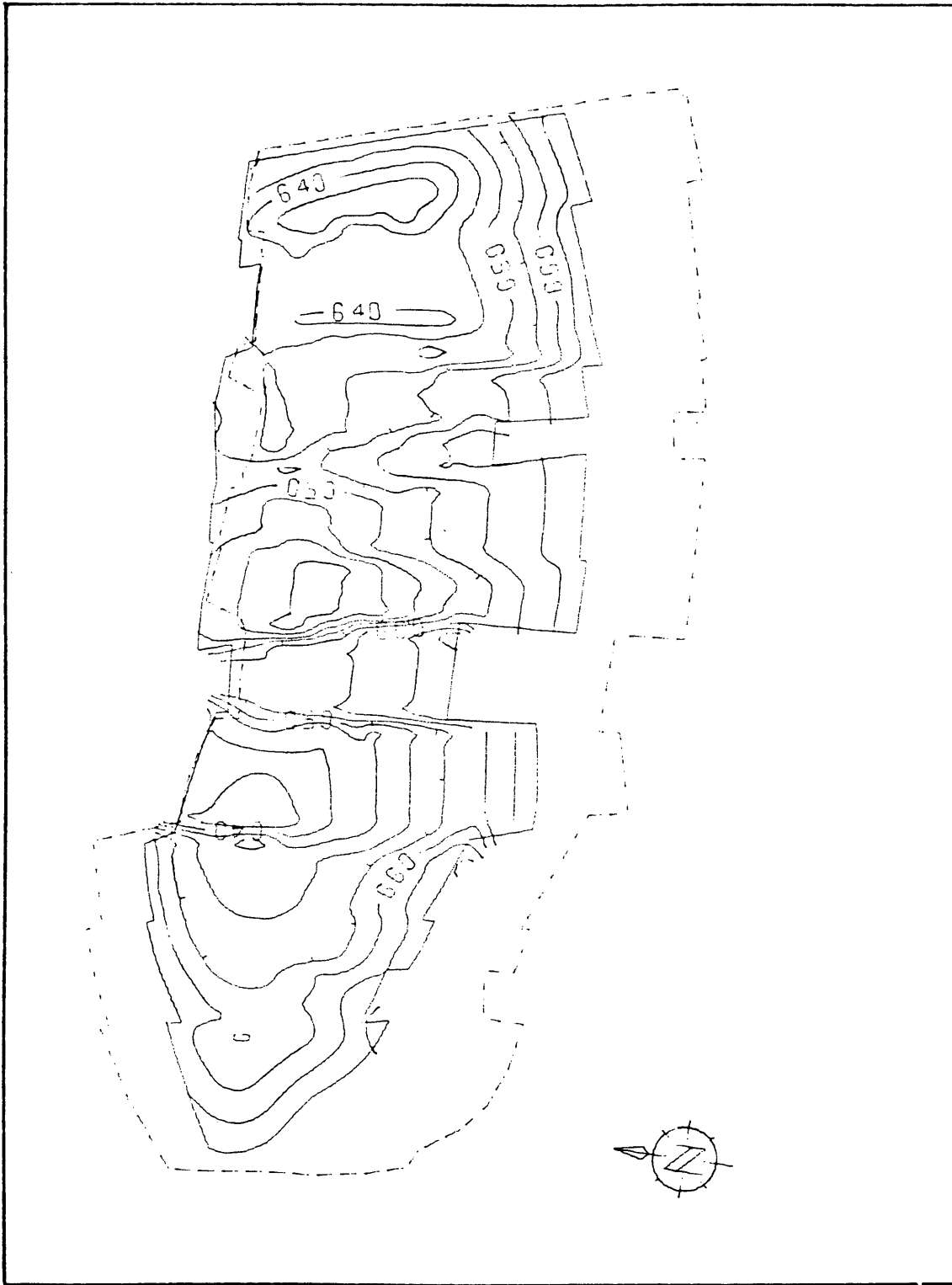


Figure 6.10. Plot of Seam 2 Topstructure Elevation.  
Contours every 5 m. Scale 1:11,000

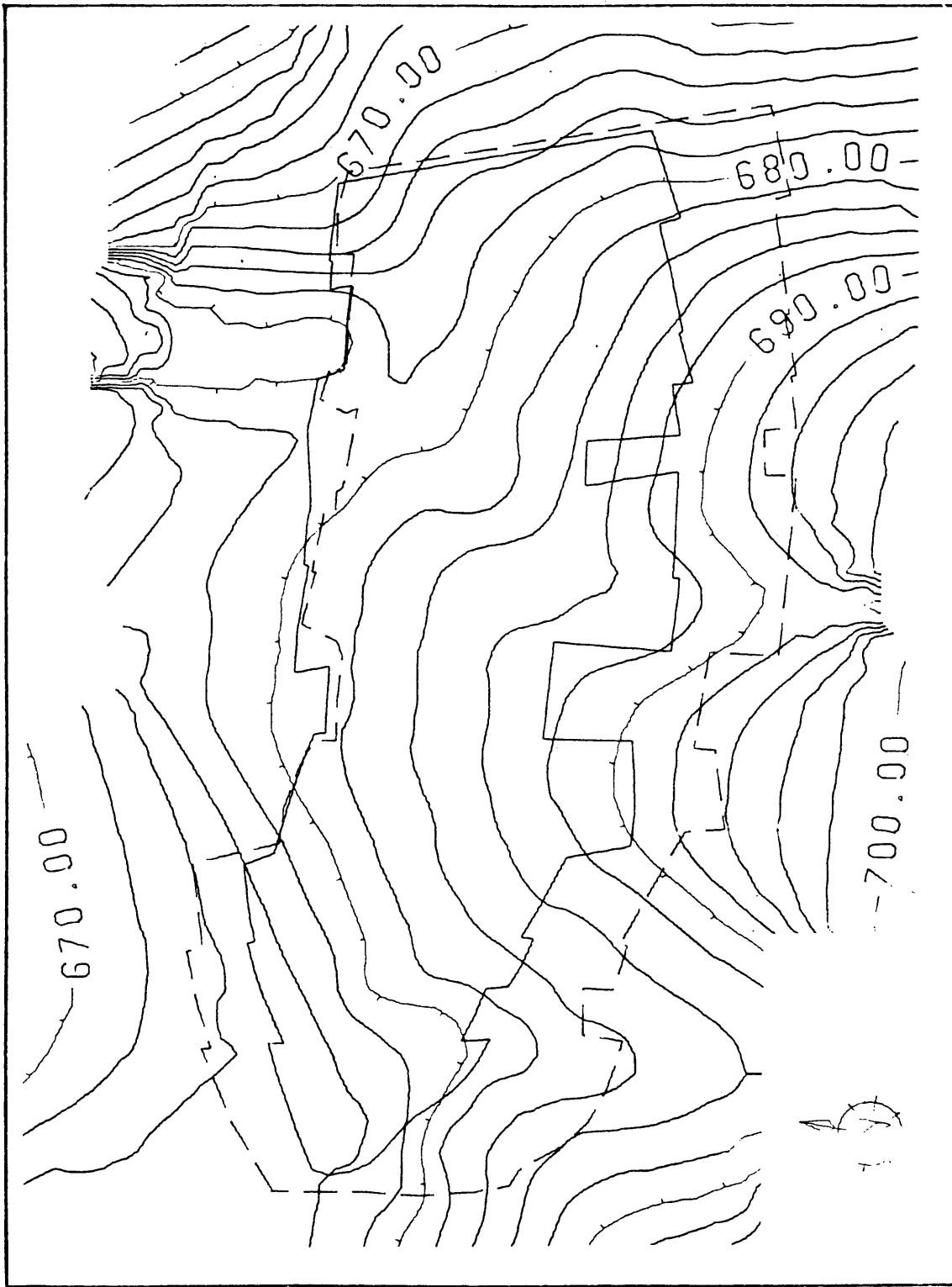


Figure 6.11. Plot of Topographic elevation. Contours every 2 m. Scale 1.11,000

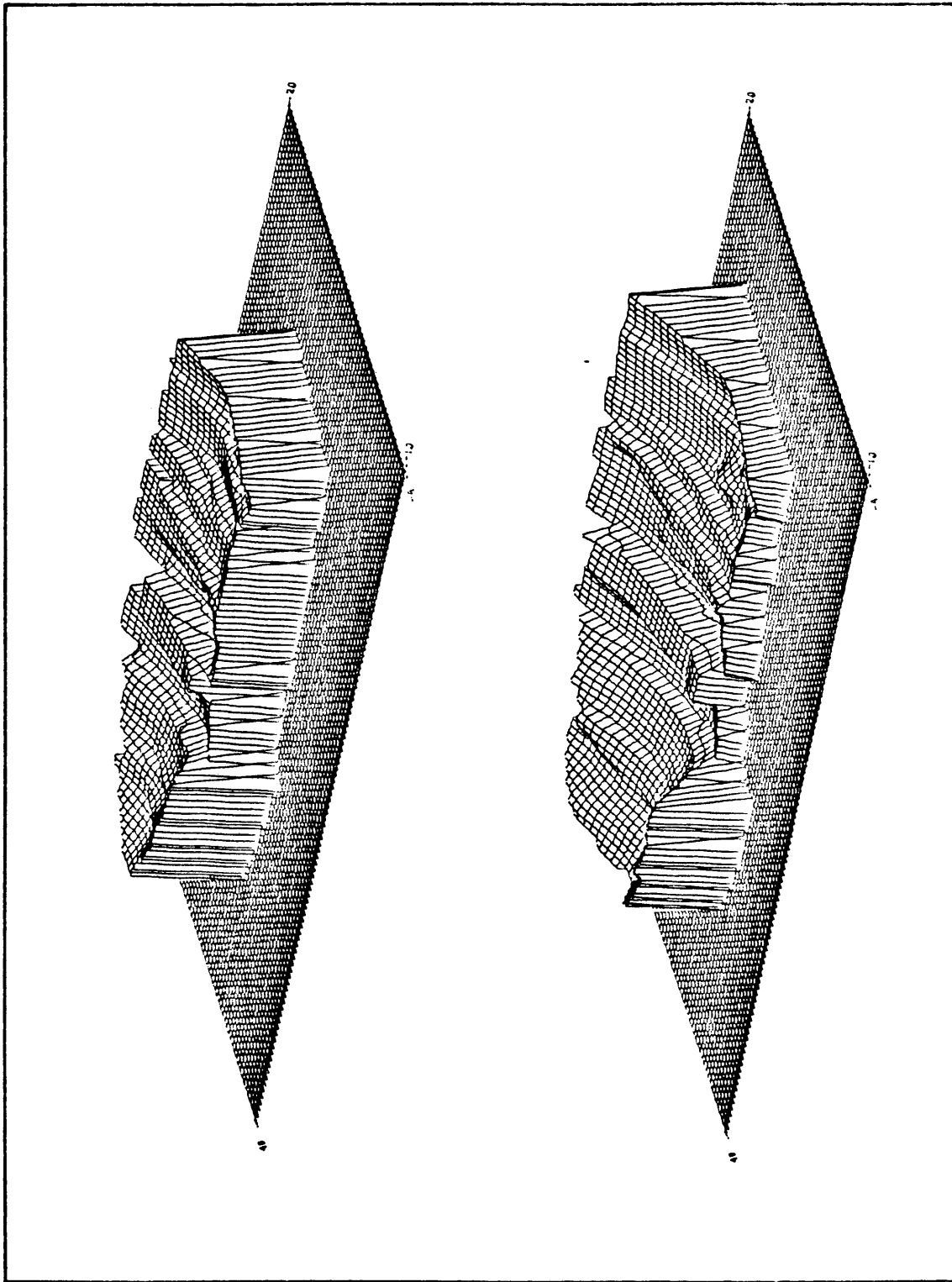


Figure 6.12. Perspective View of Topstructure of Both Seams Showing the Faults. Vertical Exaggeration Factor X 100.

within the model are stored, and second, the quantity and quality parameters of each block, by type of block, are stored. Double checking routines are executed to verify that no overlapping between seams occur and no coal block is lost.

The generated data base includes the following data files:

a) A three-dimensional array that contains the block codes. Blocks that include the coal seams or the topographic surface are identified by one digit. This file is used for display generation and to generate the block extraction sequence equations.

b) Several two-dimensional grids that contain data related to seam topstructure elevation, thickness, tonnage and ash content as in-situ, after extraction and after cleaning, and topographic elevation.

c) Several data files where in-situ coal data is stored. These files are organized by bench, and they include information about waste volumes overlaying and underlaying the coal seam in a coal bearing block.

Finally, MINSIM.FOR modifies the quantity and quality data of coal blocks accounting for mining and cleaning losses, to simulate their extraction and processing. The output files are stored as grids, by seam, and they are

directly accessed by the Linear Programming matrix generator, LP.FOR.

#### 6.4 Short Term Production Planning

The short term plan is obtained by applying Linear Programming to the problem, as discussed in Chapter 5. The final formulation used in this case study is as follows:

$$\text{Max } F = \sum_{i=1}^c \sum_{t=1}^T \text{Priority}(X_{it} + V_{it} + Z_{it})$$

subject to:

a) Production demand

$$\sum_{i=1}^c X_{it} C'_i + \sum_{i=1}^c V_{it-1} C'_i \leq 55,000 \quad t=1, T$$

$$\sum_{i=1}^c X_{it} C''_i + \sum_{i=1}^c V_{it-1} C''_i \geq 45,000 \quad t=1, T \quad \text{for all } i$$

b) Production Quality Requirements

$$\sum_{i=1}^c X_{ip} C''_i (A''_i - 36.0) \leq 0 \quad t=1, T \quad \text{for all } i$$

c) Mining Sequence

$$\sum_{p=1}^t (X_{jp} + V_{jp} + Z_{jp}) - X_{ip} - V_{ip} - Z_{ip} \geq a_i - a_j \quad t=1, T$$

for j before i.

## d) Block Capacity

$$\sum_{t=t_1}^{t_2} (X_{it} + V_{it} + Z_{it}) = 1 \quad \text{for all } i \text{ that are tail blocks}$$

$$\sum_{t=t_1}^t (X_{it} + V_{it} + Z_{it}) \leq (1 - a_i) \quad \text{for all independent } i$$

## e) Raw Coal Stockpile Requirements

$$\sum_{i=1}^n V_i C'_i \leq 6,000 \quad t=1, T \quad \text{for all } i$$

$$\sum_{i=1}^n V_i C'_i \geq 10,000 \quad t=1, T \quad \text{for all } i$$

$$\sum_{i=1}^c V_{it} C''_i (A''_i - 36.0) < 0 \quad t=1, T \quad \text{for all } i$$

The planning horizon used for the case study was variable, between two and seven months, with an average of five months. The planning horizon will be divided into several one month periods. The main reason for such a short time horizon is that the largest problem size that could be solved with the available L.P. code is about 100 blocks and 6 periods. Therefore, determining the production schedule

for several years involves several cycles for which the matrix generator and the L.P. program are run, the data files are updated, and production and mining advance are recorded. The matrix generator includes a main program, LP.FOR, and six other subroutines written in FORTRAN by the author. The block-time allocation can be performed manually or automatically. If manually, detailed bench-by-bench statistics on coal quantity and quality are displayed to facilitate the decision. This is very important, since it was observed that infeasible solutions were obtained if not enough number of time periods were allocated to each block. To perform this critical task, cross-sections, plan views, and ash content plots of the area of interest were used to visualize the block extraction sequence and estimate a viable block-time allocation. A sample run of LP.XF4 is included in Appendix 4.

The Linear Programming code available, MINOS64, from COMPUSERVE. Inc., generates a data file where the optimal solution is stored. The report generator is now run. This program, REPORT.FOR, written in FORTRAN IV, reads the solution data file and generates a report of the coal utilization per period, and is included in Appendix 5. Quantity and quality of coal used from each seam and totals are calculated. A sample run is included in the Appendix 6.

The subroutine GRAF.FOR is called by the user at will; it displays a plan view of the area of interest by bench, showing the utilization of each coal block in approximate percentages, allowing the user to visualize the mining advance at the end of each period. STORE.FOR is a subroutine called from REPORT.FOR and it updates the block model by "converting to air" all the coal blocks that have been fully utilized. This is done taking into account the mining sequence equations to check which blocks may be left untouched at the mining face for later use. The model update is done on two files, DISPL.UPD and BETA.UPD that store the block status and the block availability respectively. In addition to that, it updates a log file, HSTORY.DAT, that stores the block utilization per period and coal destination.

After the report generator is executed, the block model is ready for another run of the matrix generator and another Linear Programming run. Once all the runs concerning the desired time horizon have been completed, the mine production plan is obtained. The final mined coal, displayed by seam, is shown in Figures 6.13 and 6.14. Table 6.1 shows a partial report of the production, stockpile, and rejected coal as obtained in this case study. In order to calculate stripping volumes, a computer program is executed

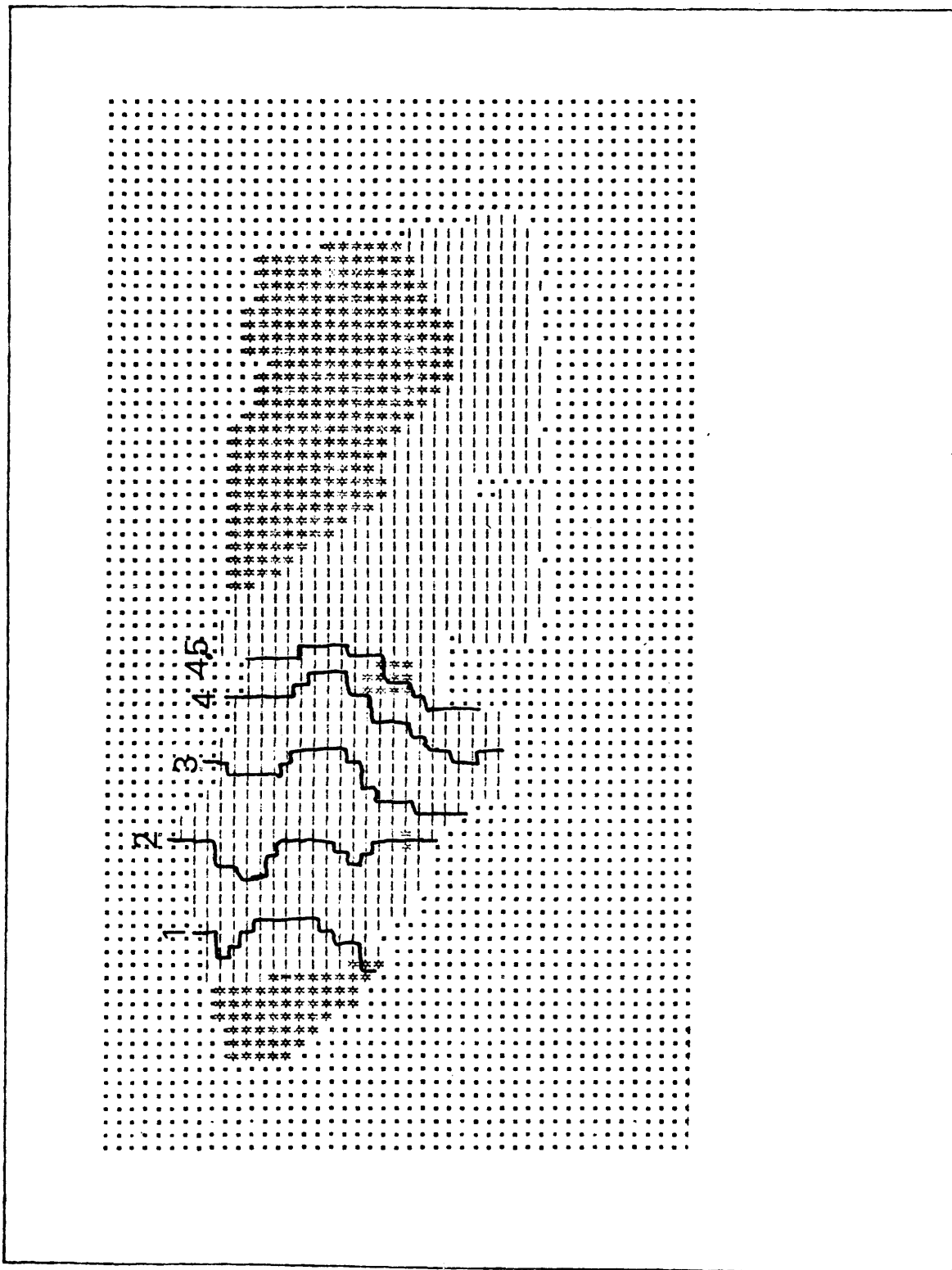


Figure 6.13. Plan View of Seam 2, Showing the Mined Area.

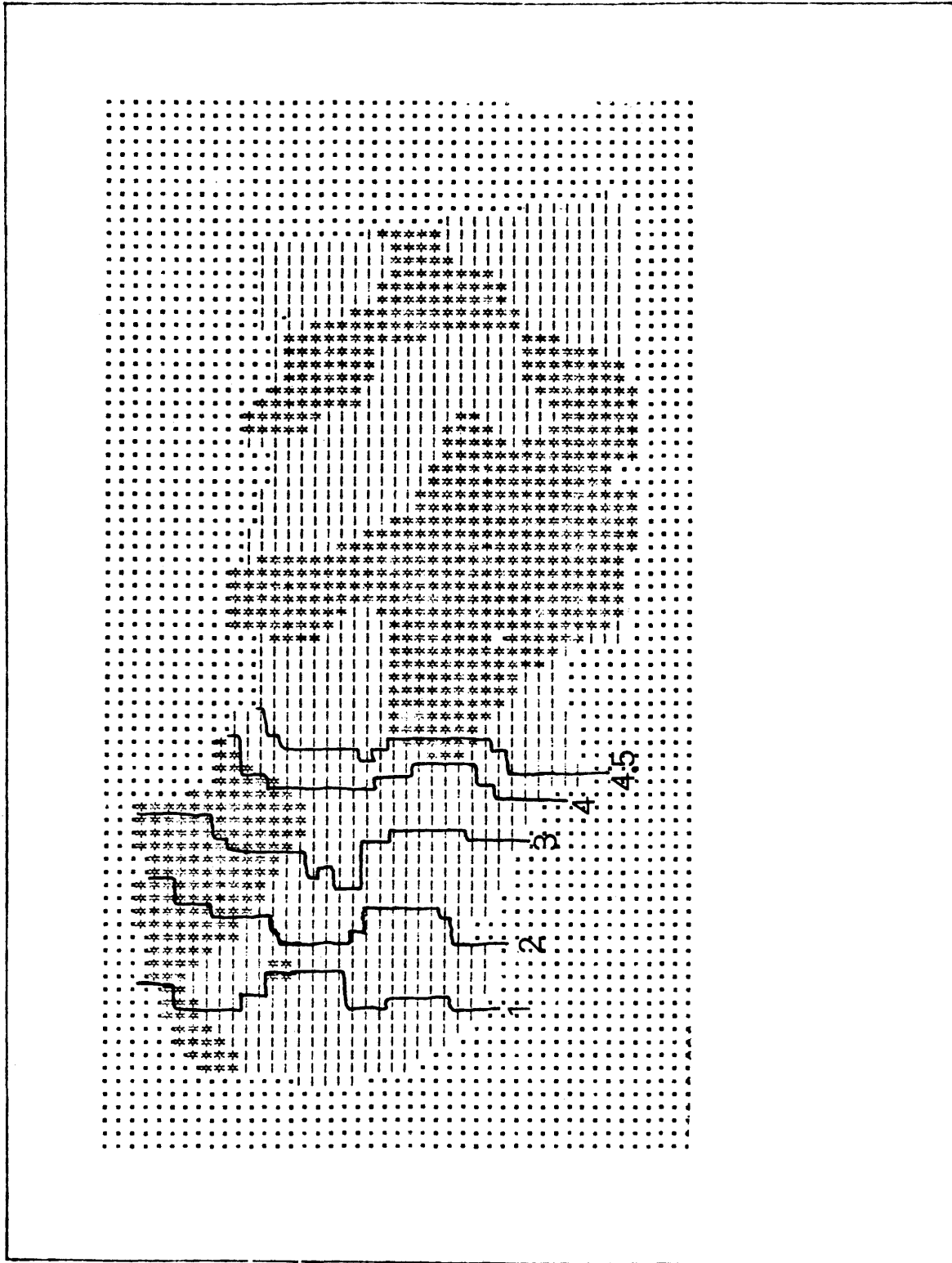


Figure 6.14. Plan View of Seam 3, Showing the Mined Area

Period (Months)	Mine Production seam 2 (tonnes)	Mine Production seam 3 (tonnes)	Delivered Coal Tonnage	Delivered Coal Ash%	Stockpiled Coal Tonnage	Stockpiled Coal Ash%	Rejected Coal Tonnage
1	32,900	31,650	55,000	36.0	6,000	36.0	123,404
2	37,500	34,480	55,000	36.0	10,000	36.0	102,980
3	33,758	36,335	55,000	36.0	10,000	36.0	29,281
4	38,480	32,513	55,000	36.0	6,000	36.0	--
5	32,154	34,500	55,000	36.0	10,000	36.0	55,415
6	40,050	20,819	47,328	36.0	6,000	36.0	11,113
7	39,482	26,937	45,000	36.0	10,000	36.0	11,507
8	29,721	38,826	45,000	36.0	6,000	36.0	121,471
9	39,639	32,500	45,000	36.0	6,000	36.0	19,373
10	42,063	23,104	55,000	36.0	6,000	36.0	--
11	12,031	53,525	55,000	36.0	6,000	36.0	--
12	46,361	14,685	55,000	36.0	6,000	36.0	--
13-24	439,837	396,702	630,000	33.2			78,734
25-36	405,514	369,661	610,000	32.4			143,712
37-48	389,723	388,798	610,000	32.6			175,123
49-54	175,511	153,201	290,000	28.5			

to generate the final pit boundaries for the mining plan. This program, NEWPIT.XF4, written in FORTRAN IV by the author, generates the pit by projecting the desired pit slopes from the bottom coal blocks. Only one pit slope is implemented for the whole deposit. Figure 6.15 shows vertical cross-sections of the mined area at the end of the four and a half year time horizon. Based on this pit and the mining plan, the waste dump space available at the end of each period was calculated. Also, the minimum stripping advance required to maintain an uncovered coal inventory of two months of production was estimated. These calculations take into account the dump generation limitations and the bench geometry.

These data were used by the program ALLOC.XF4, the matrix generator for a final Linear Programming run that minimizes the stripping requirement deviation from the calculated average, as developed in Chapter 5. The final formulation is as follows:

$$\text{Minimize } Z = \sum_{t=1}^T (X'_t + X''_t)$$

subject to:

$$X_t - X_{t+1} + X'_t - X''_t = 0.0$$



$$\sum_{p=1}^t X_p \cong \sum_{p=1}^t W_p \quad t=1,54$$

$$1.3 \sum_{t=1}^t X_t \leq \sum_{t=1}^t D_t \quad t=1,54$$

where the values of  $W$  and  $D$  are different for each period. Fifty-four periods were involved in the plan, generating a problem of 217 constraints and 163 variables. The optimal waste removal allocation plan was plotted and is shown in Figure 6.16. In this figure, the sizable increase in the stripping requirements in periods 13-14 is due to the presence of an important fault that displaces the seams deeper underground. Also, some increase in stripping can be expected, as the initial cut was in the zone of the deposit with the least amount of overburden. Further analysis of the results show that the extrem stripping requirements in periods 13-14 could be eliminated if outside dumping was permitted. However, such practices are not desirable due to rehandling costs, and are discouraged by law in many situations. The results of this case study show that only 24% of the coal outside the contract specifications is actually rejected, and generally stripping requirements may be uniformly distributed over the life of the operation.

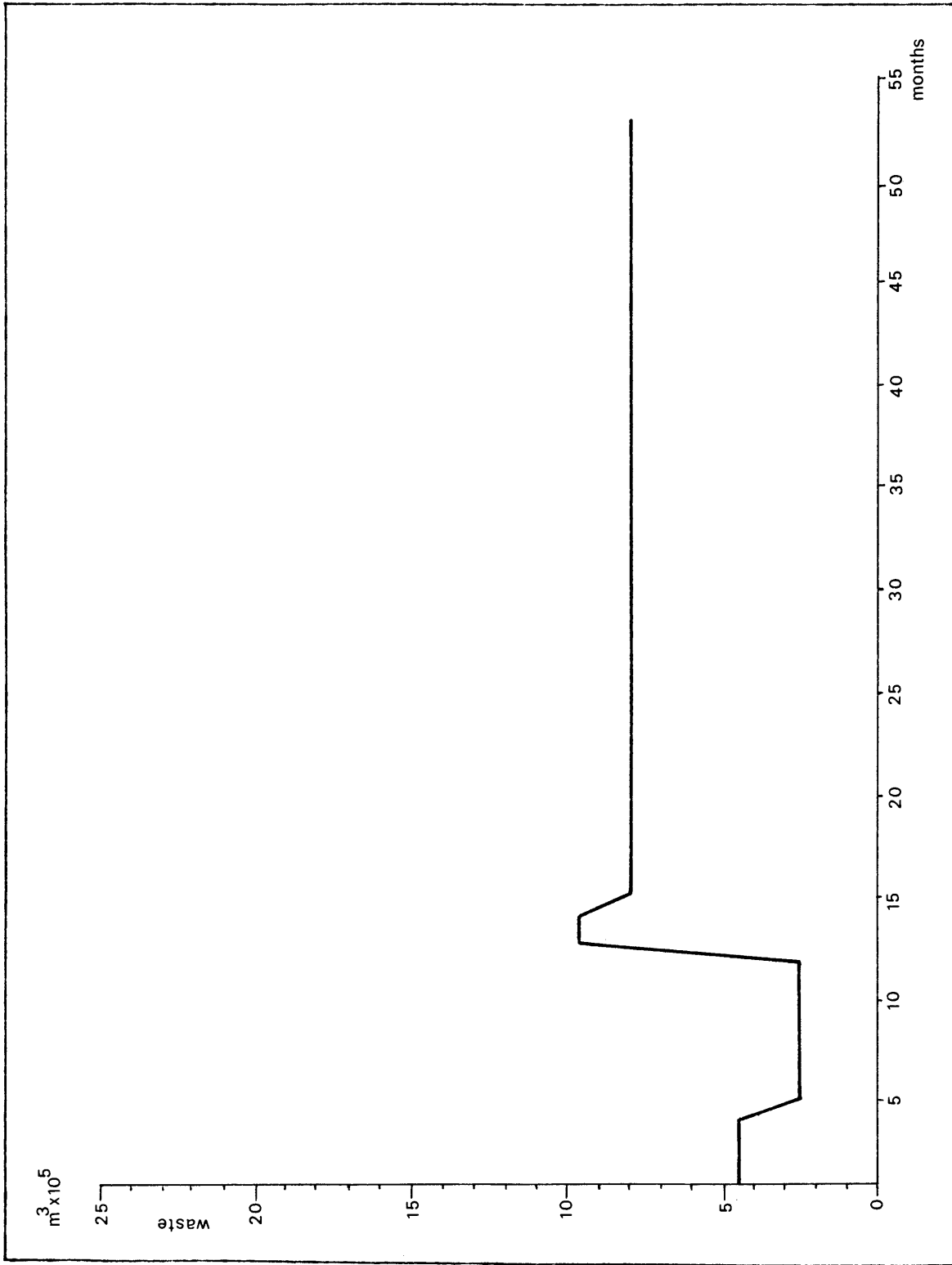


Figure 6.16. Plot of Projected Waste Removal Capacity

## CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

The present thesis shows the successful utilization of Linear Programming as a tool for planning an open pit haul-back mining operation. The present work was applied to planning a mining operation with a method that follows a well defined orientation and where the extraction process is done in a single pass over the deposit.

This thesis also provides a method to generate a block model for layered deposits that follows the case study mining procedure. The case study shows that the ability of developing the mining plan by short increments provides the user with good control of the production plan as it is generated. In addition to that, updated versions of the plan may be obtained for specific portions of the deposit without requiring to rerun the overall plan.

An area of further development resides in the planing matrix generator code. The results obtained from several linear programming runs during the case study show the need for a more sophisticated block-time allocation routine in order to avoid infeasible solutions at this stage. Although workable, the block-time allocation should be more reliable

to avoid the need for reruns.

Also, although the goal used in this case study was expressed as maximizing the coal reserves utilization, other objectives may be used instead.

Finally, coordinating this approach with on-line interactive graphics routines would provide an excellent tool for short range mine planning.

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Appendix 1

CPS-1 Control Files

```

$VC JOB=1,NROW=60,NCOL=104 $END
PLOT TOPSEAM3.DATA:3SEAM,3BOUND,3FAULT(.NEW).RUN# 7
$VC CXIC=1,XMIN=-4.0,XMAX=48.0 $END
$VC CYIC=1,YMIN=-10.0,YMAX=20.0 $END
$VC READ=1,LUN=24,FILE=1 $END
$VC REWD=1,LUN=39,ITYP=1 $END
$VC COPY=1,NCRD=51,LUN=39,FILE=1,LUNG=22 $END
$VC REWD=1,LUN=39,ITYP=1 $END
$VC CMNT=1 $END
*****
ONCE THE FILE IS READ, THE PLOTTING SUBROUTINE STARTS:
*****
CEND
$VC PDEF=1,XSCL=3.75,YSCL=3.75,MPEN=2,PSCL=0.5,DXO=0.5,DYO=1.0,IAOV=1 $END
$VC BRDR=1 $END
$VC LABL=1,NLBY=-1,NLBX=-1,XML=4.0,MYL=4.0,XMNL=-4.0,MYNL=-10.0,NDEC=0,ITYP=1 $END
$VC LETR=1,XCOR=1.5,ycor=1.5,SIZE=0.2,THET=350.0,NCH=0,ITYP=1,ISCL=2 $END
$VC LETR=1,XCOR=1.5,ycor=1.0,THET=0.0,NCH=30,SIZE=0.2,ITYP=1,ISCL=2 $END
TOP COAL ELEVATION OF SEAM # 3
$VC CLV1=1,ZIDA=1,DEL=5.0,ICRT=1 $END
$VC CMNT=1 $END
*****
NOW A POLYGONAL IS DRAWN FOLLOWING THE BOUNDARY OF THE SEAM:
*****
CEND
$VC SRCH=1,LUN=39,FILE=1,ITYP=3 $END
$VC POLY=1,MODE=4,NPC=51,ISCL=1,LUN=39,ISBM=4,LTP=2 $END
$VC POLY=1,MODE=1,NPC=69,ISCL=1,LUN=21,ISBM=0,LTP=1 $END
$VC NWP=1 $END
$VC STOP=1 $END

```

```

$VC JOB=1,NROW=60,NCOL=104 $END
SEAM2 TOPO REGRIDDING TEST,FAULTS:FOR.53:BLANKED. TEST 2F
$VC CXIC=1,XMIN=-4.,XMAX=48.0 $END
$VC CYIC=1,YMIN=-10.0,YMAX=20.0 $END
$VC COPY=1,NCRD=150,LUN=40,IPRT=0,FILE=0,LUNB=53 $END
$VC REWD=1,LUN=40,ITYP=1 $END
$VC ZFEX=1,NDC=75,LUN=40,FTYP=3,FILE=0,IPRT=0,IFMT=2 $END
(2F10.3,/2F10.3)
$VC ZFIT=1,ITYP=2,LUN=50,IFMT=2,NCP=818,DEL2=1.2 $END
(2F10.3,5X,F9.3)
$VC RFIT=1,ZIDA=1,ZIDB=1,NREF=2,ITYP=1,JTYP=2 $END
$VC SAVE=1,LUN=20,ZIDA=1,FILE=1 $END
$VC SAVE=1,LUN=20,ZIDA=0,FILE=2 $END
$VC REWD=1,LUN=40,ITYP=1 $END
$VC ZFEX=1,NDC=75,LUN=40,FTYP=3,FILE=0,IPRT=0,IFMT=2 $END
(2F10.3,/2F10.3)
$VC ZFIT=1,ITYP=2,LUN=20,IFMT=3,FILE=2,MODE=4,LUNT=20 $END
$VC RFIT=1,ZIDA=1,ZIDB=0,ITYP=2,LUN=33,FILE=1,NREF=1 $END
$VC PNCH=1,ZIDA=1,LUN=2 $END
$VC SAVE=1,LUN=20,ZIDA=1,FILE=3 $END
$VC SAVE=1,LUN=20,ZIDA=0,FILE=4 $END
$VC REWD=1,LUN=40,ITYP=1 $END
$VC ZFEX=1,NDC=75,LUN=40,FTYP=4,FILE=0,IPRT=0,IFMT=2 $END
(2F10.3,/2F10.3)
$VC ZFIT=1,ITYP=2,LUN=20,IFMT=3,FILE=2,MODE=4,LUNT=20 $END
$VC RFIT=1,ZIDA=1,ZIDB=0,ITYP=2,LUN=33,FILE=1,NREF=1 $END
$VC STAT=1 $END
$VC PNCH=1,ZIDA=1,LUN=2 $END
$VC PDEF=1,XSCL=3.75,YSCL=3.75,MPEN=1,PSCL=1.0,DXQ=0.5,DYD=1.0,IAOV=1 $END
$VC PAUS=1,IPEN=2 $END
$VC REWD=1,LUN=50,ITYP=1 $END
$VC LGPT=1,NCP=51,NZ=1,SIZE=0.1,MODE=2,LUN=50 $END
$CD FILD=1,IPSN=3,NCLS=2 $END
(2F10.3,3X,I2,2X,3A1,////////)
$VC BRDR=1 $END
$VC LABL=1,NLBY=-1,NLBX=-1,XMXL=2.0,YMXL=2.0,XMNL=0.0,YMNL=0.0,NDEC=0,ITYP=2 $END
$VC LETR=1,XCOR=1.5,YCOR=9.5,THET=0.0,NCH=100,SIZE=0.1,ITYP=1,ISCL=2 $END
BOTTOM COAL ELEVATION OF SEAM #2.ENCASUR PROPERTY.TEST 2F .
$VC PAUS=1,IPEN=1,MPEN=0 $END
$VC CTYP=1,SIZE=0.07,NDEC=0,LABR=2,BWID=2.0 $END
$VC CLV1=1,ZIDA=1,DEL=2.0,ICRT=1 $END
$VC PAUS=1,MPEN=3 $END
$VC REWD=1,LUN=40,ITYP=1 $END
$VC REWD=1,LUN=51,ITYP=1 $END
$VC POLY=1,MODE=1,NPC=86,ISCL=1,IFMT=2,LUN=51,IPRT=0,ISMB=0,LTYP=2 $END
(2F10.3)
$VC POLY=1,MODE=4,NPC=150,ISCL=1,IFMT=2,LUN=40,IPRT=0,ISMB=0,LTYP=2 $END
(2F10.3)
$VC NWPG=1$END
$VC STOP=1 $END

```

```

$VC JOB=1,NROW=60,NCOL=104,INOT=9999.99 $END
ENCASUR MINE CONTOURS DISPLAYS.GRIDDED DATA FILES.CPS-1.
$VC CXIC=1,XMIN=-4.,XMAX=48. $END
$VC CYIC=1,YMIN=-10.,YMAX=20. $END
$VC USUB=1,NSUB=1 $END
$VC PDEF=1,XSCL=4.,YSCL=4.,DX0=1.125,DY0=2.5,PSCL=1.0 $END
$VC CTPY=1,NDEC=0,SIZE=0.05,DIS1=1.5,BWID=2.0,LABR=2,BOLD=5,DIS2=1.0,$END
$VC PAUS=1,MPEN=2 $END
$VC POLY=1,IFMT=2,NPC=5,LTPY=2,ISMB=0,IPRT=0,LUN=35 $END
0.5 0.5 0.5 10.8 15.125 10.8 15.125 0.50 0.50 0.50
$VC PAUS=1,IPEN=2 $END
$VC BRDR=1 $END
$VC LABEL=1,SIZE=0.07,NLBX=-1,NLBY=-1,ITYP=2,NDEC=0,XXL=2.,YYL=2. $END
$VC LETR=1,XCOR=2.125,YCOR=3.5,THET=350.,NCH=0,ITYP=1,ISCL=2,SIZE=0.25, $END
$VC LETR=1,XCOR=1.125,YCOR=1.9,NCH=62,SIZE=0.21,THET=0.0,LUN=35 $END
      ENCASUR "EMMA" COAL MINE
$VC LETR=1,XCOR=1.125,YCOR=1.65,NCH=-66,SIZE=0.14,LUN=5 $END
$VC LETR=1,XCOR=1.125,YCOR=1.4,NCH=62,SIZE=0.10,LUN=35 $END
      SCALE: 1UNIT=63.5M.(208 FT.) Drawn by F. J. SAMANIEGO
$VC LETR=1,XCOR=1.125,YCOR=1.1,NCH=59,SIZE=0.10,LUN=35 $END
      SOLID RED LINE REPRESENTS THE BOUNDARY OF COAL SEAM #2
$VC LETR=1,XCOR=1.125,YCOR=0.8,NCH=62,SIZE=0.10,LUN=35 $END
      DASHED BLACK LINE REPRESENTS THE BOUNDARY OF COAL SEAM #3
$VC LETR=1,XCOR=1.125,YCOR=0.6,NCH=54,SIZE=0.10,LUN=35 $END
      GOLDEN,OCTOBER,28, 1982

$VC PAUS=1,IPEN=3,MPEN=3 $END
$VC POLY=1,MODE=1,IPRT=0,NPC=86,LTPY=1,ISMB=0,ISCL=1,IFMT=2,LUN=27$END
$VC PAUS=1,IPEN=2,MPEN=0 $END
$VC POLY=1,MODE=1,IPRT=0,ISMB=0,NPC=69,ISCL=1,IFMT=2,LUN=28,GAP=0.062,DASH=0.12
5 $
END
$VC CTPY=1,NDEC=0,SIZE=0.05,DIS1=1.5,BWID=2.0,LABR=2,BOLD=5,DIS2=1.0,$END
$VC CLV4=1,NCV=50,ICRT=1, $END
$VC PAUS=1,IPEN=3 $END
VEND
$VC INPT=1,ZIDC=1,LUN=20,IFMT=2,N2=1,IGRO=1,NCP=0,MODE=1 $END
(12F7.2)
$VC BLNK=1,ZIDA=1,ZIDC=2,NPC=86,ISID=2,IFMT=2,IPRT=0,LUN=27 $END
(2F10.3)
$VC STAT=1 $END
$VC REWD=1,LUN=27 $END
$VC CALL=1,NSUB=1,ZIDA=2,CUMN=38.0,DEL=-2.0 $END
(5(2F))
PREDICTED AFTER-PLANT ASH% OF SEAM #2.CONTOUR INTERVAL = 2%
(2F10.3)
(2F10.3)
$VC CTPY=1,NDEC=0,SIZE=0.05,DIS1=1.5,BWID=2.0,LABR=2,BOLD=5,DIS2=1.0,$END
$VC CLV4=1,NCV=50,ICRT=1,CUMN=40.0,ZIDA=2,DEL=2.0 $END
$VC N#JFG=1 $END
$VC STOP=1 $END

```

```
TY ASHTBK.CPS [,CPS
[9:44:46]
$VC JOB=1,NROW=60,NCOL=104 $END
CREATING AND PLOTTING ISOASH AND ISOPACHS.SEAM#2
$VC CXIC=1,XMIN=-4.0,XMAX=48.0 $END
$VC CYIC=1,YMIN=-10.0,YMAX=30.0 $END
$VC MGRD=2,LUN=40,DEL2=8.0,IFMT=2,NZ=2,NCP=43,SLM=15.,IANL=-1,LUNE=39 $END
(2F10.2,29X,2F8.2)
$VC STAT=1 $END
$VC PNCH=1,ZIDA=1,IFMT=1,LUN=51,NCP=0 $END
$VC PNCH=1,ZIDA=2,IFMT=1,LUN=52,NCP=0 $END
$VC STOP=1 $END
```

Appendix 2

Listings of Computer Programs Used for  
The Planning Block Model Generation

```

C      **** ASH39.XF4 ****
      DIMENSION A(81),B(81)
      DOUBLE PRECISION FILE
      WRITE(4,1)
1      FORMAT(' INPUT DATA FILENAME.:',*)
      READ(4,2)FILE
2      FORMAT(A10)
      OPEN(UNIT=30,FILE=FILE)
      DO 200 KI=1,45
      READ(30,3)(A(J),J=1,81)
3      FORMAT(81F5.2)
      DO 100 J=1,81
      B(J)='.'
      IF(A(J).GT.0.0.AND.A(J).LT.36.0)B(J)='-/'
      IF(A(J).GE.36.0)B(J)='*'
100     CONTINUE
      WRITE(32,4)(B(J),J=1,81)
4      FORMAT(81A1)
200     CONTINUE
      WRITE(32,2)FILE
      STOP
      END

```

```

C      *** ALFBET.XF4 ***
C----- THIS PROGRAM INITIALIZES ALPHA.UPD & BETA.UPD FILES -----
      DIMENSION A(81),B(81)
      OPEN(UNIT=30,FILE='DISPL.UPD')
      OPEN(UNIT=34,FILE='BETA.UPD')
      DO 100 K=1,11
      DO 100 I=1,45
      READ(30,2)(A(J),J=1,81)
2      FORMAT(81I1)
      DO 50 J=1,81
      B(J)=0.00
      IF(A(J).EQ.0)B(J)=1.0
50     CONTINUE
      WRITE(34,1)(B(J),J=1,81)
1      FORMAT(81F4.2)
100     CONTINUE
      CLOSE(UNIT=34,FILE='BETA.UPD')
      CLOSE(UNIT=30,FILE='DISPL.UPD')
      STOP
      END

```

```
C      THIS IS CODED.FOR
      DIMENSION ARRAY(60,104),BOUND(60,104)
      DOUBLE PRECISION A
      DATA (( BOUND(I,J),I=1,60),J=1,104)/6240*'..'/

      WRITE(4,1)
1      FORMAT(1X,'ENTER INPUT GRID FILENAME:',$)
      READ(4,2)A
2      FORMAT(A10)

      OPEN(UNIT=22,FILE=A,ACCESS='SEQIN')

      DO 100 I=1,60
      READ(22,3)(ARRAY(I,J),J=1,104)
C3     FORMAT(14(8E10.4,/),7E10.4)
3      FORMAT(7(13F7.2,/),13F7.2)
100    CONTINUE

      DO 1040 J=1,104
      DO 4 I=1,60
      IF(ARRAY(I,J) .EQ. 0.0) GO TO 4
      BOUND(I,J)='*'
4      CONTINUE
1040   CONTINUE

      OPEN(UNIT=16,FILE='CODED.DAT',ACCESS='SEQOUT')
      DO 400 I=1,60
      WRITE(16,7)(BOUND(I,J),J=1,104)
7      FORMAT(1X,104A1)
400    CONTINUE
      STOP 'A FILE "CODED.DAT" HAS BEEN CREATED'
      END
```

```
C      THIS IS CORTE.FOR PROGRAM TO GET X-SECTIONS.
      DIMENSION A(45,81,11)
      DOUBLE PRECISION F
      WRITE(4,210)
210     FORMAT(' ENTER FILENAME :',*)
      READ(4,211)F
211     FORMAT(A10)
      OPEN(UNIT=1,FILE=F)
      DO 100 K=1,11
      DO 110 I=1,45
      READ(1,1)(A(I,J,K),J=1,81)
110     CONTINUE
100     CONTINUE

300     WRITE(4,2)
2      FORMAT(' ENTER VERTICAL X-SECTION NUMBER (N-S) -0 TO QUIT-',*)
      READ(4,3)J
3      FORMAT(I)
      IF(J.EQ.0)STOP
      WRITE(4,6)J
6      FORMAT(/3X,' CROSS SECTION OF COLUMN #',14,' NORTH-SOUTH',/48('='),/)

      DO 200 K=1,11
      K1=12-K
      WRITE(4,7)(A(I,J,K1),I=1,45)
7      FORMAT(3X,45I1)
200     CONTINUE

1      FORMAT(81I1)
      GOTO300
      STOP
      END
```

```

C     *** CHECK1.XF4 ***
C     THIS PROGRAM CHECKS COORDINATION BETWEEN DISPL.UPD
C     AND COAL???.DAT FILES....
      DIMENSION NCODE(45,81,11)

      DOUBLE PRECISION FILE

      OPEN (UNIT=30,FILE='DISPL.UPD')
      DO 100 K=1,11
      DO 100 I=1,45
      READ(30,1)(NCODE(I,J,K),J=1,81)
100   CONTINUE

1     FORMAT(90I1)
      OPEN(UNIT=35,FILE="WASTEM.DAT")
      DO 1102 IW=1,2000
      READ(35,1104,END=1110)IW,JW,KW
1104  FORMAT(1X,3I2)
      IF(NCODE(IW,JW,KW).EQ.9)GO TO 1111
      IF(NCODE(IW,JW,KW).EQ.2)GO TO 1112
      IF(NCODE(IW,JW,KW).EQ.3)GO TO 1113
      IF(NCODE(IW,JW,KW).EQ.1)GO TO 1114
      IF(NCODE(IW,JW,KW).EQ.5)W5=W5+1
      WRITE(4,2222)IW,JW,KW
2222  FORMAT(' THIS BLOCK IS IN DISPL AS "5":',3I2)
      GO TO 1102
1111  WOK=WOK+1
      GO TO 1102
1112  W2=W2+1
      WRITE(4,2223)IW,JW,KW
2223  FORMAT(' THIS BLOCK IS "2":',3I2)
      GO TO 1102
1113  W3=W3+1
      WRITE(4,2224)IW,JW,KW
2224  FORMAT(' THIS BLOCK IS A "3":',3I2)
      GO TO 1102
1114  W1=W1+1
      WRITE(4,2225)IW,JW,KW
2225  FORMAT(' THIS BLOCK IS A "1":',3I2)
      GO TO 1102
1115  W5=W5+1
      WRITE(4,2226)IW,JW,KW
2226  FORMAT(' AND THIS BLOCK IS "5":',3I2)
1102  CONTINUE
1110  TW=IW-1
C     WRITE(4,1124)TW,WOK,W1,W2,W3,W5
C1124  FORMAT('*** TOTAL WASTE BLOCKS READ=',I5,'=====')
C     $ ,/'*** OK WASTE BLOCKS.....=',I5,

```

```

C   & /'*** SEAM2 OVERLAPPING.....=',15,
C   & /'*** SEAM3 OVERLAPPING.....=',15,
C   & /'*** TOPOG OVERLAPPING.....=',15,
C   & /'*** FULL1 OVERLAPPING.....=',15)

      STOP

      DO 390 K=4,8
      IF(K.EQ.4)FILE='COAL2D.DAT'
      IF(K.EQ.5)FILE='COAL2E.DAT'
      IF(K.EQ.6)FILE='COAL2F.DAT'
      IF(K.EQ.7)FILE='COAL2G.DAT'
      IF(K.EQ.8)FILE='COAL2H.DAT'
      OPEN(UNIT=31,FILE=FILE,ACCESS='SEQIN')
      READ(31,222)M
222  FORMAT(G)
      DO 1200 I2=1,M
      READ(31,20)N2,IC,JC,KC
20   FORMAT(I1,3I2,F7.0,F4.1,F5.2,F4.1)
      IF(NCODE(IC,JC,KC).EQ.2)GO TO 1199
      WRITE(4,2)N2,IC,JC,KC
      WRITE(4,333)NCODE(IC,JC,KC)
333  FORMAT(' *** THE NCODE IS =',I1,' ***')
      MS2=MS2+1
      GO TO 1200
1199 NCODE(IC,JC,KC)=7
      BS2=BS2+1
2    FORMAT(' THIS BLOCK IS NOT IN DISPL.UPD:',4I3)
1200 CONTINUE
      TOTM=TOTM+M
      CLOSE(UNIT=31)
390  CONTINUE
      DO 392 K=1,9
      IF(K.EQ.1)FILE='COAL3A.DAT'
      IF(K.EQ.2)FILE='COAL3B.DAT'
      IF(K.EQ.3)FILE='COAL3C.DAT'
      IF(K.EQ.4)FILE='COAL3D.DAT'
      IF(K.EQ.5)FILE='COAL3E.DAT'
      IF(K.EQ.6)FILE='COAL3F.DAT'
      IF(K.EQ.7)FILE='COAL3G.DAT'
      IF(K.EQ.8)FILE='COAL3H.DAT'
      IF(K.EQ.9)FILE='COAL3I.DAT'
      OPEN(UNIT=31,FILE=FILE,ACCESS='SEQIN')
      READ(31,222)M
      DO 1201 I2=1,M
      READ(31,20)N2,IC,JC,KC
      IF(NCODE(IC,JC,KC).EQ.3)GO TO 1211
C   WRITE(4,2)N2,IC,JC,KC

```

```

        MS3=MS3+1
        GO TO 1201
1211  NCODE(IC,JC,KC)=8
        BS3=BS3+1
1201  CONTINUE
        CLOSE (UNIT=31,FILE=FILE)
        TOTM=TOTM+M
392  CONTINUE

        DO 200 K=1,11
        DO 200 I=1,45
        DO 200 J=1,81
        IF(NCODE(I,J,K).EQ.7.OR.NCODE(I,J,K).EQ.8)N78=N78+1
        IF(NCODE(I,J,K).EQ.2.OR.NCODE(I,J,K).EQ.3)MM=MM+1
200  CONTINUE
3    FORMAT(' NCODE IS STILL UNCHANGED AT ',3I3)
        WRITE(4,445)MM,MS2,MS3
445  FORMAT(' BLOCKS IN DISPL.UPD NOT IN COALS=',I5
& ,/' BLOCKS SEAM2 NOT IN DISPL=',I5,'BLOCKS SEAM 3 NOT IN DISPL=',I5)
        WRITE(4,444)TOTM,BS2,BS3
444  FORMAT(' TOTAL READ CBLOCKS=',I5,'/OK S2=',I5,'/OK S3=',I5)
        WRITE(4,6280)N78
6280 FORMAT(' N78=',I6)
        STOP 'OK,SUCCESSFUL RUN'
        END

C    *** TALF.XF4 ***
C    THIS CHECKS VALUES OF ALPHA,BETA IN THE ARRAYS
        DIMENSION A(45,81,11)
        DOUBLE PRECISION FILE
300  READ(4,44)FILE
'44  FORMAT(A10)
        OPEN (UNIT=20,FILE=FILE)
        DO 100 K=1,11
        DO 100 I=1,45
        READ(20,1)(A(I,J,K),J=1,81)
100  CONTINUE
200  CONTINUE
2    FORMAT(' ENTER BLOCK COORDINATES (I,J,K):',3)
        WRITE(4,2)
        READ(4,3)I,J,K
3    FORMAT(3I)
1    FORMAT(81F4.2)
        WRITE(4,4)A(I,J,K),I,J,K
4    FORMAT(' VALUE=',F4.2,'(BLOCK=',3I2,')')
        GO TO 200
        STOP
        END

```

```

C      ***MINSIM.XF4***
C-----
      DOUBLE PRECISION FILE
      STON=0.0
      NRUN=0
100    WRITE(4,1)
1      FORMAT(' ENTER INPUT FILENAME...:',$)
      READ(4,2)FILE
2      FORMAT(A10)
      OPEN(UNIT=25,FILE=FILE)
      READ(25,3)NB
3      FORMAT(I)
      WRITE(26,3)NB
      DO 200 I=1,NB
      READ(25,4)N,I1,J,K,T,ASH,P,OVER,UNDER
4      FORMAT(I1,3I2,4F5.2,F4.1)
      D=1.6
      IF(N.EQ.2)D=1.534
      DP=2.1
      P=0
      IF(N.EQ.3)P=.15*T
      D1=((T-P)*D+P*DP)/T
      ACOAL=(T*ASH*D1-P*DP*100.)/((T-P)*D)
      TLIN=(T-P-.12)*.98*D+P*DP*.98*.2
      ASHS=((T-P-.12)*D*ACOAL+P*.2*DP*100.)*.98/TLIN
      TON=TLIN*31.75*31.75
      STON=STON+TON
      J=J-12
      I1=I1-11
      WRITE(26,5)N,I1,J,K,TON,ASHS,OVER,UNDER,T,ASH
5      FORMAT(I1,3I2,F7.0,F4.1,F5.2,F4.1,F5.2,F5.2)
200    CONTINUE
      CLOSE(UNIT=25)
      NRUN=NRUN+1
      IF(NRUN.EQ.14)GO TO 300
      GO TO 100
300    WRITE(4,6)STON
6      FORMAT(' TOTAL DEPOSIT TONNAGE.:',F12.0)
      CLOSE(UNIT=26)
      STOP
      END

```

```

C      ***TANGR.XF4*** .
C      THIS PROGRAM GENERATES THE ASH/ TON ARRAYS FOR BOTH SEAMS
C=====
      DIMENSION ASH2(45,81),ASH3(45,81),TON2(45,81),TON3(45,81)
      DIMENSION TONM2(45,81),TONM3(45,81),VOL2(45,81),VOL3(45,81)
      DOUBLE PRECISION FILE
      OPEN(UNIT=20,FILE='ASH2AP.GRD')
      OPEN(UNIT=21,FILE='TON2AP.GRD')
      OPEN(UNIT=22,FILE='TON2AM.GRD')

      OPEN(UNIT=23,FILE='CLAS2.GRD')
      OPEN(UNIT=24,FILE='CLAS3.GRD')
      DO 100 I=1,45
      DO 100 J=1,81
      ASH2(I,J)=0.
      ASH3(I,J)=0.
      TON2(I,J)=0.
      TON3(I,J)=0.
      VOL2(I,J)=0.
      VOL3(I,J)=0.
100    CONTINUE
          DO 390 K=4,8
          IF(K.EQ.4)FILE='COAL2D.DAT'
          IF(K.EQ.5)FILE='COAL2E.DAT'
          IF(K.EQ.6)FILE='COAL2F.DAT'
          IF(K.EQ.7)FILE='COAL2G.DAT'
          IF(K.EQ.8)FILE='COAL2H.DAT'
          OPEN(UNIT=30,FILE=FILE,ACCESS='SEQIN')
          READ(30,3)M
3        FORMAT(I)
          DO 1200 I2=1,M
          READ(30,20)N2,IC,JC,KC,TON1,ASH1,UP,WLO,TH1,AS0
          ASH2(IC,JC)=ASH1
          TON2(IC,JC)=TON1
          TONM2(IC,JC)=31.75**2*((TH1-.12-.2)*1.534+.2*2.1)
          VOL2(IC,JC)=31.75**2*(TH1+UP+WLO)
20        FORMAT(I1,3I2,F7.0,F4.1,F5.2,F4.1,F5.2,F4.1)
1200    CONTINUE
          CLOSE(UNIT=30)
390    CONTINUE
          DO 200 I=1,45
          WRITE(20,1)(ASH2(I,J),J=1,81)
          WRITE(21,2)(TON2(I,J),J=1,81)
          WRITE(23,2)(VOL2(I,J),J=1,81)
          WRITE(22,2)(TONM2(I,J),J=1,81)
1        FORMAT(81F5.2)
2        FORMAT(81F7.0)
200    CONTINUE

```

```

CLOSE(UNIT=20)
CLOSE(UNIT=21)
CLOSE(UNIT=22)
CLOSE(UNIT=23)

```

```

C----- AND NOW FOR SEAM # 3 -----
OPEN(UNIT=20,FILE='ASH3AP.GRD')
OPEN(UNIT=21,FILE='TON3AP.GRD')
OPEN(UNIT=22,FILE='TON3AM.GRD')
DO 392 K=1,9
  IF(K.EQ.1)FILE='COAL3A.DAT'
  IF(K.EQ.2)FILE='COAL3B.DAT'
  IF(K.EQ.3)FILE='COAL3C.DAT'
  IF(K.EQ.4)FILE='COAL3D.DAT'
  IF(K.EQ.5)FILE='COAL3E.DAT'
  IF(K.EQ.6)FILE='COAL3F.DAT'
  IF(K.EQ.7)FILE='COAL3G.DAT'
  IF(K.EQ.8)FILE='COAL3H.DAT'
  IF(K.EQ.9)FILE='COAL3I.DAT'
OPEN(UNIT=30,FILE=FILE,ACCESS='SEQIN')
READ(30,3)M
  DO 1201 I2=1,M
    READ(30,20)N2,IC,JC,KC,TON1,ASH1,UP,WLO,TH1,ASO
    ASH3(IC,JC)=ASH1
    TON3(IC,JC)=TON1
    VOL3(IC,JC)=31.75**2*(TH1+UP+WLO)
    TONM3(IC,JC)=31.75**2*((TH1-.12-.57)*1.6+2.1*.57)
1201  CONTINUE
CLOSE(UNIT=30)
392  CONTINUE
DO 400 I=1,45
  WRITE(20,1)(ASH3(I,J),J=1,81)
  WRITE(21,2)(TON3(I,J),J=1,81)
  WRITE(22,2)(TONM3(I,J),J=1,81)
  WRITE(24,2)(VOL3(I,J),J=1,81)
400  CONTINUE
CLOSE(UNIT=20)
CLOSE(UNIT=21)
CLOSE(UNIT=22)
CLOSE(UNIT=24)
STOP
END

```

```

C----- *** ASH2.XF4 *** -----
C      THIS PROGRAM SIMULATES THE ASH VALUES OF SEAM 2 AFTER PROCESSING
      DOUBLE PRECISION FILE
      STON=0.0
      NRUN=0
100    WRITE(4,1)
1      FORMAT(' ENTER INPUT FILENAME...:',$)
      READ(4,2)FILE
2      FORMAT(A10)
      OPEN(UNIT=25,FILE=FILE)
      READ(25,3)NB
3      FORMAT(I)
      WRITE(26,3)NB
      DO 200 I=1,NB
      READ(25,4)N,I1,J,K,TON,ASH,OVER,UNDER,T,A
4      FORMAT(I1,3I2,F7.0,F4.1,F5.2,F4.1,F5.2,F4.1)
      D=1.534
      DP=2.1
      P=0.2
      D1=((T-P)*D+P*DP)/T
      ACCOAL=(T*ASH*D1-P*DP*100.)/((T-P)*D)
      TLIN=(T-P-.12)*.98*D+P*DP*.98*.2
      ASHS=((T-P-.12)*D*ACCOAL+P*.2*DP*100.)*.98/TLIN
      TON=TLIN*31.75*31.75
      STON=STON+TON
      WRITE(26,5)N,I1,J,K,TON,ASHS,OVER,UNDER,T,A
5      FORMAT(I1,3I2,F7.0,F4.1,F5.2,F4.1,F5.2,F5.2)
200    CONTINUE
      CLOSE(UNIT=25)
      NRUN=NRUN+1
      IF(NRUN.EQ.5)GO TO 300
      GO TO 100
300    WRITE(4,6)STON
6      FORMAT(' TOTAL SEAM2 TONNAGE.:',F12.0)
      CLOSE(UNIT=26)
      STOP
      END

```

```

C      *** XSECT1.FOR ***
      COMMON NCODE(81,11)
      DOUBLE PRECISION FILE
91     FORMAT(A10)
      WRITE(4,9)
9      FORMAT(' ENTER FILE NAME:',*)
      READ(4,91)FILE
1111  WRITE(4,4)
4      FORMAT(' ENTER THE DESIRED CROSS-SECTION NUMBER (I):',*)
      READ(4,5)IX
5      FORMAT(2I)
      OPEN (UNIT=31,FILE=FILE,ACCESS='SEQIN')
33     DO 300 K=1,11
          IF(IX.EQ.1)GO TO 200
          DO 320 I1=1,IX-1
          READ(31,31)IDUM
320    CONTINUE
200    READ(31,31)(NCODE(J,K),J=1,81)
31     FORMAT(8111)
          IF(1.EQ.45)GO TO 300
          DO 330 I1=IX+1,45
          READ(31,31)IDUM
330    CONTINUE
300    CONTINUE
C.....Once the input has been made,the x-sections are printed:...
C.....
      WRITE(4,43)I,FILE
43     FORMAT(///,' CROSS-SECTION OF THE ROW I=',I2,8X,A10,/,48('_'),/)
      DO 1000 K=1,11
          K2=12-K
          WRITE(4,22)(NCODE(J,K2),J=1,81)
22     FORMAT(1X,8111)
1000  CONTINUE
      CLOSE (UNIT=31,FILE=FILE,ACCESS='SEQIN')
100   CONTINUE
      WRITE(4,443)
443   FORMAT(//' ANOTHER RUN ? (Y/N):',*)
      READ(4,777)MN
777   FORMAT(A1)
      IF(MN.EQ.'Y')GO TO 1111
      STOP
      END

```

```

C      THIS IS JOINT.FOR SUBROUTINE.
      SUBROUTINE JOINT(BLOCK,TYPE,VALUE,TOTAL,NT,N,JMIN,JMAX)
      DIMENSION BLOCK(200),TYPE(200),VALUE(200),TOTAL(3,200)
      DIMENSION JB(200)
      INTEGER BLOCK

C***** DATA<(TOTAL(I,J),I=1,3),J=1,200) /600*0.0/

      DO 100 I=1,N
      JB(I)=(BLOCK(I)-(BLOCK(I)/10000)*10000)/100
100    CONTINUE

      NT=0
      DO 200 J=JMAX,JMIN,-1

          DO 210 I=1,N
          IF(JB(I).EQ.J)GO TO 220
          GO TO 210

220    CONTINUE
      IF(TYPE(I).EQ.'X2'.OR.TYPE(I).EQ.'Y2')NBL=BLOCK(I)+2000000
      IF(TYPE(I).EQ.'X3'.OR.TYPE(I).EQ.'Y3')NBL=BLOCK(I)+3000000
      DO 230 IT=1,NT
      I2=IT
      IF(NBL.EQ.TOTAL(I,I2))GO TO 240
230    CONTINUE

          NT=NT+1
          TOTAL(I,IT)=NBL
240    IF(TYPE(I).EQ.'X2'.OR.TYPE(I).EQ.'X3')TOTAL(2,IT)=VALUE(I)
          IF(TYPE(I).EQ.'Y2'.OR.TYPE(I).EQ.'Y3')TOTAL(3,IT)=VALUE(I)
210    CONTINUE
200    CONTINUE
      WRITE(4,250)NT
250    FORMAT(' TOTAL NUMBER OF BLOCKS INVOLVED:',I4)
      RETURN
      END

```

Appendix 3

Linear Programming Matrix Generator Code

```

      OPTIONS DEBUG
      PROGRAM LP
C     ***** LP.XF4 *****
C     MINOS RUN FILE GENERATOR
C     =====
      DOUBLE PRECISION OBJ, RUNAME, FILE
      DIMENSION NCODE(45,10,11), TON2(45,10), TON3(45,10), ASH2(45,10), ASH3(45,10)
      DIMENSION BETA(45,10,11), TONM2(45,10), TONM3(45,10), UNCO(10)
      DIMENSION IAIB2(2,10), IAIB3(2,10)
      REAL MI, MX, LEVASH
      INTEGER E, PL, BELL
      DATA BELL/007/
      OPEN(UNIT=31, FILE='DISPL.UPD')
      OPEN(UNIT=34, FILE='BETA.UPD', ACCESS='SEQIN')
      OPEN(UNIT=22, FILE='MINOSX.CON', ACCESS='SEQOUT')
      OPEN(UNIT=23, FILE='MINOSY.CON', ACCESS='SEQOUT')
      OPEN(UNIT=27, FILE='SEQNCE.DAT')
      OPEN(UNIT=26, FILE='RHS.CON', ACCESS='SEQOUT')
      OPEN(UNIT=25, FILE='MINOSZ.CON', ACCESS='SEQOUT')
      OPEN(UNIT=32, FILE='ROWS.CON', ACCESS='SEQOUT')
      OPEN(UNIT=24, FILE='MINOSV.CON', ACCESS='SEQOUT')

C#####
C##### INPUT PROBLEM DEFINITION PARAMETERS #####
C#####
      WRITE(4,1)
1     FORMAT(3X, 'ENTER WINDOW FOR SEAM #2 (JMIN, JMAX):', $)
      READ(4,2) JMIN2, JMAX2
      WRITE(4,3)
3     FORMAT(3X, 'ENTER WINDOW FOR SEAM #3 (JMIN, JMAX):', $)
2     FORMAT(2I)
      READ(4,2) JMIN3, JMAX3
C     WRITE(4,4)
4     FORMAT(3X, 'ENTER PERIOD LENGTH (MONTHS):', $)
C     READ(4,2) PL
      WRITE(4,5)
5     FORMAT(3X, 'ENTER RUN NUMBER :', $)
      READ(4,2) NRUN
      WRITE(4,6)
6     FORMAT(3X, 'ENTER POST-PROCESSING STOCKPILE RESERVES (Tm):', $)
      READ(4,7) RSTOKQ
7     FORMAT(2G)
      WRITE(4,11)
11    FORMAT(3X, 'ENTER OBJECTIVE FUNCTION NAME (8 char.):', $)
      READ(4,10) OBJ
10    FORMAT(A8)
C     WRITE(4,12)
12    FORMAT(3X, ' ENTER AVAILABLE IN-PIT DUMP SPACE (M3):', $)

```

```

C      READ(4,7)DISVOL
14     FORMAT(A1)
       WRITE(4,16)
16     FORMAT(3X,' DO YOU WANT CROSS SECTIONS PRINTED?(Y/N).:','$)
       READ(4,14)VIEW
       WRITE(4,44144)
44144  FORMAT(' BLOCK-TIME ALLOCATION MANUAL (M) OR AUTOMATIC (A):','$)
       READ(4,44145)TBA
44145  FORMAT(A1)
       AMAX=36.0
C***** LOAD DATA FROM COALS DATA FILES *****

```

```

       MRU='N'
       NNB=JMAX2-JMIN3+1
       NNB2=JMAX2-JMIN2+1
       NNB3=JMAX3-JMIN3+1
C----- ENTER UPDATED DATA FILES -----
C----- DISPL.UPD -----
C----- READ BETA ARRAY -----
       JM=JMIN3-1
           DO 380 K=1,11
           DO 379 I=1,45
           READ(31,17)(DUMMY,IZ=1,JM),(NCODE(I,J,K),J=1,NNB)
17         FORMAT(10411)
           READ(34,19)(DUMB,NN=1,JM),(BETA(I,J,K),J=1,NNB)
19         FORMAT(81F4.2)
           DO 782 J=1,NNB
           IF(NCODE(I,J,K).EQ.2.AND. J.LT.(JMIN2-JMIN3+1))NCODE(I,J,K)=0
           IF(NCODE(I,J,K).EQ.3.AND. J.GT.(JMAX3-JMIN3+1))NCODE(I,J,K)=0
782        CONTINUE
379        CONTINUE
380        CONTINUE
C----- FOR SEAM # 2 -----
       SUMT2=0.0
       ASHT2=0.0
       OPEN(UNIT=36,FILE='TON2AP.GRD')
       OPEN(UNIT=37,FILE='TON2AM.GRD')
       OPEN(UNIT=38,FILE='ASH2AP.GRD')
       DO 390 I=1,45
       READ(36,20)(DUMMY,IZ=1,JM),(TON2(I,J),J=1,NNB)
20     FORMAT(81F7.0)
       READ(37,20)(DUMMY,IZ=1,JM),(TONM2(I,J),J=1,NNB)
       READ(38,21)(DUMMY,IZ=1,JM),(ASH2(I,J),J=1,NNB)
C     WRITE(4,21)(ASH2(I,J),J=1,NNB)

```

```

390  CONTINUE
      CLOSE(UNIT=36)
      CLOSE(UNIT=37)
      CLOSE(UNIT=38)
21   FORMAT(81F5.2)
      DO 1203 I=1,45
      DO 1203 J=JMIN2-JMIN3+1,NNB
          DO 1200 K=1,11
              IF(NCODE(I,J,K).EQ.2)GO TO 1222
1200  CONTINUE
      GO TO 1203
1222  SUMT2=SUMT2+TON2(I,J)*(1-BETA(I,J,K))
      ASHT2=ASHT2+TON2(I,J)*(1-BETA(I,J,K))*ASH2(I,J)
      IF(ASH2(I,J).LE.AMAX)TONOK=TONOK+TON2(I,J)*(1-BETA(I,J,K))
      IF(ASH2(I,J).LE.AMAX)ASHOK=ASHOK+TON2(I,J)*ASH2(I,J)*(1-BETA(I,J,K))
1203  CONTINUE
      ASHV62=ASHT2/SUMT2
      WRITE(4,1184)SUMT2,ASHV62
1184  FORMAT(/,' TOTAL INPUT TONNAGE OF SEAM 2 IS',F10.0,' 2 ',F5.2,'% ASH')
388  FORMAT(' LINE=',I4)

```

C----- AND NOW FOR SEAM # 3 -----

```

      SUMT3=0.0
      ASHT3=0.0
      OPEN(UNIT=36,FILE='TON3AP.GRD')
      OPEN(UNIT=37,FILE='TON3AM.GRD')
      OPEN(UNIT=38,FILE='ASH3AP.GRD')
      DO 392 I=1,45
      READ(36,20)(DUMMY,I2=1,JM),(TON3(I,J),J=1,NNB)
      READ(37,20)(DUMMY,I2=1,JM),(TONM3(I,J),J=1,NNB)
C    WRITE(4,20)(TON3(I,J),J=1,NNB)
      READ(38,21)(DUMMY,I2=1,JM),(ASH3(I,J),J=1,NNB)
392  CONTINUE
      CLOSE(UNIT=36)
      CLOSE(UNIT=37)
      CLOSE(UNIT=38)
      DO 1204 I=1,45
      DO 1204 J=1,NNB3
          DO 1201 K=1,11
              IF(NCODE(I,J,K).EQ.3)GO TO 1223
1201  CONTINUE
      GO TO 1204
1223  SUMT3=SUMT3+TON3(I,J)*(1-BETA(I,J,K))
      ASHT3=ASHT3+TON3(I,J)*(1-BETA(I,J,K))*ASH3(I,J)
      IF(ASH3(I,J).LE.AMAX)TONOK=TONOK+TON3(I,J)*(1-BETA(I,J,K))
      IF(ASH3(I,J).LE.AMAX)ASHOK=ASHOK+TON3(I,J)*ASH3(I,J)*(1-BETA(I,J,K))
1204  CONTINUE

```

```

      ASHVG3=ASHT3/SUMT3
      WRITE(4,1524)SUMT3,ASHVG3
1524  FORMAT(' TOTAL INPUT TONNAGE OF SEAM 3 IS',F10.0,' @ ',F5.2,'% ASH')
      TTT=SUMT2+SUMT3
      AAA=ASHT2+ASHT3
      AAAVGE=AAA/TTT
      WRITE(4,1534)TTT,AAAVGE,BELL
1534  FORMAT(1X,79('-'),/' TOTAL INPUT TONNAGE (OVERALL) IS',F10.0,' @ ',F5.2,
      & '% ASH',1R1)
      ASOK=ASHOK/TONOK
      WRITE(4,8)AMAX,TONOK,ASOK
8      FORMAT(' TOTAL INPUT TONNAGE UNDER',F6.2,'% IS',F10.0,' @ ',F6.2,'% ASH')

1620  FORMAT(' END OF INPUT DATA ')
      WRITE(4,1620)
      WRITE(4,22)
22     FORMAT(3X,'ENTER DESIRED PRODUCTION PER PERIOD :',%)
      READ(4,23)TONDEM
23     FORMAT(G)
      ABAD=(AAA-ASHOK)/(TTT-TONOK)
      T=TONOK*(ASOK-AMAX)/(AMAX-ABAD)
      IF((T+TONOK).GT.TTT)T=TTT-TONOK
      NREC=1+(TONOK+T)/TONDEM
      WRITE(4,24)NREC
24     FORMAT(' MAXIMUM NUMBER OF PERIODS=',I2)
      WRITE(4,18)
      READ(4,2)NP
18     FORMAT(3X,'HOW MANY PERIODS ARE TO BE RUN SIMULTANEOUSLY?:',%)
      IF(TBA.EQ.'M')CALL BLKTIM(ASH2,ASH3,TON2,TON3,NNB,IA1B2,
      & NCODE,AMAX,NP,IA1B3,NNB2,NNB3,JMIN2,JMAX2,JMIN3)
C***** INITIATE A SEARCH FOR THE BLOCKS RELATIONSHIPS *****
C
C----- FOR SEAM # 2 -----
      WRITE(4,1842)
1842  FORMAT(' CALL SEARCH TO GENERATE SEQUENCE.DAT?(Y/N):',%)
      READ(4,14)SS
      B2=0
      OPEN(UNIT=21)
      IF(SS.EQ.'N')GO TO 1983
      GO TO 1981
1983  WRITE(4,1984)
1984  FORMAT(' ENTER NUMBER OF SEQUENCE EQUATIONS:',%)
      READ(4,2)NEQ
C      IF(VIEW.EQ.'Y')GO TO 1981
      GO TO 1982
1981  DO 230 I=1,45
      DO 220 J=NNB-NNB2+1,NNB
      DO 220 K=1,11

```

```

                IF(NCODE(I,J,K).NE.2)GO TO 220
                B2=B2+1
C                IF(SS.EQ.'N')GO TO 220
                CALL SEARCH(J,K,NNB,NCODE,I,MRU,NEQ,BETA,JMIN3,NNB3)
220                CONTINUE
221                IF(VIEW.EQ.'N')GO TO 230
                CALL XSECTN(I,NNB,NCODE)
230                CONTINUE

                WRITE(4,1530)B2
1530                FORMAT(' DETECTED #2 SEAM BLOCKS=',I2)
C----- AND NOW FOR SEAM # 3 -----
                B3=0
C                IF(SS.EQ.'N')GO TO 1982
                DO 231 I=1,45
                DO 2210 J=1,NNB3
                DO 2210 K=1,11
                IF(NCODE(I,J,K).NE.3)GO TO 2210
                CALL SEARCH(J,K,NNB,NCODE,I,MRU,NEQ,BETA,JMIN3,NNB3)
                B3=B3+1
2210                CONTINUE
231                CONTINUE
                WRITE(4,1610)B3
1610                FORMAT(' DETECTED #3 SEAM BLOCKS=',I2)
1982                CLOSE(UNIT=27,FILE='SEQNCE.DAT')
                CLOSE(UNIT=21)
                WRITE(4,2)NEQ
C***** WRITE HEADINGS IN MINOS FILES *****
2080                WRITE(4,30)BELL
30                FORMAT(3X,'ENTER MINOS FILE HEADING (MAX 30 CHR.):',1R1)
                READ(4,31)A1,A2,A3,A4,A5,A6
31                FORMAT(6A5)
                WRITE(32,32)A1,A2,A3,A4,A5,A6
32                FORMAT('NAME',4X,6A5)
                WRITE(32,33)
33                FORMAT('ROWS')
                WRITE(32,34)OBJ
34                FORMAT(2X,'N',2X,A8)
                DO 501 NT=1,NP
C                IF(NT.EQ.NP)GO TO 36
                WRITE(32,503)NT
                WRITE(32,511)NT
36                WRITE(32,504)NT
C                WRITE(32,505)NT
C                WRITE(32,506)NT
                WRITE(32,507)NT
                WRITE(32,508)NT
                WRITE(32,509)NT

```

```

C          WRITE(32,510)NT
501         CONTINUE
503         FORMAT(2X,'G',2X,I3,'DLTON')
511         FORMAT(2X,'G',2X,I3,'DLTONL')
504         FORMAT(2X,'L',2X,I3,'ASHMX')
505         FORMAT(2X,'L',2X,I3,'UNCMX')
506         FORMAT(2X,'G',2X,I3,'UNCMN')
507         FORMAT(2X,'L',2X,I3,'STKMX')
508         FORMAT(2X,'G',2X,I3,'STKMN')
509         FORMAT(2X,'L',2X,I3,'STKASH')
510         FORMAT(2X,'L',2X,I1,'DUMP')
          NNROWS=1+6*NP-1
          WRITE(22,39)
39          FORMAT('COLUMNS')
          WRITE(26,40)
40          FORMAT('RHS')
           DO 35 IP1=1,NP
           TDEM=TQNDM
           IF(IP1.EQ.1)TDEM=TDEM-RSTOKQ
           TDEMU=TDEM+5000.
           TDEML=TDEM-5000.
           T1=0.0
           IF(IP1.EQ.NP)GO TO 602
           WRITE(26,601)NRUN,IP1,TDEMU,IP1,TDEML
601          FORMAT(1X,I3,'RUN',3X,I2,'DLTON',F10.0,3X,I2,'DLTONL',F10.0)
602          AKMX=10000.
           AKMN=6000.
           IF(IP1.EQ.NP)AKMX=100000.
           IF(IP1.EQ.NP)AKMN=0.
           WRITE(26,603)NRUN,IP1,AKMX,IP1,AKMN
603          FORMAT(1X,I3,'RUN',3X,I2,'STKMX',F8.0,2X,I2,'STKMN',F7.0)
           WRITE(26,604)NRUN,IP1,IP1,T1
604          FORMAT(1X,I3,'RUN',3X,I2,'STKASH',5X,'0.0',2X,I2,'ASHMX',F10.0)
35          CONTINUE
           NOZERO=NOZERO+NP*6-1
2490         FORMAT(' END OF HEADINGS',1R1)
           WRITE(4,2490)BELL
C***** END OF HEADINGS *****
C
C***** WRITE THE REST OF THE MINOS DATA FILE *****

          WRITE(4,2590)
2590         FORMAT(' -----START OF 550 LOOP-----')
           OPEN(UNIT=21)

```

```

OPEN(UNIT=27,FILE='SEQNCE.DAT')
NBLOCK=0
DO 550 K=1,11
DO 550 JK=1,NNB
J=JK
DO 550 I=1,45
IF(BETA(I,J,K).EQ.1.0)GO TO 550
IF(NCODE(I,J,K).NE.2.AND.NCODE(I,J,K).NE.3)GO TO 550
JJ1=JMIN2-JMIN3+1
IF(NCODE(I,J,K).EQ.2.AND.J.LT.JJ1)GO TO 550
JJ1=JMAX3-JMIN3+1
IF(NCODE(I,J,K).EQ.3.AND.J.GT.JJ1)GO TO 550
C          THIS BLOCK IS IN THE FORMULATION ZONE
C          WRITE QUANTITY AND QUALITY CONSTRAINTS
C
C----- CHECK FOR INDEPENDENCY -----

NNCOL=2
IF(NZ.EQ.1)NNCOL=NNCOL+1
IF(NZ.EQ.0)NNCOL=NNCOL+1
C THIS ACCOUNTS FOR X AND V VARIABLES
INDEP=1
DO 401 N=1,1000
READ(27,52,END=2900)I3,J3,K3
52  FORMAT(3I2)
IF(I.EQ.I3.AND.J.EQ.J3.AND.K.EQ.K3)GO TO 402
401  CONTINUE
GO TO 2900
402  INDEP=0
2900  REWIND 27
C----- COUNT BLOCK AND WRITE -----
,
IF(NCODE(I,J,K).EQ.2)DTON=TON2(I,J)*(1.-BETA(I,J,K))
IF(NCODE(I,J,K).EQ.3)DTON=TON3(I,J)*(1.-BETA(I,J,K))
IF(NCODE(I,J,K).EQ.2)ASHA=ASH2(I,J)
IF(NCODE(I,J,K).EQ.3)ASHA=ASH3(I,J)
IF(NCODE(I,J,K).EQ.2)DMTON=TONM2(I,J)*(1.-BETA(I,J,K))
IF(NCODE(I,J,K).EQ.3)DMTON=TONM3(I,J)*(1.-BETA(I,J,K))

NZ=0
IF(ASHA.GT.AMAX)NZ=1
INIT=1
NBLOCK=NBLOCK+1
C WRITE(4,2845)I,J,K,NCODE(I,J,K),NBLOCK,NZ,BELL
2845  FORMAT(' USING BLOCK :',4I2,' BLOCK #',2I3,1R1)
NAME=1000*I+100*(J+JMIN3-1)+K
DASH=DTON*(ASHA-AMAX)
TDTON=TDTON+DTON

```

```

      TDASH=TDASH+DASH
C     CALL VOLWAS(I,J,K,VOL,JMIN2,DUMP)
      CALL TAIL(I,J,K,NEQ,ITAIL)

      NCOD=NCODE(I,J,K)
      IF(TBA.EQ.'M')GO TO 3250
      CALL PERIOD(NNB2,NNB3,NNB,NP,J,IA,IB,NCOD)
      GO TO 3255
3250  IA=IAIB2(1,J)
      IB=IAIB2(2,J)
      IF(NCOD.EQ.3)IA=IAIB3(1,J)
      IF(NCOD.EQ.3)IB=IAIB3(2,J)
3255  RHSU=1.0-BETA(I,J,K)
      IF(INDEP.EQ.1.OR.(ITAIL.EQ.1))GO TO 608
C     IF(INDEP.EQ.1)GO TO 608
      GO TO 404
608   WRITE(26,605)NRUN,NBLOCK,RHSU
      NOZERO=NOZERO+1
605   FORMAT(1X,13,'RUN',3X,13,'UNIT',5X,F4.2)
      WRITE(32,6080)NBLOCK
6080  FORMAT(2X,'E',2X,13,'UNIT')
      NNROWS=NNROWS+1
C***** INITIATE A LOOP FOR PERIODS WITHIN BLOCK *****

404   NCOL=NCOL+(IB-IA+1)*NNCOL
      WRITE(4,4044)I,J,K,NCOD,IA,IB
4044  FORMAT(2X,4I2,' IA=',13,' IB=',13)
      DO 530 IP1=IA,IB
C----- WRITE OBJECTIVE FUNCTION COEFFICIENTS -----
C----- GENERATE THE PRIORITY BONUSES -----
      IIAA=I-23
      OBCX=(60.-ASHA)*100
      IF(NZ.EQ.0)OBCX=100000
C     IF(NZ.EQ.0)GO TO 3356
      OBCX=OBCX-IABS(IIAA)
      IF(NZ.EQ.1)OBCZ=-ASHA+AMAX
          WRITE(22,531)NAME,IP1,OBJ,OBCX
          NOZERO=NOZERO+1
          WRITE(24,3442)NAME,IP1,OBJ,OBCX
          NOZERO=NOZERO+1
3442  FORMAT(2X,16,'V',11,3X,A8,F10.2,2X)
531   FORMAT(2X,16,'X',11,3X,A8,F10.2,2X)
C     IF(NZ.EQ.1)WRITE(25,3455)NAME,IP1,OBJ,OBCZ
      OBCY=-OBCX*100
      IF(NZ.EQ.0)WRITE(23,3454)NAME,IP1,OBJ,OBCY
      NOZERO=NOZERO+1

```

```

3455          FORMAT(2X,16,'Z',11,3X,A8,F10.0)
3454          FORMAT(2X,16,'Y',11,3X,A8,F10.0)
C----- END OF OBJECTIVE FUNCTION COEFFICIENTS -----
C----- WRITE DLTON, ASHMAX COEFFICIENTS -----
3356  IF(IP1.EQ.NP)GO TO 3244
3460  WRITE(22,3240)NAME,IP1,IP1,DTON,IP1,DTON
3240          FORMAT(2X,16,'X',11,4X,12,'DLTON',F10.0,4X,12,'DLTONL',F10.0)
          NOZERO=NOZERO+2
3244  IF(IP1.EQ.1B)GO TO 3242
15    IP2=IP1+1
          IF(IP2.EQ.NP)GO TO 3242
          WRITE(24,3243)NAME,IP1,IP2,DTON,IP2,DTON
3243          FORMAT(2X,16,'V',11,4X,12,'DLTON',F10.0,4X,12,'DLTONL',F10.0)
          NOZERO=NOZERO+2
3242          WRITE(22,532)NAME,IP1,IP1,DASH
          NOZERO=NOZERO+1
532          FORMAT(2X,16,'X',11,4X,12,'ASHMX',F10.0)
          IP11=IP1+1
C----- STOKMAX,STOKMIN,STOKASH CONSTRAINTS -----
5410          CONTINUE
          WRITE(24,552)NAME,IP1,IP1,DMTON,IP1,DMTON
          NOZERO=NOZERO+2
552          FORMAT(2X,16,'V',11,4X,12,'STKMX',F10.0,2X,12,'STKMN',F10.0)
          WRITE(24,553)NAME,IP1,IP1,DASH
          NOZERO=NOZERO+1
553          FORMAT(2X,16,'V',11,4X,12,'STKASH',2X,F12.0)
C----- UNIT CONSTRAINTS -----

559          IF((INDEP.EQ.1).OR.(ITAIL.EQ.1))GO TO 3810
C559  IF(INDEP.EQ.1)GO TO 3810
          GO TO 562
3810          WRITE(22,560)NAME,IP1,NBLOCK
          NOZERO=NOZERO+1
560          FORMAT(2X,16,'X',11,3X,13,'UNIT',5X,'1.0')
          WRITE(24,5600)NAME,IP1,NBLOCK
          NOZERO=NOZERO+1
5600          FORMAT(2X,16,'V',11,3X,13,'UNIT',5X,'1.0')
          IF(NZ.EQ.0)GO TO 3910
          WRITE(25,5601)NAME,IP1,NBLOCK
          NOZERO=NOZERO+1
5601          FORMAT(2X,16,'Z',11,3X,13,'UNIT',5X,'1.0')
          GO TO 4480
3910          WRITE(23,5602)NAME,IP1,NBLOCK
          NOZERO=NOZERO+1
5602          FORMAT(2X,16,'Y',11,3X,13,'UNIT',5X,'1.0')
4480          CONTINUE

```

```

562      CALL SEQENS(I,J,K,NEQ,JMIN3,BETA,NZ,NCODE,IP1,INDEP
&      ,NOZERO,NRUN,NNROWS,NBLOCK,NNB2,NNB3,NNB,NP,INIT,TBA,IAIB2,IAIB3)

```

```

C-----+++++++-----

```

```

530      CONTINUE

```

```

550      CONTINUE

```

```

403      CLOSE(UNIT=21)

```

```

C

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```

C----- WRITE THE FINAL LINES AND CLOSE FILES -----

```

```

2626     WRITE(26,2626)
        FORMAT(2X,'ENDATA')
        CLOSE(UNIT=31,FILE='DISPL.UPD',ACCESS='SEQIN')
        CLOSE(UNIT=32,FILE='ROWS.CON',ACCESS='SEQOUT')
        CLOSE(UNIT=22,FILE='MINOSX.CON',ACCESS='SEQOUT')
        CLOSE(UNIT=23,FILE='MINOSY.CON',ACCESS='SEQOUT')
        CLOSE(UNIT=27,FILE='SEQNCE.DAT')
        CLOSE(UNIT=25,FILE='MINOS2.CON',ACCESS='SEQOUT')
        CLOSE(UNIT=24,FILE='MINOSV.CON',ACCESS='SEQOUT')
        CLOSE(UNIT=26,FILE='RHS.CON',ACCESS='SEQOUT')
        WRITE(4,60)NNROWS,BELL
60      FORMAT(3X,'THE MATRIX HAS ',15,' ROWS',2R1)
        NCOL=NCOL+1
        WRITE(4,62)NCOL,BELL,BELL
62      FORMAT(3X,'THE MATRIX HAS ',15,' COLUMNS',2R1)
        WRITE(4,61)NOZERO,BELL,BELL,BELL
61      FORMAT(3X,'THE MATRIX HAS ',15,' NON ZERO VALUES',3R1)
        STOP
        END

```

```

C#####
C##### SUBROUTINE HORIZ #####
C#####

```

```

        SUBROUTINE HORIZ(I,J1,K1,JMIN,J2,NCODE,NNB3)
        DIMENSION NCODE(45,10,11)
        J2=J1
        DO 700 J=JMIN,J1-1
        JA=J1-1-J+JMIN
        NC=NCODE(I,JA,K1)
        IF(NC.EQ.2.OR.(NC.EQ.3))GO TO 710
700      CONTINUE
        GO TO 720
710      J2=JA

```

```

720  CONTINUE
711  RETURN
      END

```

```

C#####
C##### SUBROUTINE XSECTN #####
C#####

```

```

      SUBROUTINE XSECTN(I,NNB,NCODE)
      DIMENSION NCODE(45,10,11)
C
      WRITE(4,43)I
43    FORMAT(3X,' CROSS-SECTION OF THE ROW I=',I2)
      DO 1000 K=1,11
      K2=12-K
      WRITE(4,22)(NCODE(I,J,K2),J=1,NNB)
22    FORMAT(1X,104I1)
1000  CONTINUE
      RETURN
      END

```

```

C#####
C##### SUBROUTINE PERIOD #####
C#####

```

```

      SUBROUTINE PERIOD(NNB2,NNB3,NNB,NP,J,IA,IB,NCOD)
      NNC=NNB2
      IF(NCOD.EQ.3)NNC=NNB3
      XMNC=FLOAT(NNC)/FLOAT(NP)
      XNPJ=FLOAT(J)/XMNC
      NPJ=INT(XNPJ+.5)-1
      IA=NPJ-1
      IB=NPJ+1
      IF(NP.EQ.2)IA=1
      IF(NP.EQ.2)IB=2
      IF(IA.LT.1)IA=1
      IF(IA.GT.NP)IA=NP
      IF(IB.GT.NP)IB=NP
      RETURN
      END

```

```
C#####  
C##### SUBROUTINE TAIL #####  
C#####  
      SUBROUTINE TAIL(I,J,K,NEQ,ITAIL)  
        ITAIL=0  
        DO 100 N=1,NEQ  
          READ(27,1)I1,J1,K1,I2,J2,K2  
1         FORMAT(2(3I2,3X))  
          IF(I.EQ.I2.AND.J.EQ.J2.AND.K.EQ.K2)GO TO 200  
100        CONTINUE  
          ITAIL=1  
          WRITE(37,2)I,J,K  
2         FORMAT(' TAIL BLOCK:',3I3)  
200        REWIND 27  
          RETURN  
        END
```

```

C#####
C##### SUBROUTINE SEQENS #####
C#####

```

```

SUBROUTINE SEQENS(I,J,K,NEQ,JMIN3,BETA,N2,NCODE,NPER,INDEP
& ,NOZERO,NRUN,NNROWS,NBLOCK,NNB2,NNB3,NNB,NP,INIT,TBA,IAIB2,IAIB3)

```

```

DIMENSION BETA(45,10,11),NCODE(45,10,11),IAIB2(2,10)
DIMENSION IAIB3(2,10)

```

```

NAME=I*10000+(J+JMIN3-1)*100+K

```

```

C----- START LOOP SEARCHING IN SEQNCE.DAT -----

```

```

DO 500 N=1,NEQ
READ(27,51,END=4800)I1,J1,K1,N1,I2,J2,K2,N2,NROW
51  FORMAT(2(3I2,1X,I1,1X),1X,I4)
IF(TBA.EQ.'M')GOTO 100
NCOD=NCODE(I1,J1,K1)
CALL PERIOD(NNB2,NNB3,NNB,NP,J1,IAI,IBI,NCOD)
NCOD=NCODE(I2,J2,K2)
CALL PERIOD(NNB2,NNB3,NNB,NP,J2,IAJ,IBJ,NCOD)
GOTO 110
100  IAI=IAIB2(1,J1)
IAJ=IAIB2(1,J2)
IBI=IAIB2(2,J1)
IBJ=IAIB2(2,J2)
IF(N1.EQ.3)IBI=IAIB3(2,J1)
IF(N2.EQ.3)IBJ=IAIB3(2,J2)
IF(N1.EQ.3)IAI=IAIB3(1,J1)
IF(N2.EQ.3)IAJ=IAIB3(1,J2)
110  IF(IBJ.LE.IBI.AND.IAI.GE.IAJ)NFIN=IBJ-IAI+1
IF(IBJ.GE.IBI.AND.IAI.LE.IAJ)NFIN=IBI-IAJ+1
IF(IBJ.LE.IBI.AND.IAI.LE.IAJ)NFIN=IBJ-IAJ+1
IF(IBJ.GE.IBI.AND.IAI.GE.IAJ)NFIN=IBI-IAI+1
IF(IBJ.LE.IAI.OR.IBI.LE.IAJ)NFIN=1
IF(I.EQ.I1.AND.J.EQ.J1.AND.K.EQ.K1)GO TO 410
IF(I.EQ.I2.AND.J.EQ.J2.AND.K.EQ.K2)GO TO 420
GO TO 500
4800 WRITE(4,4805)I,JK,K,NCODE(I,J,K)
4805  FORMAT(' ERROR IN READING SEQNCE.DAT.BLOCK=',4I2)
STOP

```

```

C----- THE BLOCK IS NOT THE FIRST --"I BLOCK"-----

```

```

410  CONTINUE

```

```

C-----

```

```

C----- BOTH BLOCKS ARE AT THE SAME LEVEL -----

```

```

IF(NFIN.EQ.1.AND.NPER.EQ.IAI)GOTO 170
IF(NPER.LT.IAI.OR.NPER.GT.(IAI+NFIN-1))GO TO 160
NP1=NPER-IAI+1

```

```

170   IF(NFIN.EQ.1)NP1=1
      WRITE(32,13)NROW,NP1
13    FORMAT(2X,'G',1X,I3,'MINE',11)
      NNROWS=NNROWS+1
      RHS:=-BETA(I2,J2,K2)+BETA(I,J,K)
      WRITE(26,8)NRUN,NROW,NP1,RHSM
8     FORMAT(2X,I2,'RUN',3X,I3,'MINE',11,5X,F4.2)
      NOZERO=NOZERO+1
160   DO 490 KN=1,NFIN
      KN1=KN
      IF(NPER.GT.IBJ)GO TO 416
      IF(NPER.GT.(IAI+KN))GO TO 490
      GO TO 423
416   KN1=NFIN
423   WRITE(22,53)NAME,NPER,NROW,KN1
53    FORMAT(2X,I6,'X',11,3X,I3,'MINE',11,9X,'-1')
      NOZERO=NOZERO+1
      WRITE(24,9)NAME,NPER,NROW,KN1
      NOZERO=NOZERO+1
9     FORMAT(2X,I9,'V',11,5X,I3,'MINE',11,9X,'-1')
      NOZERO=NOZERO+1
      IF(NZ.EQ.1) WRITE(25,1)NAME,NPER,NROW,KN1
1     FORMAT(2X,I6,'Z',11,5X,I3,'MINE',11,9X,'-1')
      IF(NZ.EQ.0) WRITE(23,6)NAME,NPER,NROW,KN1
      NOZERO=NOZERO+1
6     FORMAT(2X,I6,'Y',11,5X,I3,'MINE',11,9X,'-1')
      IF(KN1.EQ.NFIN) GO TO 500
490   CONTINUE
      GO TO 500

C
C----- THIS BLOCK IS PRECEDENT -"J BLOCK"-----
420   CONTINUE
C----- THE BLOCKS ARE AT DIFFERENT LEVELS -----
      DO 970 KN=1,NFIN
      IF(NFIN.EQ.1)GOTO 54
      IF(NPER.GT.(IAI+KN-1))GO TO 970
54    WRITE(22,50)NAME,NPER,NROW,KN
50    FORMAT(2X,I6,'X',11,3X,I5,'MINE',11,8X,'1')
      NOZERO=NOZERO+1
      WRITE(24,61)NAME,NPER,NROW,KN
61    FORMAT(2X,I6,'V',11,5X,I3,'MINE',11,8X,'1')
      NOZERO=NOZERO+1
      IF(NZ.EQ.1) WRITE(25,52)NAME,NPER,NROW,KN
52    FORMAT(2X,I6,'Z',11,5X,I3,'MINE',11,8X,'1')
      IF(NZ.EQ.0) WRITE(23,971)NAME,NPER,NROW,KN
971   FORMAT(2X,I6,'Y',11,5X,I3,'MINE',11,8X,'1')
      NOZERO=NOZERO+1
970   CONTINUE

```

```

500  CONTINUE

      REWIND 27
      RETURN
      END
C     THIS IS THE SUBROUTINE FOR MANUAL TIME-BLOCK ALLOCATION
C-----
      SUBROUTINE BLKTIM(ASH2,ASH3,TON2,TON3,NNB,IAIB2,NCODE,AMAX,NP
& ,IAIB3,NNB2,NNB3,JMIN2,JMAX2,JMIN3)
      DIMENSION NCODE(45,10,11),ASH2(45,10),TON2(45,10),ASH3(45,10)
      DIMENSION IAIB2(2,10),TON3(45,10),IAIB3(2,10)

      WRITE(4,1)
1     FORMAT(/,8X,' ***** GOOD QUALITY COAL STATISTICS *****',/
& 1X,13X,'SEAM2',17X,'SEAM3',17X,'TOTAL',/1X,65(' '),/
& 1X,'COL BLKS TONNAGE % ASH BLKS TONNAGE % ASH TONNAGE % ASH')

      DO 100 J=1,NNB
      NB2=0
      TT2=0.
      NB3=0
      TT3=0.
      TASH2=0.
      TASH3=0.
      TASH=0.
      DO 90 I=1,45
      DO 90 K=1,11
      IF(NCODE(I,J,K).NE.2.AND.NCODE(I,J,K).NE.3)GOTO 90
      IF(NCODE(I,J,K).EQ.3)GO TO 80
      NB2=NB2+1
      IF(ASH2(I,J).GT.AMAX)GOTO 90
      TASH2=TASH2+TON2(I,J)*ASH2(I,J)
      TASH=TASH+ASH2(I,J)*TON2(I,J)
      TT2=TT2+TON2(I,J)
      GOTO 90
80     NB3=NB3+1
      IF(ASH3(I,J).GT.AMAX)GOTO 90
      TASH3=TASH3+TON3(I,J)*ASH3(I,J)
      TASH=TASH+ASH3(I,J)*TON3(I,J)
      TT3=TT3+TON3(I,J)
90     CONTINUE
      SA=0.
      SA2=0.
      SA3=0.
      TT=TT2+TT3
      IF(TT2.EQ.0.0)GO TO 120
      SA2=TASH2/TT2
120    IF(TT3.EQ.0.0)GOTO 130
      SA3=TASH3/TT3
130    IF(TT.EQ.0.0)GOTO140

```

```

SA =TASH /TT
140 CONTINUE
    J1=J+JMIN3-1
    WRITE(4,2)J1,NB2,TT2,SA2,NB3,TT3,SA3,TT,SA
2   FORMAT(1X,12,1X,2(2X,I3,F10.2),F7.2),F10.2,F7.2)
100 CONTINUE
    WRITE(4,3)
3   FORMAT(/,1X'NOW ENTER THE DESIRED TIME FRAME VALUES:')
    DO 300 NK=2,3
    IF(NK.EQ.2)WRITE(4,6)NK,NNB2
    IF(NK.EQ.3)WRITE(4,6)NK,NNB3
6   FORMAT(/,1X,'      **** SEAM #',I1' ****  (',12,' COLUMNS)')
    NA=JMIN2-JMIN3+1
    NB=JMAX2-JMIN3+1
    IF(NK.EQ.3)NA=1
    IF(NK.EQ.3)NB=NNB3
    DO 200 N=NA,NB
    N1=JMIN3+N-1
    IF(NK.EQ.2)N1=JMIN3+N-1
151 WRITE(4,4)N1
4   FORMAT(1X,'COLUMN',I3,' MINIMUM,MAXIMUM PERIODS=',$,)
    IF(NK.EQ.2)READ(4,5)IAIB2(1,N),IAIB2(2,N)
    IF(NK.EQ.3)READ(4,5)IAIB3(1,N),IAIB3(2,N)

C   IF(NK.EQ.2)WRITE(4,5)IAIB2(1,N),IAIB2(2,N)
C   IF(NK.EQ.3)WRITE(4,5)IAIB3(1,N),IAIB3(2,N)
5   FORMAT(2I)
200 CONTINUE
300 CONTINUE
    RETURN
    END

```

```

C#####
C##### SUBROUTINE SEARCH #####
C#####
      SUBROUTINE SEARCH(J,K,NNB,NCODE,I,MRU,NEQ,BETA,ALPHA,JMIN3,NNB3)
      INTEGER A,B
      DIMENSION NCODE(45,10,11),BETA(45,10,11),ALPHA(45,10,11)
C----- INITIALIZE -----
      JMIN=1
      JMAX=NNB
      NAME=I*10000+J*100+K
      NNAME=I*10000+(J+JMIN3-1)*100+K
      INDEP=1
C----- GENERAL SEARCH -----
221  IF(J.EQ.JMIN)GO TO 100
      IF(K.EQ.11)GO TO 110
      CALL HORIZ(I,J,K,JMIN,J2,NCODE,NNB3)
      IF(J2.EQ.J)GO TO 120
C          ++++++WRITE+++++
      NAME2=I*10000+J2*100+K
      NNAME2=I*10000+(J2+JMIN3-1)*100+K
      NEQ=NEQ+1
      IF(ALPHA(I,J2,K).LT.1.0)INDEP=0
      WRITE(27,6)NAME,NCODE(I,J,K),NAME2,NCODE(I,J2,K),NEQ,INDEP
6      FORMAT(2(I6,1X,I1,1X),1X,2I4)
      WRITE(35,6)NNAME,NCODE(I,J,K),NNAME2,NCODE(I,J2,K),NEQ,INDEP
222  JMINA=J2+2
      IF(J.NE.JMAX)GO TO 130
190  K3=K+1
      J3=J+1
      IF(JMINA.GE.JMAX)GO TO 250
      GO TO 170
100  IF(K.EQ.11)GO TO 250
120  JMINA=JMIN
      IF(J.EQ.JMAX)GO TO 190
130  J3=J+1
      K3=K+1
170  IF(NCODE(I,J3,K3).EQ.2.OR.NCODE(I,J3,K3).EQ.3)GO TO 201
      CALL HORIZ(I,J3,K3,JMINA,J2,NCODE,NNB3)
      IF(J2.EQ.J3)GO TO 140
C      IF(NCODE(I,J2,K3).NE.2.AND.NCODE(I,J2,K3).NE.3)GO TO 139
C          ++++++WRITE+++++
      NEQ=NEQ+1
      NAME2=10000*I+100*J2+K3
      NNAME2=I*10000+(J2+JMIN3-1)*100+K3
      INDEP=0
      WRITE(27,6)NAME,NCODE(I,J,K),NAME2,NCODE(I,J2,K3),NEQ,INDEP
      WRITE(35,6)NNAME,NCODE(I,J,K),NNAME2,NCODE(I,J2,K3),NEQ,INDEP

```

```

C          ++++++WRITE+++++
139      JMINA=J2+1
140      IF(JMINA.NE.JMIN)JMINA=JMINA+1
150      J3=J3+1
          K3=K3+1
          IF(K3.GT.11)GO TO 250
          IF(J3.LE.JMAX)GO TO 170
160      J3=JMAX
          IF(J3.LT.JMINA)GO TO 250
          GO TO 170

110      CALL HOR12(I,J,K,JMIN,J2,NCODE,NNB3)
          IF(J2.EQ.J)GO TO 250
          GO TO 200
201      J2=J3
C          ++++++WRITE+++++
200      NEQ=NEQ+1
          NAME2=10000*I+100*J2+K3
          NNAME2=I*10000+(J2+JMIN3-1)*100+K3
          INDEP=0
          WRITE(27,6)NAME,NCODE(I,J,K),NAME2,NCODE(I,J2,K3),NEQ,INDEP
          WRITE(35,6)NNAME,NCODE(I,J,K),NNAME2,NCODE(I,J2,K3),NEQ,INDEP
C          ++++++WRITE+++++
250      IF(INDEP.NE.1)GO TO 251
C          WRITE(21,27)I,J,K
          JJJ=J+JMIN3-1
          WRITE(36,27)I,JJJ,K
27       FORMAT(3I2)
251      RETURN
          END

```

Appendix 4

LP.XF4 Sample Run

OK  
 EXE LP.XF4,SEARCH,SEQENS  
 LINK: Loading  
 [LNKXCT LP execution]  
 ENTER WINDOW FOR SEAM #2 (JMIN,JMAX):14,14  
 ENTER WINDOW FOR SEAM #3 (JMIN,JMAX):11,11  
 ENTER RUN NUMBER :04  
 ENTER POST-PROCESSING STOCKPILE RESERVES (Tm):4828  
 ENTER OBJECTIVE FUNCTION NAME (8 char.):RUN04\*\*\*  
 DO YOU WANT CROSS SECTIONS PRINTED?(Y/N):N  
 BLOCK-TIME ALLOCATION MANUAL (M) OR AUTOMATIC (A):M

TOTAL INPUT TONNAGE OF SEAM 2 IS 85924.0 36.81% ASH  
 TOTAL INPUT TONNAGE OF SEAM 3 IS 79685.0 29.85% ASH

-----  
 TOTAL INPUT TONNAGE (OVERALL) IS 165609.0 33.45% ASH  
 TOTAL INPUT TONNAGE UNDER 30.00 % IS 109555.0 30.49 % ASH  
 END OF INPUT DATA

ENTER DESIRED PRODUCTION PER PERIOD :50000

MAXIMUM NUMBER OF PERIODS= 4  
 HOW MANY PERIODS ARE TO BE RUN SIMULTANEOUSLY?:4

\*\*\*\*\* GOOD QUALITY COAL STATISTICS \*\*\*\*\*  
 SEAM2 SEAM3

		SEAM2				SEAM3				TOTAL	
COL	BLKS	TONNAGE	% ASH	BLKS	TONNAGE	% ASH	TONNAGE	% ASH	TONNAGE	% ASH	
11	0	0.00	0.00	24	68572.00	28.20	68572.00	28.20			
12	0	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	
13	0	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	
14	13	34983.00	34.97	0	0.00	0.00	34983.00	34.97			

NOW ENTER THE DESIRED TIME FRAME VALUES:

\*\*\*\* SEAM #2 \*\*\*\* ( 1 COLUMN)  
 COLUMN 14 MINIMUM,MAXIMUM PERIODS=1,4

\*\*\*\* SEAM #3 \*\*\*\* ( 1 COLUMN)  
 COLUMN 11 MINIMUM,MAXIMUM PERIODS=1,4

CALL SEARCH TO GENERATE SEQUENCE.DAT?(Y/N):Y

DETECTED #2 SEAM BLOCKS=13  
 DETECTED #3 SEAM BLOCKS=24

ENTER MINDS FILE HEADING (MAX 30 CHR.):RUN04/11,11/14,14/4PERIODS  
 END OF HEADINGS

-----START OF 550 LOOP-----  
 THE MATRIX HAS 61 ROWS  
 THE MATRIX HAS 445 COLUMNS  
 THE MATRIX HAS 1922 NON ZERO VALUES  
 STOP

OK  
 COMBINE \*.CON TO T11-14.DAT  
 Files combined:  
 (60225,2)  
 ROWS.C  
 A>06

OK  
 COMBINE \*.CON TO T11-14.DAT  
 Files combined:  
 [60225,2]  
 ROWS.CON        MINOSX.CON        MINOSY.CON        MINOSZ.CON        MINOSV.CON  
 RHS.CON

OK  
 R MINOS6  
 MINOS64 V 3(3),7        8-May-83    00:26

Minos: INPUT T11-14.DAT

Minos: ROWS 70

Minos: COLU 450

Minos: ELEM 2000

Minos: MAXI

Minos: SOLUTION NO

Minos: SOLUTION T11-14.SOL

Minos: PUNCH T11-14.PUN

Minos: GO

INPUT LISTING

```

-----
      1  NAME            11/14
      2  ROWS
      65 COLU
     1551 RHS
     1600 ENDATA
  
```

NAMES SELECTED

```

-----
OBJECTIVE:  RUN04*** (MAX)        1
RHS:        4RUN                    50
RANGES:                            0
BOUNDS:                            0
  
```

MATRIX STATISTICS

```

-----
          TOTAL        NORMAL        FREE        FIXED        BOUNDED
ROWS:            62            24            1            37            0
COLUMNS:        445            444            0            1            0
  
```

```

NO. OF MATRIX ELEMENTS:    1852        DENSITY:        6.713
NO. OF REJECTED COEFFS:    0        AIJTOL:  1.00000E-10
BIGGEST AND SMALLEST COEFFS:  4.50450E+04  1.00000E+00
                                  (EXCLUDING OBJ AND RHS)
  
```

NUMBER OF WORDS USED (AVAILABLE) = 3600(15000)

## ITERATIONS

-----  
ITN 0 -- INFEASIBLE. NUM = 34 SUM = 3.083690000E+05  
ITN 46 -- INFEASIBLE. NUM = 3 SUM = 1.305016360E+01  
TRISWAPS 1 SPKSWP 1 REJECTED 0 MIN PIV RATIO 0.62500 TOLS 0.00100 0.10000  
ITN 96 -- INFEASIBLE. NUM = 1 SUM = 5.041597971E+00

ITN 135 -- FEASIBLE SOLUTION. OBJECTIVE = 2.509589286E+06

EXIT -- OPTIMAL SOLUTION FOUND.

NO. OF ITERATIONS: 136 PHASE: 2 OBJECTIVE: 2.62321200E+06

BASIS PUNCHED ON FILE ; T11-14.PUN

SOLUTION SAVED ON FILE ; T11-14.SOL

Minos: ^C

OK

Appendix 5

Report Generator Code

```

      OPTIONS DEBUG
C     *** REPORT.XF4 ***
C     THIS PROGRAM READS,DISPLAYS,CHECKS AND MODIFIES
C     THE MINOS SOLUTION AND UPDATES DATA FILES
C     ACCORDINGLY.
C=====
      DIMENSION X(45,10,11),Z(45,10,11),V(45,10,11),LINE(81)
      DIMENSION BET(45,10,11),NCODE(45,10,11),RSTOKQ(11),RSTOKA(11)
      DIMENSION BLINE(81),TONM2(45,10),TONM3(45,10),TUSED(10)
      DIMENSION ASH2(45,10),ASH3(45,10),TON2(45,10),TON3(45,10)
      INTEGER BELL
      DOUBLE PRECISION FILE1
      DATA BELL/007/

      WRITE(4,1)
1     FORMAT(' ENTER NUMBER OF PERIODS OF THE RUN.:',%)
      READ(4,2)NPER
2     FORMAT(1)
      WRITE(4,5)
5     FORMAT(' ENTER CORRESPONDENT FIRST OVERALL PERIOD.:',%)
      READ(4,2)NFIRST
      WRITE(4,3)BELL
3     FORMAT(' ENTER JMIN2,JMAX2,JMIN3,JMAX3 :',1R2,%)
      READ(4,1315)JMIN2,JMAX2,JMIN3,JMAX3
1315  FORMAT(4I)
      WRITE(4,11)BELL
11    FORMAT(' ENTER MINOS SOLUTION FILENAME.:',1R1,%)
      READ(4,12)FILE1
12    FORMAT(A10)
      WRITE(4,23)
23    FORMAT(' ENTER EXISTING RAW COAL STOCKPILE RESERVES (TON., ASH%):',%)
      READ(4,24)RSTOKQ(1),RSTOKA(1)
24    FORMAT(2G)
      NNB=JMAX2-JMIN3+1
      NNB2=JMAX2-JMIN2+1
      NNB3=JMAX3-JMIN3+1
      OPEN(UNIT=35,FILE='DISPL.UPD')
      OPEN(UNIT=34,FILE='BETA.UPD')
C----- ENTER UPDATED DATA FILES -----
C----- READ BETA ARRAY -----
      JM=JMIN3-1
      DO 380 K=1,11
      DO 379 I=1,45
      READ(35,20)(DUMB,NN=1,JM),(NCODE(I,J,K),J=1,NNB)
C     WRITE(4,20)(NCODE(I,J,K),J=1,NNB)
      READ(34,19)(DUMB,NN=1,JM),(BET(I,J,K),J=1,NNB)
19    FORMAT(81F4.2)

```

```

20      FORMAT(8111)
379      CONTINUE
380      CONTINUE
C----- READ TON, ASH DATA FILES -----
      OPEN(UNIT=25,FILE='TON2AP.GRD')
      CLOSE(UNIT=35,FILE='DISPL.UPD')
      CLOSE(UNIT=34,FILE='BETA.UPD')
      DO 500 I=1,45
      READ(25,6)(DUMB,NNN=1,JM),(TON2(I,J),J=1,NNB)
6      FORMAT(81F7.0)
500     CONTINUE
      CLOSE(UNIT=25)
C
      OPEN(UNIT=25,FILE='TON3AP.GRD')
      DO 501 I=1,45
      READ(25,6)(DUMB,NNN=1,JM),(TON3(I,J),J=1,NNB)
C      WRITE(4,6)(TON3(I,J),J=1,NNB)
501     CONTINUE
      CLOSE(UNIT=25)
C
      OPEN(UNIT=25,FILE='ASH2AP.GRD')
      DO 502 I=1,45
      READ(25,7)(DUMB,NNN=1,JM),(ASH2(I,J),J=1,NNB)
C      WRITE(4,7)(ASH2(I,J),J=1,NNB)
7      FORMAT(81F5.2)
502     CONTINUE
      CLOSE(UNIT=25)
      OPEN(UNIT=25,FILE='TON2AM.GRD')
      DO 505 I=1,45
      READ(25,6)(DUMB,NNN=1,JM),(TONM2(I,J),J=1,NNB)
505     CONTINUE
      CLOSE(UNIT=25)
C
      OPEN(UNIT=25,FILE='ASH3AP.GRD')
      DO 503 I=1,45
      READ(25,7)(DUMB,NNN=1,JM),(ASH3(I,J),J=1,NNB)
503     CONTINUE
      CLOSE(UNIT=25)
C
      OPEN(UNIT=25,FILE='TON3AM.GRD')
      DO 504 I=1,45
      READ(25,6)(DUMB,NNN=1,JM),(TONM3(I,J),J=1,NNB)
504     CONTINUE
      CLOSE(UNIT=25)
C
      WRITE(4,1444)
1444    FORMAT(' *** END OF INPUT')
C----- END OF INPUT -----

```

```

      DO 1000 ITIM=1,NPER
      NOUT=0
      CALL READ(X,2,V,BET,ITIM,JMIN3,FILE1,ASH2,ASH3,TON2,TON3,NCODE,NFIRST
& ,TONM2,TONM3,TUSED,RSTOKG,RSTOKA,JMAX2,NPER,JMAX2)
      WRITE(4,21)BELL
21  FORMAT(' DO YOU WANT A PRINTOUT OF THE INPUT?',1R1,$)
      READ(4,4)PRINTT
4   FORMAT(A1)
      IF(PRINTT.EQ.'N')GO TO 200
      NPE=NFIRST+ITIM-1
      CALL GRAF(X,2,V,BET,NPE,JMIN3,JMAX2,NCODE,NOUT,ASH3,ASH2)
200  CONTINUE

1000  CONTINUE
      CALL STORE(X,2,V,JMIN3,NNB,NPER,NCODE,BET,FILE1)

      CLOSE(UNIT=35,FILE='DISPL.UPD')
      CLOSE(UNIT=34,FILE='BETA.UPD')
C----- UPDATE THE FILES BETA,NCODE -----

      OPEN(UNIT=35,FILE='DISPL.UPD')
      OPEN(UNIT=34,FILE='BETA.UPD')
      OPEN(UNIT=45,FILE='DISPL.NEW')
      OPEN(UNIT=44,FILE='BETA.NEW')
      JM=JMIN3-1
      DO 381 K=1,11
      DO 378 I=1,45
      READ(34,19)(BLINE(I1),I1=1,81)
C      WRITE(4,19)(BLINE(I1),I1=1,81)
      READ(35,20)(LINE(I2),I2=1,81)
C      WRITE(4,20)(LINE(I2),I2=1,81)
      DO 100 I4=1,NNB
      BLINE(JM+I4)=BET(I,I4,K)
      LINE(JM+I4)=NCODE(I,I4,K)
100  CONTINUE
C      WRITE(4,20)(LINE(I1),I1=1,81)
      WRITE(44,19)(BLINE(I1),I1=1,81)
      WRITE(45,20)(LINE(I2),I2=1,81)
378  CONTINUE
381  CONTINUE
      CLOSE(UNIT=35,FILE='DISPL.UPD')
      CLOSE(UNIT=34,FILE='BETA.UPD')
      CLOSE(UNIT=45,FILE='DISPL.NEW')
      CLOSE(UNIT=44,FILE='BETA.NEW')
      STOP
      END

```

```

C   *** GRAF.XF4 ***
C   GRAPHICS SUBROUTINE FOR MINOS SOLUTION FILES
      SUBROUTINE GRAF(X,Z,V,BET,ITIM,JMIN,JMAX,NCODE,NOUT,ASH3,ASH2)
      DIMENSION X(45,10,11),Z(45,10,11),V(45,10,11),ASH2(45,10),ASH3(45,10)
      DIMENSION BET(45,10,11),DIS(90),NCODE(45,10,11)
      WRITE(4,2)
2    FORMAT(' CODE: LEFT=EXTRACTED RIGHT=UNCOVERD "-"=OUTSIDE'
& , ' "?"=WASTE "*"=FULLY "+"=.9-1.0 "N"=(N-.1)%-N%')

      IF(NOUT.EQ.1)WRITE(4,3)
3    FORMAT(' *** OUTPUT OF STATUS AFTER MODIFICATION ***')
      DO 1000 K=1,11
      WRITE(4,1)ITIM,K
1    FORMAT(/,3X,'PERIOD=',I3,48X,'*** LEVEL',I4,' ***')
      WRITE(4,901)
901   FORMAT(' J  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19
& 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
& 43 44 45',/1X,'==',45(' ='))
      DO 900 JJ=JMIN,JMAX
      J=JMAX+1-JJ
      DO 800 I=1,45
      IF(NCODE(I,J,K).EQ.0)GO TO 810
      IF(NCODE(I,J,K).EQ.1.OR.NCODE(I,J,K).EQ.9)GO TO 820
      IF(NCODE(I,J,K).EQ.5)GOTO 821
      IF(NCODE(I,J,K).EQ.7)GOTO 820
      IF(NOUT.EQ.1)GO TO 840
      CODEX=X(I,J,K)+V(I,J,K)+BET(I,J,K)
      CODEY=ASH2(I,J)
      IF(NCODE(I,J,K).EQ.3)CODEY=ASH3(I,J)
      GO TO 850
840   CODEX=BET(I,J,K)
850   IF(CODEX.EQ.1.0)A='*'
      IF(CODEX.LT.1.0)A='+'
      IF(CODEX.LT.0.9)A='9'
      IF(CODEX.LT.0.8)A='8'
      IF(CODEX.LT.0.7)A='7'
      IF(CODEX.LT.0.6)A='6'
      IF(CODEX.LT.0.5)A='5'
      IF(CODEX.LT.0.4)A='4'
      IF(CODEX.LT.0.3)A='3'
      IF(CODEX.LT.0.2)A='2'
      IF(CODEX.LT.0.1)A='1'
      IF(CODEX.EQ.0.0)A='0'
      IF(CODEY.GT.36.0)B='1'
      IF(CODEY.LE.36.0)B='0'

```

```
      GO TO 830
810   A='-'
      B='-'
      GO TO 830
820   A='W'
      B='W'
      GOTO 830
821   A='T'
      B='T'
C----- GENERATE A LINE OF DISPLAY (90 CHR) -----
830   DO 750 KN=1,2
      N=2*(I-1)+KN
      IF(KN.EQ.1)DIS(N)=A
      IF(KN.EQ.2)DIS(N)=B
750   CONTINUE
800   CONTINUE
      J2=JMIN+J-1
      WRITE(4,10)J2,(DIS(N),N=1,90)
10    FORMAT(1X,I2,' ',45(1X,2A1))
900   CONTINUE
1000  CONTINUE

      RETURN
      END
```

```

C     *** STORE.XF4 ***
C     THIS PROGRAM SAVES THE LP SOLUTION BY TIME PERIOD, ONCE IT HAS
C     BEEN READ AND COMPUTED.
C-----
      SUBROUTINE STORE(X,Z,V,JMIN3,NNB,NPER,NCODE,BET,FILE1)
      DIMENSION X(45,10,11),NCODE(45,10,11),Z(45,10,11),V(45,10,11)
      DIMENSION BET(45,10,11)
      DOUBLE PRECISION FILE1

      OPEN(UNIT=31,FILE='HISTORY.DAT',ACCESS='APPEND')
      OPEN(UNIT=32,FILE='SEQUENCE.DAT')
      DO 2000 ITIM=1,NPER-1
      REWIND 30
      READ(30,303)TRASH
303   FORMAT(A1)
      DO 100 NN=1,5000
      READ(30,5,ERR=50)I,NJ,K,TYPE,NTIME,VALUE
      IF(VALUE.LT.0.0001)GOTO100
63    IF(NTIME.NE.ITIM)GO TO 100
      J=NJ-JMIN3+1
5     FORMAT(4X,3I2,A1,I1,13X,E11.5)
      IF(TYPE.EQ.'X')X(I,J,K)=VALUE
      IF(TYPE.EQ.'Z')Z(I,J,K)=VALUE
      IF(TYPE.EQ.'V')V(I,J,K)=VALUE
      GOTO100
C----- ERROR AND END TRAPPING -----
50    BACKSPACE 30
      READ(30,10,ERR=60)I,NJ,K,TYPE,NTIME,VALUE
10    FORMAT(4X,I1,2I2,A1,I1,14X,E11.5)
      GO TO 63
60    BACKSPACE 30
      READ(30,6)FLAG
6     FORMAT(A3)
      IF(FLAG.EQ.'END')GO TO 180
      STOP ' *** ERROR READING MINOS.SOL ***'
100   CONTINUE
180   DO 101 K=1,11
      DO 101 I=1,45
      DO 101 J1=1,NNB

      DMP=0.0
      J2=NNB+1-J1
      IF(BET(I,J2,K).EQ.1.)GO TO 101
      IF(NCODE(I,J2,K).NE.2.AND.NCODE(I,J2,K).NE.3)GOTO101
      J=J2+JMIN3-1
      EXTR=X(I,J2,K)+V(I,J2,K)
      IF((EXTR+Z(I,J2,K)).LT.0.0001)GOTO 101

```

```

C          ***GET NEXT BLOCKS***
WRITE(4,2)I,J,K,X(I,J2,K),V(I,J2,K),Z(I,J2,K)
2  FORMAT(1X,'BLOCK (' ,2(I2,' '),I2,' ) X,V,Z=',3F6.2)
    REWIND 32
    DO 200 NEQ=1,300
    READ(32,3,END=210)IA,JA,KA,IB,JB,KB
3  FORMAT(2(3I2,3X))
    IF(IB.EQ.I.AND.JB.EQ.J2.AND.KB.EQ.K)GOTO90
    GOTO200
90  EXTRA=X(IA,JA,KA)+V(IA,JA,KA)
    IF(EXTRA.GT.0.001.OR.BET(IA,JA,KA).GT.0.9999)GOTO181
200  CONTINUE
    IF(EXTR.EQ.0)GOTO 101
210  GOTO 190
181  DMP=Z(I,J2,K)

190  BET(I,J2,K)=BET(I,J2,K)+DMP+EXTR
    IF(BET(I,J2,K).GT.0.9999)BET(I,J2,K)=1.0
310  IF(BET(I,J2,K).LT.0.0001)BET(I,J2,K)=0.0
    WRITE(31,1)I,J,K,NCODE(I,J2,K),ITIM,EXTR,DMP
1  FORMAT(4I2,' ','P=',I3,2F5.2)
    IF(BET(I,J2,K).GT.0.9999)NCODE(I,J2,K)=0
101  CONTINUE
2000 CONTINUE
    CLOSE(UNIT=31)
    CLOSE(UNIT=32)
    RETURN
    END

```

```

      SUBROUTINE READ(X,Z,V,BET,ITIM,JMIN3,FILE1,ASH2,ASH3,TON2
& ,TON3,NCODE,NFIRST,TONM2,TONM3,TUSED,RSTOKQ,RSTOKA,NPER,JMAX2)
C
C
      *** SUBROUTINE READ MINOS SOLUTION FILE ***
      DIMENSION X(45,10,11),Z(45,10,11),V(45,10,11)
      DIMENSION BET(45,10,11),TONM2(45,10),TONM3(45,10),TUSED(10)
      DIMENSION TON2(45,10),TON3(45,10),ASH2(45,10),ASH3(45,10),NCODE(45,10,11)
      DIMENSION RSTOKQ(11),RSTOKA(11)
      INTEGER BLOCK,T,BELL
      DOUBLE PRECISION FILE1
      DATA BELL/007/
      DO 61 I=1,45
      DO 61 J=1,10
      DO 61 K=1,11
      X(I,J,K)=0.
      V(I,J,K)=0.
      Z(I,J,K)=0.
61  CONTINUE
      OPEN(UNIT=30,FILE=FILE1)
      READ(30,3)TRASH
      3  FORMAT(A4)
      NB=0
      NPE=ITIM+NFIRST-1
      NPAR=0
      XT2=0
      VT2=0

      ZT2=0
      XA2=0
      VA2=0
      ZA2=0
      XT3=0
      VT3=0
      ZT3=0
      XA3=0
      VA3=0
      ZA3=0
      VAA2=0
      VAA3=0

      DO 100 NV=1,5000
      READ(30,5,ERR=50)I,NJ,K,TYPE,NTIME,VALUE
      IF(VALUE.LT.0.0001)GOTO100
63  IF(NTIME.NE.ITIM)GO TO 100
      J=NJ-JMIN3+1
      IF(NCODE(I,J,K).EQ.2)GOTO25
      XX=ASH3(I,J)
      GOTO26

```

```

25     XX=ASH2(I,J)
26     WRITE(4,20)I,NJ,K,TYPE,NTIME,VALUE,XX
20     FORMAT(1X,3I2,A1,I1,F9.5,F6.2)
5      FORMAT(4X,3I2,A1,I1,13X,E11.5)
      IF(ITIM.GT.1)GO TO 62
      IF(VALUE.GT.1.0)WRITE(4,7)I,NJ,K,TYPE,NTIME,VALUE
7      FORMAT(' WARNING!! THE VARIABLE '1X,3I2,A1,I1,' HAS THE VALUE',F6.2)
62     CONTINUE
      IF(TYPE.EQ.'X')X(I,J,K)=VALUE
      IF(TYPE.EQ.'Z')Z(I,J,K)=VALUE
      IF(TYPE.EQ.'V')V(I,J,K)=VALUE
      IF(TYPE.EQ.'Y'.AND.VALUE.GT.0.0001)WRITE(4,4414)I,J,K,VALUE
4414   FORMAT(1X,'***!! WARNING !!*** Y('2(I2,' '),I2,' ')=',F6.2)
      IF(NCODE(I,J,K).EQ.3)GO TO 70
      IF(NCODE(I,J,K).NE.2.AND.NCODE(I,J,K).NE.3)WRITE(4,222)NCODE(I,J,K),I,NJ,K
222   FORMAT(' ***WARNING*** NCODE=' ,I2,3I3)
C----- FOR SEAM 2 -----
C     WRITE(4,21)TON2(I,J)
C     WRITE(4,21)ASH2(I,J)
21    FORMAT(' SEAM2=' ,F10.2)
      IF(TYPE.NE.'X')GOTO 23
      XT2=XT2+X(I,J,K)*TON2(I,J)*(1-BET(I,J,K))
      XA2=XA2+X(I,J,K)*TON2(I,J)*ASH2(I,J)*(1-BET(I,J,K))
23    IF(TYPE.NE.'Z')GOTO 24
      ZT2=ZT2+Z(I,J,K)*TON2(I,J)*(1-BET(I,J,K))
      ZA2=ZA2+Z(I,J,K)*TON2(I,J)*ASH2(I,J)*(1-BET(I,J,K))
24    IF(TYPE.NE.'V')GOTO 100
      VT2=VT2+V(I,J,K)*TON2(I,J)*(1-BET(I,J,K))
      VAA2=VAA2+V(I,J,K)*TON2(I,J)*(1-BET(I,J,K))
      VA2=VA2+V(I,J,K)*TON2(I,J)*ASH2(I,J)*(1-BET(I,J,K))
      GO TO 90
C----- FOR SEAM 3 -----
70    IF(TYPE.NE.'X')GOTO 33
      XT3=XT3+X(I,J,K)*TON3(I,J)*(1-BET(I,J,K))
C     WRITE(4,30)TON3(I,J),ASH3(I,J)
30    FORMAT(' SEAM 3=' ,2F10.2)
      XA3=XA3+X(I,J,K)*TON3(I,J)*ASH3(I,J)*(1-BET(I,J,K))
33    IF(TYPE.NE.'Z')GOTO 34
      ZT3=ZT3+Z(I,J,K)*TON3(I,J)*(1-BET(I,J,K))
      ZA3=ZA3+Z(I,J,K)*TON3(I,J)*ASH3(I,J)*(1-BET(I,J,K))
34    IF(TYPE.NE.'V')GOTO 100
      VT3=VT3+V(I,J,K)*TON3(I,J)*(1-BET(I,J,K))
      VAA3=VAA3+V(I,J,K)*TON3(I,J)*ASH3(I,J)*(1-BET(I,J,K))
      GO TO 90
C----- ERROR AND END TRAPPING -----
50    BACKSPACE 30
      READ(30,10,ERR=60)I,NJ,K,TYPE,NTIME,VALUE

```

```

10   FORMAT(4X,11,2I2,A1,11,14X,E11.5)
      GO TO 63
60   BACKSPACE 30
      READ(30,6)FLAG
6    FORMAT(A3)
      IF(FLAG.EQ.'END')GO TO 180
      STOP '   *** ERROR READING MINOS.SOL ***'
90   IF(NTIM.EQ.NPER)GO TO 91
      IF(NTIM.EQ.(NPER-1))GOTO 92
      GOTO 100
91   X(I,J,K)=0.0
      V(I,J,K)=0.0
      Z(I,J,K)=0.0
      GOTO 100
92   Z(I,J,K)=0.0
100  CONTINUE
C----- CHECK ON BLOCK UTILIZATION -----
180  CONTINUE
      DO 170 K=1,11
      DO 170 I=1,45
      DO 170 J=1,JMAX2-JMIN3+1
      JJ=J+JMIN3-1
      XTOT=X(I,J,K)+V(I,J,K)+Z(I,J,K)
      IF(NCODE(I,J,K).NE.2.AND.NCODE(I,J,K).NE.3)GO TO 170
      IF(XTOT.EQ.0.0)GO TO 170
      IF((XTOT.LT.0.999.OR.XTOT.GT.1.001))WRITE(4,171)I,JJ,K,XTOT
171  FORMAT(' WARNING!!!, THE BLOCK ',3I2,' TAKES THE OVERALL VALUE OF ',F5.4)
170  CONTINUE
C----- QUANTITY AND QUALITY CALCULATIONS -----
      TX=XT2+XT3+RSTOKQ(ITIM)
      TXA=XA2+XA3+RSTOKA(ITIM)
      TZ=ZT2+ZT3
      TZA=ZA2+ZA3
      TV=VT2+VT3
      RSTOKQ(ITIM+1)=VAA2+VAA3
      RSTOKA(ITIM+1)=VA2+VA3
      TT=TX+TZ+VAA2+VAA3
      IF(ITIM.EQ.1) GO TO 190
      TUSED(ITIM)=TUSED(ITIM-1)+XT2+XT3+VAA2+VAA3+TZ
      GO TO 191
190  TUSED(ITIM)=TT
191  AX=TXA/TX
      AV=RSTOKA(ITIM+1)/RSTOKQ(ITIM+1)
      AZ=TZA/TZ
      IF(XT2.EQ.0.0)GO TO 101
      AX2=XA2/XT2
101  IF(ZT2.EQ.0.0)GO TO 102
      AZ2=ZA2/ZT2

```

```

102 IF(VAA2.EQ.0.0)GO TO 103
    AV2=VA2/VAA2
103 IF(XT3.EQ.0.0)GO TO 104
    AX3=XAS/XT3
104 IF(ZT3.EQ.0.0)GO TO 105
    AZ3=ZAS/ZT3
105 IF(VAA3.EQ.0.0)GO TO 106
    AV3=VA3/VAA3
106 IF(VT2.EQ.0.0)AV2=0.0
    IF(VT3.EQ.0.0)AV3=0.0
    WRITE(4,9),BELL
9    FORMAT('          *** END OF DATA INPUT ***',1R2)
    WRITE(4,11)
11   FORMAT(/,98('='),/7X,'OPERATION',27X,'TONNAGE',21X,'QUALITY -ASH%-',/98('='))
    WRITE(4,12)
12   FORMAT(29X,'SEAM 2',4X,'SEAM 3',5X,'STOCK',5X,'TOTAL',4X,'SEAM 2',2X,'SEAM 3',
& 3X,'STOCK',2X,'TOTAL')
    IF(RSTOKQ(ITIM).EQ.0.0)GO TO 212
    ASHSTK=RSTOKA(ITIM)/RSTOKQ(ITIM)
    GOTQ 22
212  ASHSTK=0.0
22   WRITE(4,13)XT2,XT3,RSTOKQ(ITIM),TX,AX2,AX3,ASHSTK,AX
13   FORMAT(5X,' DELIVERED COAL',7X,4F10.2,4(2X,F5.2,1X))
    WRITE(4,14)VT2,VT3,TV,AV2,AV3,AV
14   FORMAT(5X,' STOCKPILED COAL',7X,2F10.2,10X,F10.2,2(2X,F5.2,1X),10X,F5.2)
    WRITE(4,15)ZT2,ZT3,TZ,A22,A23,AZ
15   FORMAT(5X,' REJECTED COAL',7X,2F10.2,10X,F10.2,2(2X,F5.2,1X),10X,F5.2)
    WRITE(4,17)
17   FORMAT(1X,97('-'))
    WRITE(4,16)NPE,TT
16   FORMAT(' TOTAL UTILIZED RESERVES IN MONTH',14,19X,F11.2)
    WRITE(4,18)NPE,TUSED(ITIM)
18   FORMAT(' TOTAL CUMULATIVE RESOURCE UTILIZATION AT END OF MONTH',14,':',F11.2,' TONS')
    WRITE(4,19)RSTOKQ(ITIM+1),AV
19   FORMAT(' EQUIVALENT POST-PROCESSING STOCKPILED RESERVES =',8X,
& F10.2,' 2 ',F5.2,' % ASH',/)
    RETURN
    END

```

Appendix 6

REPORT.XF4 Sample Run

EXE REPORT,GRAF,READ,STORE

LINK: Loading

[LINKCT REPORT execution]

ENTER NUMBER OF PERIODS OF THE RUN.:4

ENTER CORRESPONDENT FIRST OVERALL PERIOD:11

ENTER JMIN2,JMAX2,JMIN3,JMAX3 : 14,14,11,11

ENTER MINOS SOLUTION FILENAME.:T11-14.PUN

ENTER EXISTING RAW COAL STOCKPILE RESERVES (TON., ASH%):4828,36

\*\*\* END OF DATA INPUT \*\*\*

OPERATION	TONNAGE				QUALITY -ASH%-			
	SEAM 2	SEAM 3	STOCK	TOTAL	SEAM 2	SEAM 3	STOCK	TOTAL
DELIVERED COAL	9825.91	40346.09	4828.00	55000.00	35.39	26.79	36.00	36.00
STOCKPILED COAL	3908.60	2091.40		6000.00	38.86	29.80		36.00
REJECTED COAL	0.00	0.00		0.00	0.00	0.00		0.00

TOTAL UTILIZED RESERVES IN MONTH 11: 60301.01  
 TOTAL CUMULATIVE RESOURCE UTILIZATION AT END OF MONTH 11: 60301.01 TONS  
 EQUIVALENT POST-PROCESSING STOCKPILED RESERVES = 5301.02 @ 36.00 % ASH

DO YOU WANT A PRINTOUT OF THE INPUT?N

\*\*\* END OF DATA INPUT \*\*\*

OPERATION	TONNAGE				QUALITY -ASH%-			
	SEAM 2	SEAM 3	STOCK	TOTAL	SEAM 2	SEAM 3	STOCK	TOTAL
DELIVERED COAL	38574.19	11124.80	5301.02	55000.01	35.95	36.18	36.00	36.00
STOCKPILED COAL	4133.34	1866.66		6000.00	39.20	27.80		36.00
REJECTED COAL	0.00	0.00		0.00	0.00	0.00		0.00

TOTAL UTILIZED RESERVES IN MONTH 12: 66320.70  
 TOTAL CUMULATIVE RESOURCE UTILIZATION AT END OF MONTH 12: 115320.69 TONS  
 EQUIVALENT POST-PROCESSING STOCKPILED RESERVES = 5320.69 @ 36.00 % ASH

DO YOU WANT A PRINTOUT OF THE INPUT?N

\*\*\* END OF DATA INPUT \*\*\*

OPERATION	TONNAGE				QUALITY -ASH%-			
	SEAM 2	SEAM 3	STOCK	TOTAL	SEAM 2	SEAM 3	STOCK	TOTAL
DELIVERED COAL	29441.58	20237.72	5320.69	55000.00	37.86	33.29	36.00	36.00
STOCKPILED COAL	0.00	6000.00		6000.00	0.00	27.04		27.04
REJECTED COAL	0.00	0.00		0.00	0.00	0.00		*****

TOTAL UTILIZED RESERVES IN MONTH 13: 59202.75  
 TOTAL CUMULATIVE RESOURCE UTILIZATION AT END OF MONTH 13: 169822.75 TONS  
 EQUIVALENT POST-PROCESSING STOCKPILED RESERVES = 4802.75 @ 27.04 % ASH

DO YOU WANT A PRINTOUT OF THE INPUT?N  
 STOP

Appendix 7

Listings of Computer Programs Used for  
The Waste Allocation Problem

```

NEWPIT.XF4
      DIMENSION A(45,81),B(45,81)
      INTEGER A,B
      OPEN(UNIT=21,FILE='DISPL.DAT',ACCESS='SEQIN')
      OPEN(UNIT=20,FILE='MODNEW.OUT',ACCESS='SEQOUT')
      OPEN(UNIT=32,FILE='T9.OUT',ACCESS='SEQOUT')
      OPEN(UNIT=31,FILE='W1.OUT',ACCESS='SEQOUT')

C
C
C.....Read and write the lowest level (not to be changed)...:
C
      DO 100 I=1,45
      READ(21,1)(A(I,J),J=1,81)
      WRITE(20,1)(A(I,J),J=1,81)
100   CONTINUE
C
C
C.....Read the second lowest level for this first run ...:
C
      DO 101 I=1,45
      READ(21,1)(B(I,J),J=1,81)
101   CONTINUE
1    FORMAT(81I1)
C.....Initialize the lower level counter....:
C
      N=1
C
800   CONTINUE
      DO 200 I=1,45
      DO 300 J=1,81
C.....Initialize the upper level counter....:
      K=N+1
      IF(A(I,J) .EQ. 0.OR.A(I,J).EQ.4)GO TO 300
      IF((A(I,J).EQ.1.OR.A(I,J).EQ.9).AND.(B(I,J).EQ.4.OR.B(I,J).EQ.5))GO TO 310
      IF(A(I,J) .EQ. 5) GO TO 320
330   DO 400 I1=I-1,I+1
      DO 400 J1=J-1,J+1
      IF(B(I1,J1) .EQ. 0)B(I1,J1)=1
      IF(B(I1,J1) .EQ. 4)B(I1,J1)=5
400   CONTINUE
      GO TO 300
C.....This do is executed if A(i,j) is a topo block..:
C
320   DO 610 I1=I-1,I+1
      DO 610 J1=J-1,J+1
      IF(B(I1,J1).EQ.4.OR.B(I1,J1).EQ.5)B(I1,J1)=5
610   CONTINUE
      GO TO 300

```

```

310   DO 340 I1=I-1,I+1
      DO 340 J1=J-1,J+1
      IF(B(I1,J1).EQ.4)B(I1,J1)=5
      IF(B(I1,J1).EQ.0)GO TO 350
      GO TO 340
350   IF(A(I1,J1).EQ.0)B(I1,J1)=1
      IF(A(I1,J1).EQ.4.OR.A(I1,J1).EQ.5)B(I1,J1)=0
340   CONTINUE
300   CONTINUE
200   CONTINUE
C
C
C.....This do-loop displays the projected level ,transfers the data (A=B)
C.....and writes the generated waste blocks in FOR31.DAT and the coordinates
C.....of the generated topo blocks in the file FOR32.DAT....:
      DO 500 I2=1,45
      DO 450 J2=1,81
      A(I2,J2)=B(I2,J2)
C     IF(A(I2,J2).EQ.4) A(I2,J2)=0
450   CONTINUE
      WRITE(20,1)(A(I2,J),J=1,81)

C501  DO 900 I=1,45
      DO 900 J=1,81
      IF(A(I2,J) .EQ. 1) GO TO 901
      IF(A(I2,J) .EQ. 5) WRITE(32,3)I2,J,K
      GO TO 900
901   K=N+1
      WRITE(31,2)A(I2,J),I2,J,K
2     FORMAT(11,3I2)
3     FORMAT(3(I2))
900   CONTINUE
500   CONTINUE
C
C
      N=N+1
      IF(N.EQ.11)GO TO 700
C
C.....Read the next upper level.....:

      DO 1000 I=1,45
      READ(21,1)(B(I,J),J=1,81)
1000  CONTINUE
      GO TO 800
C
C
700  CONTINUE
      STOP
      END

```

```
C      THIS IS PSLOPE.FOR PROGRAM
      DIMENSION MODEL(45,81,11)
      OPEN(UNIT=31,FILE='MODEL.OUT',ACCESS='SEQIN')
      OPEN(UNIT=30,FILE='PSLOPE.DAT')
      DO 100 K=1,11
      DO 100 I=1,45
      READ(31,1)(MODEL(I,J,K),J=1,81)
1      FORMAT(8111)
100     CONTINUE

      DO 300 I=1,45
      DO 310 J=1,81
      DO 320 K=1,11
      IF(MODEL(I,J,K).EQ.1) GO TO 330
      IF(MODEL(I,J,K).EQ.2)GO TO 310
      IF(MODEL(I,J,K).EQ.3)GO TO 310

      GO TO 320
330     MODEL(I,J,K)=7
      WRITE(30,2)I,J,K
2      FORMAT(312)
320     CONTINUE
310     CONTINUE
300     CONTINUE
      DO 400 K=1,11
      DO 400 I=1,45
      WRITE(26,1)(MODEL(I,J,K),J=1,81)
400     CONTINUE

1000    STOP
      END
```