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APPLICATION OF CONDITIONAL SIMULATION MODEL TO RUN-OF-MINE COAL SAMPLING FREQUENCY DETERMINATION AND COAL QUALITY CONTROL AT THE POWER PLANT

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APPLICATION OF CONDITIONAL SIMULATION MODEL TO RUN-OF-MINE COAL SAMPLING FREQUENCY DETERMINATION AND COAL QUALITY CONTROL AT THE POWER PLANT

by

Sukhendu Lal Barua

A Dissertation Submitted to the Faculty of the

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For the Degree of

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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As members of the Final Examination Committee, we certify that we have read

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SIGNED: Sukhendu Bose

To my mother, Suniti Prava Barua:

A source of inspiration for life.

I will do the best that I can and hope to match the good she has accomplished.

She taught my brother and me to be HONEST, LOYAL, and all those things that have become OLD-FASHIONED.

Her dedication to my education is one of my life's greatest REWARDS....

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ABSTRACT

Run-of-mine (ROM) coal sampling is one of the most important factors in determining the disposition of ROM coal for an overall emission control strategy. Determination of the amount of sample, or still better, the frequency of ROM coal sampling is thus essential to the analyses of overall emission control strategies.

A simulation model of a portion of the Upper Freeport coal seam in western Pennsylvania was developed employing conditional simulation. On the simulated deposit, different mining methods were simulated to generate ROM coal data. ROM coal data was statistically analyzed to determine the sampling frequency. Two schemes were suggested: 1) the use of geostatistical techniques if there is spatial correlation in ROM coal quality, and 2) the use of classical statistics if the spatial correlation in ROM coal quality is not present. Conditions under which spatial correlation in ROM coal quality can be expected are also examined.

To link the ROM coal and coals from other sources to coal stockpiles and subsequently to solve coal blending problems, where varying qualities of stockpiled coals are normally used, an interactive computer program was developed. Simple file-handling, for stockpiling problems,

and multi-objective goal programming technique, for blending problems, provided their solutions. The computer program was made suitable for use on both minicomputer and microcomputer. Menu-driven and interactive capabilities give this program a high level of flexibility that is needed to analyze and solve stockpiling and blending problems at the power plant.

CHAPTER 1

INTRODUCTION

Due to the recent downward shift in the world oil prices, the coal market in the U.S. has dampened a bit, but the consumption of coal to generate electricity continues to rise. More than 50% of the electrical power in the U.S. in 1983 was supplied by coal (1983 Keystone Manual) and it is projected to remain on the same level into 1990 (see Figure 1.1) and most likely beyond 1990, according to the United States Department of Energy.

The U.S. could rely more on coal to meet its energy requirements, and the idea is appealing. The U.S. has abundant coal reserves - enough, according to some estimates, to last 200 years. Coal burning plants can be built more quickly and cheaply than, say, nuclear ones. But combined coal facilities in the U.S. pump thousands of tons of SO2 and other pollutants into the air each day. They are one of the major causes of acid rain, which is slowly destroying some U.S. and Canadian lakes and may be damaging forest areas.

In order to limit the amount of SO_2 entering the atmosphere, the Environmental Protection Agency has imposed strict standards on the amount of SO_2 that can be emitted

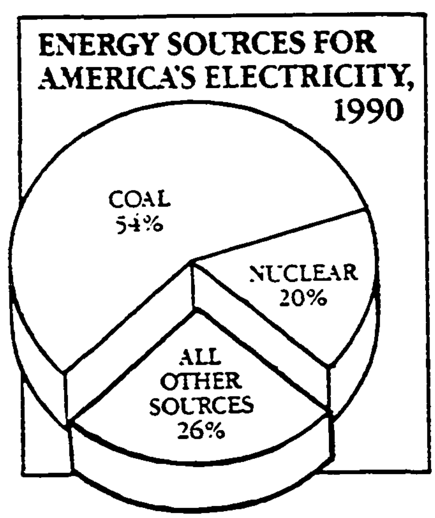


Figure 1.1 The United States Department of energy estimates by 1990. (Source: Energy Information Administration, U.S. Dept. of Energy)

from coal burning plants. According to the Clean Air Act of 1970 and 1978, a coal burning plant is required to emit less than 1.2 pounds of sulfur per million Btu generated. To stay in compliance, the feed to the plant must not exceed this threshold value in terms of sulfur content and heating (Btu) value.

Most of the coal burning plants in the U.S. are located in the east of the Mississippi and about 87 percent of the total national coal supply (Zimmerman, 1975) comes from this region. Coals from this region are predominantly high in sulfur (more than 1.5 percent). They are commonly blended with low sulfur (1.5 percent and less) western coal (remaining 13 percent of the national total) to comply with emission regulations. Other options to reduce SO_2 emission besides blending are: removal of sulfur from coal by cleaning the coal and removal of SO_2 from the smoke.

Clearly then, to control emission, one must have prior knowledge of the feed entering a power station. Likewise, to manage the feed to a desired level of quality, one must trace the source of the coal. Therefore, the quality characteristics of coal reserves play an important role in the development of emission control strategy. The coal must be characterized by its mean values of sulfur and Btu as well as by the expected variation in these qualities.

Extreme variation in quality of coal entering a power plant over a short time period (a few hours) is a very critical problem to the utility companies because most emission regulations set a limit that cannot be exceeded at any time. This extreme variation is the combined result of many variables. Some of these are: 1) the number of captive mines supplying coal to the plant, 2) the number of external suppliers to complement the captive mine coal, 3) the nature of blending and/or cleaning that occurs at the plant, and 4) the serial variability of the coal produced from each source. These causes can be easily recognized by looking at the schematic diagram of coal flow from a source (i.e., a mine) to the power plant as shown in Figure 1.2 The variability of ROM coal from each mine is, in turn, caused by the inherent in-situ variability of the coal quality as well as the particular mining methods used to extract the coal.

Therefore, to achieve a reasonable success in controlling coal quality, proper and effective policies have to be developed at various stages of coal movement. With this in view, a mining research team at the University of Arizona has developed several coal quality control strategies during the past five years. The next section will briefly summarize them.

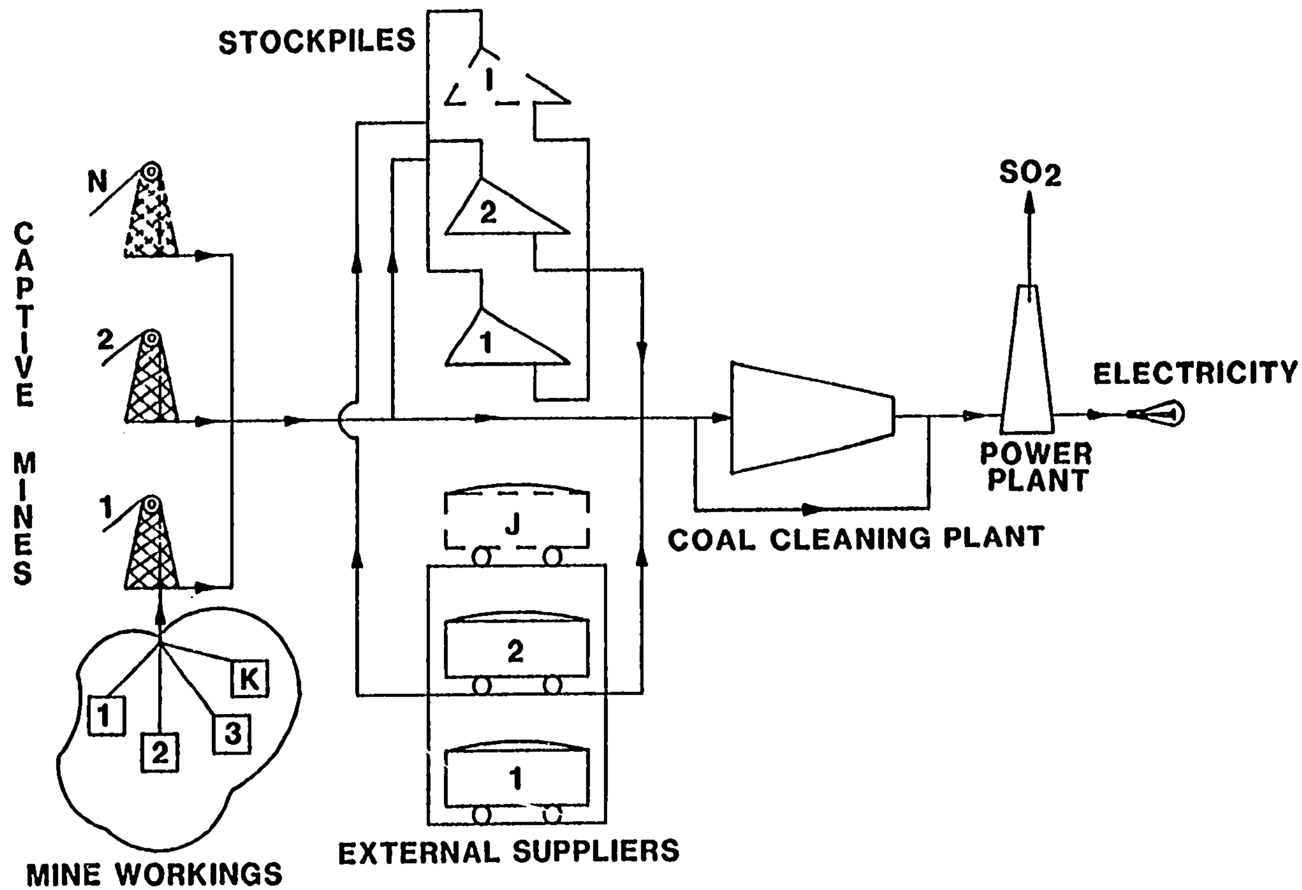


Figure 1.2 A schematic diagram of coal flow from mines to power plant.

Coal Quality Control Policies

The entire process of coal movement from the ground to the boiler can be categorized into three stages; pre-mining stage, mining stage, and post-mining stage.

Pre-mining Stage

Before coal is mined, a reasonably good knowledge of the deposit is necessary. This includes; 1) statistical information on distribution of coal characteristics, 2) their spatial correlation, 3) presence of any geological discontinuties like faults, washouts, etc. This information is usually obtained by collecting data from coal beds by means of diamond drill holes (DDH) and analyzing the data with the aid of geostatistical programs such as "BLUEPACK" or "GEOBASE". BLUEPACK was developed at Centre de Geostatistique, Fontainebleau, France and GEOBASE was developed at the University of Arizona. Both of these computer packages essentially enable a user to perform a geostatistical study of the deposit and gather necessary information during the pre-mining stage.

Mining Stage

Most underground coal mining methods do not allow poor quality coal to be left in place, except as pillars to provide ground support. Therefore, coal quality control during the mining stage can only be achieved by effective mine planning. Having pre-mining knowledge of coal quality distribution across the coal bed, maps of in-situ coal qualities can be drawn. With such maps it is possible to know, in advance, the effect of mining from different sections of the mine as to whether the needed quality and quantity of coals are mined by adopting a given mine plan.

Geostatistics and operations research (OR) techniques can help. Using geostatistical tools, the mineable coal qualities during the long term and short term planning horizon can be optimally estimated. With OR techniques, the optimality of a proposed mine plan under various management can be tested before putting the proposed plan into practice.

Kim and Knudsen (1981) have developed a short term mine planning model called STPM to assist the short term mine planning. The results of the short term mine plans are tested for feasibility and desirability by a "zero-one" face scheduling program called COMPF2, developed by Baafi (1983). The necessary data transfer from STPM model to COMPF2 program is made simple by an interactive graphics program called MPIG (Barua and Kim, 1984). The relationship between the STPM system of programs, MPIG, and COMPF2 programs is illustrated in Figure 1.3. Running the series of programs shown in this figure for a given mine provides individual coal quality estimates from each work area and also the

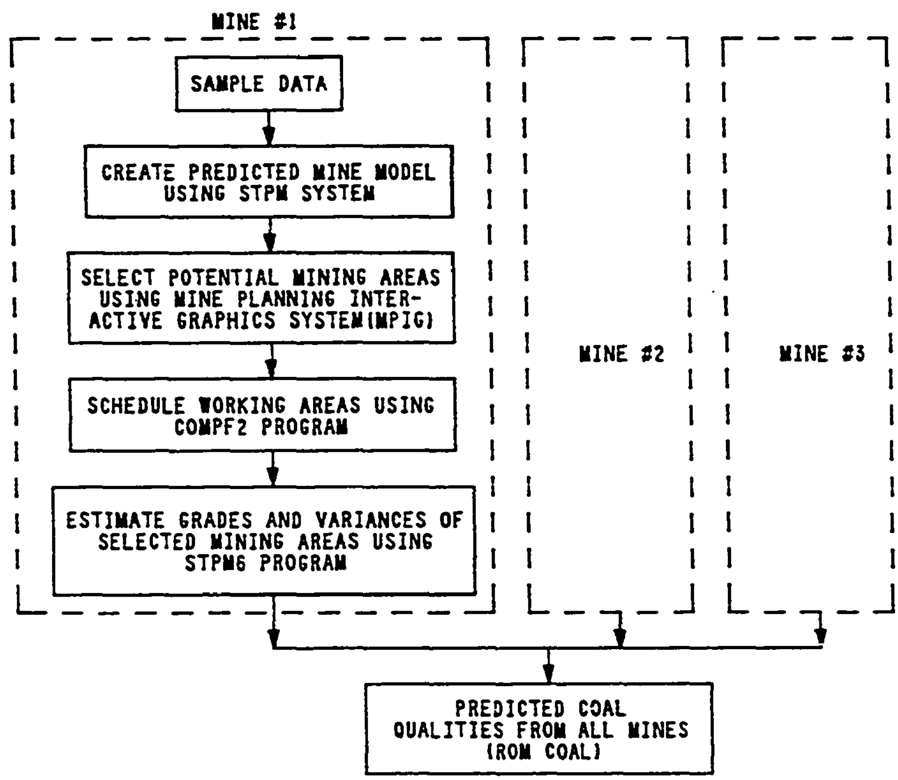


Figure 1.3 Routine tasks to be performed for ROM coal quality prediction.

overall average coal quality of mineable coal from this mine. The overall average coal quality, in fact, is ROM coal quality when the out-of-seam dilution during mining is properly and accurately accounted for.

Post-mining Stage

Often, it is difficult to obtain coal from a single source that provides all the desired qualities and quantity. To ensure the desired quality of end product and continuity of supply, the power plant must rely on a consortium of suppliers where each one supplies a different product with regard to quality. To meet the coal quality goals under such circumstances, in both long and short term time frame, a coal procurement effort is required.

The main aim of a long term coal procurement effort is to ensure a continual supply of desired coal from various suppliers by placing them under a long term, let's say seven to ten years, contract. The contract will usually contain a clause concerning the quality and quantity of the coal to be delivered. Each coal supplier is normally asked by the utility to provide information regarding the quality and quantity of future coal supply. The utility will use this information together with the in-house coal quality information to determine the amount of coal required from each supplier per planning period. The objective of this planning is to ensure that the resultant blended end product fulfills all quality requirements as closely as possible.

Short term coal procurement plans, on the other hand, shift the emphasis from predictions for contractual purposes to prediction for controlling the feed quality to the power plant. Precise prediction of near future coal deliveries are required for short term period of ,say, day-to-day or a week. Even precise prediction does result in blended end product that does not meet the power plant specifications. In such an event, the spot market coal is purchased to ensure the proper blend.

In other words, a power plant operator must have the capability of quickly solving the power plant feed blending problem if the feed quality is to be met consistently. With this in mind, Baafi (1983, pp. 44-48) developed a computer program called EXCOAL that solves the blending problem using a linear programming (LP) technique.

This LP model solves for the quantity of coal that should be purchased from each supplier to meet the quality requirements of blended coal at a minimum cost. The LP technique is rather rigid in problem formulation in that, if all the constraints in a LP formulation are not satisfied, then an LP solution becomes "infeasible". To avoid this rigidity, Lonergan (1983, pp. 56-81) used a multi-objective OR technique called goal programming (GP). The flexibilty of GP is that it treats the constraints of LP formulation as additional objectives. The optimal solution in GP is the one that comes closest to satisfying all the objectives in the problem formulation. Using GP, he developed a program called GOAL, which is similar to EXCOAL, to solve the feed blending problems. The task of developing external coal purchasing strategy during post-mining stage is shown in Figure 1.4.

Current Sampling Practices of Run-Of-Mine (ROM) Coal

In Figure 1.4, the estimated ROM coal is mixed with external coal. This ROM coal as well as the external coal must be properly sampled before they can be mixed since the mixing ratio depends on individual quality. To look into the actual sampling practices of ROM coal, a power generating station located in Johnstown, Pennsylvania was considered. This station is called Homer City Generating Station, jointly owned by the Pennsylvania Electric Company (Penelec) and the New York State Electric and Gas Corporation (NYSEG).

Homer City station receives coal from two sources: 1) in-house coal from dedicated mines, namely the Helen and Helvetia mines (Lucerne 6, Lucerne 8, and Lucerne 9), and 2) external coal from a group of twenty to thirty suppliers (McGraw 1983). This station has three power generating units, namely Units 1, 2, and 3.

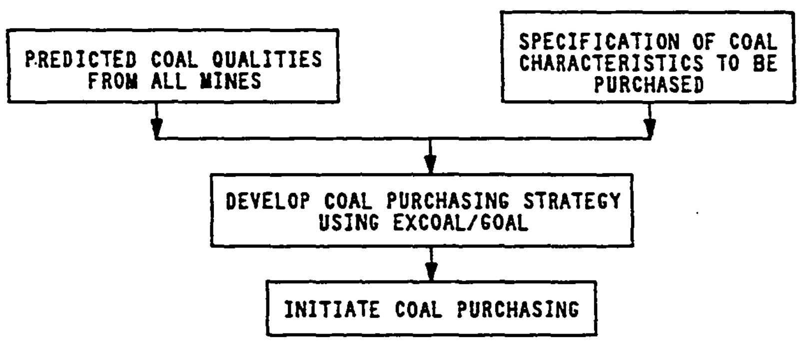


Figure 1.4 The task of developing external coal purchasing strategy.

Homer City Coal Sampling System

<u>In-house Coal:</u> ROM coal from Helen and Helvetia are sent to a bin via two separate conveyor belts. In this bin, two identical automatic samplers are housed; one for Helen coal and another for Helvetia coal. Coals get mixed inside this bin after samples are collected. The automatic sampler has three sample cutters: primary, secondary, and tertiary.

The primary cutter is located at the point where coal (top size of 1.25") drops off the conveyor belt into the bin. The cutter chute advances and retracts through the stream of coal flowing into the bin. This cutter can take 40 cuts per hour and 108 lbs per cut. The number of cuts per hour can be varied by changing the timer which controls dwell time. Pounds per cut will depend on the speed of the conveyor and the amount of coal it is carrying. For instance, in the case of Helen mine, the conveyor carries about 450 tons of coal per hour, the primary cutter takes 16 cuts per hour, and 80 lbs at each cut. That is, 1280 (16 x 80) lbs or 0.64 ton of sample for every 450 tons of conveyor coal.

The coal sample, collected by primary cutter, is crushed to a top size of 8 mesh and the secondary cutter takes its sample cut from this crushed coal. The primary and secondary cutters are similar and operate on the same principle. The secondary cutter can take 40 cuts per hour and 0.185 lb per cut i.e., 7.4 (40 x 0.185) lbs per hour.

The third and final sample cutter takes its sample cut from a vertically falling secondary cutter sample. This cutter is of a different design than the primary and secondary cutter. Here the cutter chute is being rotated continuously at a constant speed. On each revolution, the chute passes through the secondary coal sample dropping from a feeder and a small portion of sample enters the cutter chute and to a five (5) gallon final sample can. The specifications of this cutter are: sample per cut = 0.0003 lb; cuts per hour = 1,800; sample per hour = 0.533 lb; and total sample per day = 13 lbs. The cutter opening is adjustable and, therefore, the amount of sample per day can be varied by adjusting the cutter opening. For Helen mine coal, the amount of tertiary sample per day is about 30 to 40 lbs.

The sample obtained from the tertiary cutter goes through a riffler to produce the final sample for assaying. The riffler insures proper mixing and equal division of sample. Three-stage division is exercised before the final sample is obtained for analysis. The divisions are as shown in Figure 1.5.

If X is the initial sample size (about 35 lbs) then the final sample size is X/12 (about 2.92 lbs or 1325 grams). Equal sized final samples are placed into three steel cans and tightly sealed to maintain moisture content of coal. One sample is sent to the coal laboratory at

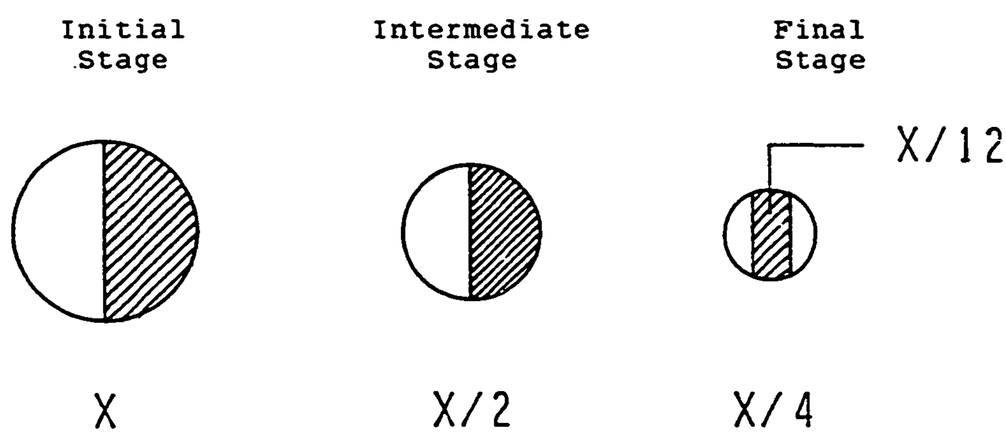


Figure 1.5 Three-stage division of coal sample.

Keystone, PA, one is sent to the mine, and one is held at the coal handling plant as a reference sample. The laboratory analysis takes two to three days (McGraw, 1983) before the results reach Homer City.

External Coal: All outside coals are supplied by truck to the Homer City station to complement the in-house coal (approximately 1.6 million tons per year, McGraw 1983). Truck samples are collected either by hand or by a portable auger. A five (5) gallon can sample (about 53 lbs) is collected from each supplier on a midnight to midnight basis and passed through a crusher for pulverizing. After pulverizing the sample is processed in the same manner as the in-house coal.

Statement of the Problem

At the Homer City Power Station small increments of coal samples are collected, throughout the day, from a conveyor belt carrying ROM coal. The basic idea behind this sampling procedure is that the sample collected during the day be representative of the daily ROM coal.

Determination of the amount of sample, or still better, the frequency of incremental samples, is a difficult task which must take the variability of ROM coal characteristics into account. The variability of coal characteristics in ROM coal depends on many variables. Some of these are: 1) the nature of in-situ coal characteristics,

2) the type of mining practices employed, and 3) the nature of blending that may occur during mining. These variables should be considered while developing a ROM coal sampling scheme.

To study the variability of coal characteristics in ROM coal prior to actual mining, simulated ROM coal data is needed. Employing geostatistical technique of conditional simulation, a coal deposit can be simulated in a computer and on this simulated deposit, different mining methods may be simulated to generate ROM coal data. Upon knowing the variability of coal characteristics in ROM coal, the minimum frequency of ROM coal sampling required can be determined such that the total sample collected per day be representative of the daily coal within a desired level of confidence. With the knowledge of daily coal, problems of coal blending and coal stockpiling can be addressed.

Coal stockpiling is an important part of an overall feed control strategy at a power plant (see Figure 1.2). The role of a stockpile, however, was not considered in designing coal quality control approaches discussed earlier. Once coal is temporarily stored in a stockpile, it should not be left unused for a long period of time due to possible oxidation and spontaneous combustion. The coal industry does not allow stockpiled coal to exceed a 45-day tonnage requirement of a utility plant (Baafi 1983, p. 85).

Therefore, to facilitate a continuous maintenance of an optimal coal inventory level in terms of both quality and quantity in various stockpiles, a dynamic coal stockpile management system is needed.

Objective of Study

Objectives of this study are as follows:

1) to review the adequacy of the existing in-house ROM coal sampling technique,
2) to determine the relationship between estimated in-situ coal and the ROM coal qualities using conditional simulation,
3) to determine the required sampling frequency of ROM coal which will provide the desired level of reliability on the ROM coal quality determination, and
4) finally, to solve coal stockpiling and coal blending problems at a power plant.

This work was performed as a sequal to the emission control strategy developed by the University of Arizona (Kim et al, 1980) for the owners of the Homer City generating station in western Pennsylvania.

Organization

This study is composed of six chapters. A brief theoretical background on coal sampling and conditional simulation are presented in chapter two. The basic requirements and mechanics of building conditional simulation model of sulfur content in a flat-lying coal deposit is described in chapter three. Chapter four presents the sampling frequency determination aspects of ROM coal. The interactive computer program designed to use ROM coal quality results in solving stockpile inventory control problems and coal blending problems are described in chapter five. Conclusions and recommendations for further work are presented in chapter six.

CHAPTER 2

BRIEF THEORETICAL BACKGROUND ON COAL SAMPLING AND CONDITIONAL SIMULATION

Coal Sampling

Sampling is the means whereby a small amount of material is taken from the main bulk in such a manner that it is representative of the larger amount. Great responsibility rests on a very small sample, so it is essential that samples are truly representative of the bulk (Lister, 1980).

A theory of sampling has been developed in selection of mineral samples according to fundamental probability theory discussed in detail in the Handbook of Mineral Dressing section on Sampling by Behre and Hassialis (1945). Probability methods have not yet been shown to be adequate in the general case to determine the minimum theoretical sample quantity. Practical procedures using probability equations have been found to be too complex for all but the very simplest case (Cooper, 1980).

The sampling method devised by Dr. Pierre Gy (1979) is often used to calculate the size of sample necessary to give the required degree of accuracy for particulate materials such as coal. The method takes into account the particle size of the material, the content and degree of liberation of the minerals, and the particle shape.

Gy's Basic Sampling Equation

Gy's basic sampling equation can be written as:

$$M = \frac{C * d^3}{s^2} \qquad 2.1$$

where M is the minimum weight of sample required in grams, C is the sampling constant for the material to be sampled ($g\ cm^{-3}$), d is the dimension of the largest pieces in the material to be sampled (cm), and s is the standard deviation of the fundamental error committed in random sampling.

The sampling constant C is specific to the material being sampled, taking into account the mineral content, and its degree of liberation,

$$C = f * g * \ell * m, \qquad 2.2$$

where f is a shape factor, normally 0.5, except for gold ores where it is 0.2; g is a particle distribution factor, usually taken as 0.25, unless the material is closely sized, in which case it is 0.5; and ℓ is a liberation factor, 0 for completely homogeneous material and 1.0 for completely heterogeneous material. Gy devised a table (Table 2.1) based on the dimension of the largest pieces in the material

(d) to be sampled, which can be taken as screen aperture that passes 95% of the material, and the practical liberation size of the material (L) i.e., for all practical purposes, the material is liberated at that size. Table 2.1 shows estimation of ℓ as a function of d/L (top particle size/liberation size).

Table 2.1 Estimation of ℓ as a Function of d/L

d/L	<1	1-4	4-10	10-40	40-100	100-400	>400
ℓ	1	0.8	0.4	0.2	0.1	0.05	0.02

Values of ℓ corresponding to the values of d/L can be estimated from the table, and m is mineralogical composition factor which can be calculated as follows:

$$m = \frac{(1 - a)}{a} [(1 - a) * r + a * t], \qquad 2.3$$

where r and t are the mean densities of the valuable mineral and gangue minerals respectively, and a is the fractional average mineral content of the material being sampled.

In the equation 2.1, s is the standard deviation of the statistical error committed in random sampling of a material which assumes normal distribution for a large number of samples taken from the material. In all sample taking, sample preparation, and analytical steps, random errors are introduced and the total error variance (s^2) is the sum of the individual error incurred at each sampling stage (Ottley, 1980).

The Gy's equation (2.1) assumes that samples are spatially independent and they are taken at random and without bias. Any nonrandom errors or biases which can occur in sampling and preparation are not provided for by the equation. Therefore any nonrandom errors should be added to the normal error in this equation.

Uses of Gy's Equation

Ottley (1980) outlined the use of Gy's equation for three basic types of sampling calculations.

i) calculation of the weight of sample (M) to be taken from larger mass (same as equation 2.1)

$$M = \frac{C * d^3}{s^2} \qquad 2.4$$

ii) determination of sampling error (s)

$$s^2 = \frac{C * d^3}{M} \qquad 2.5$$

iii) calculation of the particle size (d) to which a sample should be crushed

$$d = \left(\frac{M * s^2}{C}\right)^{1/3} \qquad 2.6$$

An Example of Coal Sample Size Determination Using Gy's Equation: Take the automatic sampler used at the Homer City Station, mentioned in chapter one. The automatic sampler has three cutters; primary, secondary, and tertiary. Sample weights at each of these three cutting stages can be calculated using Gy's equation.

Consider, for instance, each incremental sample taken by the primary cutter at a top size of 1.25 in. (3.175 cm) to be representative of the ROM coal at the time of sampling. These incremental samples, as mentioned before, are crushed to a top size of 8 mesh (0.18 cm) and conveyed to the secondary cutter and finally from the secondary cutter to the tertiary cutter where the final sample is collected. No further crushing of ROM coal is done between the secondary and the tertiary sampling stages.

Suppose, this ROM coal, assaying about 2.4% total sulfur, out of which 1.5% is pyritic sulfur, is routinely sampled for assaying to a confidence level of ± 0.075% pyritic sulfur 95 times out of 100. Fine pyrite is assumed to be liberated from coal at a particle size (L) of 150 mesh (0.01 cm) (Benzon and Burgess, 1966).

Note that, only the pyritic sulfur is considered here for liberation instead of the total sulfur because, in

American coal,20 to 80% of the total sulfur is the completely inaccessible organic sulfur (Gluskoter, 1968).

In this example, there are three stages of sampling. If the statistical errors incurred at the primary, secondary, and the tertiary stages are s_p, s_s, and s_t respectively, then the total error (s_T^2) would be given by:

$$s_T^2 = s_p^2 + s_s^2 + s_t^2$$

The step or stage which introduces the largest error will have greatest effect on the total error. Large errors usually occur in the primary sampling stage and at coarser particle size. However, for simplicity, if equal errors are assumed at each stage, then

$$s_p^2 = s_s^2 = s_t^2 = s_T^2 / 3.$$

Since a confidence level, of 1.5% ± 0.075% pyritic sulfur 95 times of 100 is to be achieved,

$$1.96s = 0.075 \quad \text{or} \quad s = 0.038$$

Therefore,

$$s_p^2 = s_s^2 = s_t^2 = (0.038)^2 / 3 = 4.8 * 10^{-4}.$$

Assuming mean densities of pyrite and coal as 4.9 and 1.3 respectively, then

$r = 4.9$ and $t = 1.3$.

The percentage of sulfur in pyrite (FeS_2) is 53.34%. Therefore, the percentage of pyrite in coal, considering 1.5% pyritic sulfur, is

$$a = 0.015 / 0.5334 = 2.8\% \text{ approximately or } 0.028.$$

Following the equation 2.3,

$$m = 166.6 \text{ g cm}^{-3} .$$

Assume average values of f and g as 0.5 and 0.25 respectively. For the primary cutting stage, at 1.25 inch (3.175 cm) top size,

$$d / L = 3.175 / 0.01 = 317.5,$$

$$\ell = 0.05 \text{ (from Table 2.1)},$$

$$C = 0.5 * 0.25 * 0.05 * 166.6 = 1.041 \text{ g cm}^{-3} \text{ , and}$$

$$M = 1.041 * (3.175)^3 / 4.8 * 10^{-4}$$

$$= 69413.0 \text{ g} = 70 \text{ kg}.$$

For the secondary cutting stage, at 8 mesh (0.18 cm) top size,

$$d / L = 0.18 / 0.01 = 18.0,$$

$$\ell = 0.2 \text{ (from Table 2.1)},$$

$$C = 0.5 * 0.25 * 0.2 * 166.6 = 4.17 \text{ g cm}^{-3} \text{ , and}$$

$$M = 4.17 * (0.18)^3 / 4.8 * 10^{-4}$$

$$= 51 \text{ g}.$$

Since the top size of coal sample, at the tertiary cutting stage, remains same at 8 mesh and the other variables in equation 2.1 also remain unchanged, the amount of sample at this stage should be the same as in the case of secondary cutting stage of 51 grams. That is, the tertiary sampling stage appears to be redundant under the current set up at the Homer City Power Station and a similar opinion was expressed by a company engineer.

Note the relationship between the minimum sample weight (M) and the top size (d) of the material being sampled. Minimum sample weight increases with increase in top size with a power of 3.

In summary, Gy's equation gives the minimum theoretical weight of sample which must be taken, but does not state how the sample is to be taken. The size of each increment taken, in the case of stream sampling like ROM coal, and the increment between successive cuts must be such that sufficient weight is obtained. Wherever possible, or practical, two to three times the minimum weight of sample should be taken to allow for the many unknowns, although, of course, over-sampling has to be avoided to preclude problems in handling and preparation.

In the above example, therefore, about 175 kg of ROM coal at the primary stage and about 130 g at the secondary stage would have to be sampled in order to give the required degree of confidence. No account has been taken here of further sample divisions required prior to assaying.

Precise determination of the sampling frequency is an exacting task employing autocorrelation statistics which involves the geostatistical technique of the variogram (Cooper, 1980). Determination of this sampling frequency of ROM coal by employing geostatistical methods is one of the central themes of this study. The influence of in-situ coal characteristics on ROM coal and the nature of coal blending that occurs during the formation of ROM coal are taken into consideration in devising a scheme for sampling frequency determination.

Conditional Simulation

The Need For Conditional Simulation

The idea of an ore body simulation is not new. Using high performance computers, many authors have proposed various stochastic or deterministic simulations of an ore body. But most of these "classical" approaches have failed to reproduce the most important characteristics, namely, the spatial correlations of variables. The relevant variables are correlated in all deposits. These correlations can be characterised by covariances, correlograms, or still better, by variograms. Therefore, it is necessary that the simulation model meets the underlying correlation functions of variables of the real deposit.

Until recently, no simulation technique was available which could be employed to reproduce the spatial characteristics of the real deposit in three-dimension. Fortunately, however, recent advances in geostatistics made possible the use of conditional simulation to answer the variability problems.

What is Conditional Simulation?

The idea of conditional simulation is to construct a numerical model of an ore/coal deposit in such a way that this model has the same mean, the same variance and the same variogram as the real deposit. Furthermore, the model has values identical to the real deposit, at all known data points. In other words, the development of a model is "conditioned" to go through all known data points.

In analytical terms, consider a random function (RF) $Z(x)$. This RF is characterized by a distribution function and a covariance or variogram function. A regionalized variable $z(x)$ is one realization of this RF, where $z(x)$ is one possible value of the RF $Z(x)$ at point x, $x \in R^3$ (R^3 is a three-dimensional space).

Suppose the RF $Z(x)$ represents the exact thickness of coal measured along a hypothetical coal seam. For illustration purposes, assume that this hypothetical coal seam is the real deposit and examine the saw-toothed plots of Figure 2.1. The first plot shows this hypothetical coal

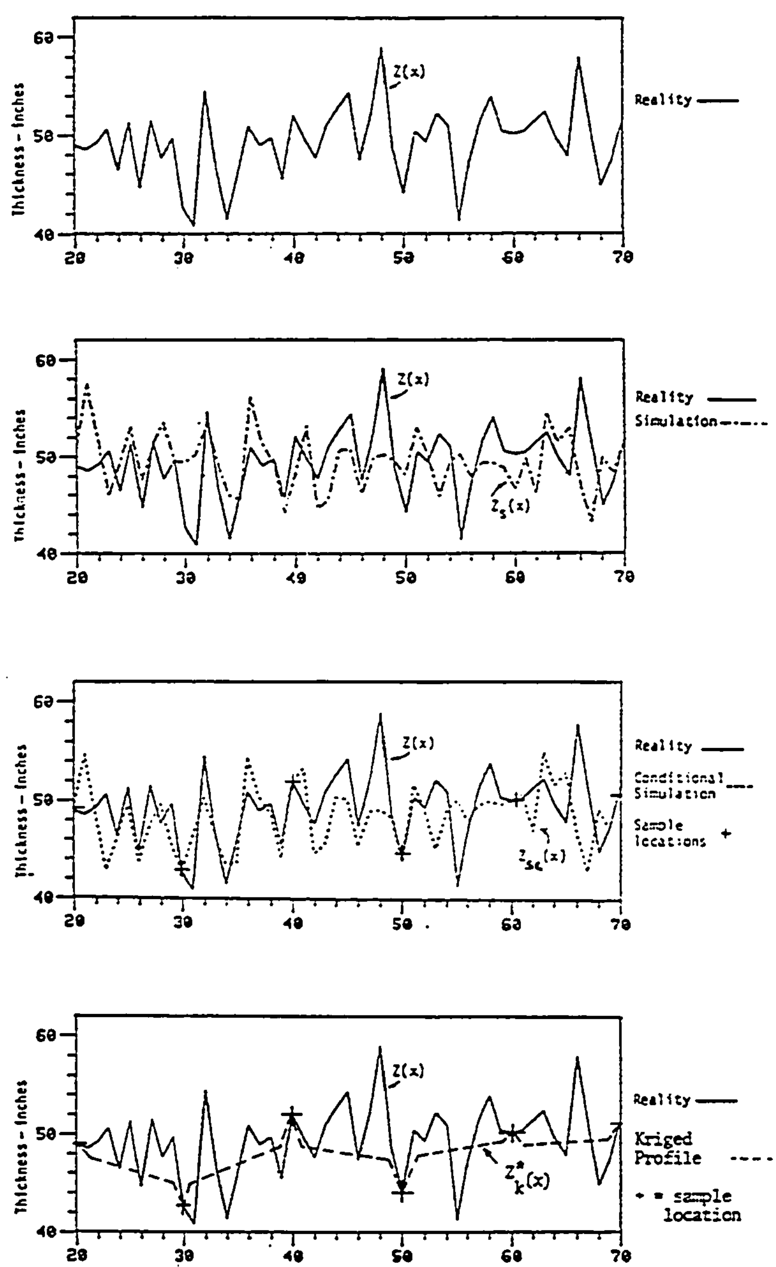


Figure 2.1 Comparison of reality and conditional simulation along a hypothetical coal seam

seam. A non-conditional simulation of this RF is made and shown in the second plot of the Figure 2.1 as $Z_s(x)$ together with the real deposit Z(x). Non-conditional simulation is obtained by using Turning Band Method proposed by Matheron (1970). Detailed theoretical framework on generating a non-conditional simulation $Z_s(x)$ with turning bands appears in a paper by Journel (1974), in Mining Geostatistics book by Journel and Huijbregts (1978), and in the Ph.D. dissertation of Knudsen (1981).

As noted earlier, the characteristics of $Z_s(x)$ are such that it has the same mean, the same variance, and the same variogram as Z(x).

Mean: $$E\{Z_s(x)\} = E\{Z(x)\} \tag{2.7}$$

Variance: $$E\{Z_s(x) - m\}^2 = E\{Z(x) - m\}^2 \tag{2.8}$$

Variogram: $$E\{Z_s(x+h) - Z_s(x)\}^2 = E\{Z(x+h) - Z(x)\}^2 \tag{2.9}$$

Simulated data in Figure 2.1 appears to model the general characteristics of the deposit fairly well, but of course, do not match the real deposit at each and every point. Next, $Z_s(x)$ is forced to pass through (i.e., conditioned through) six data points, thus generating the conditional simulation $Z_{sc}(x)$. The third plot in Figure 2.1 shows $Z_{sc}(x)$ and Z(x).

The resulting conditional simulation $Z_{sc}(x)$ relates more closely to the real deposit Z(x) than the nonconditional simulation $Z_s(x)$. Also notice that at sample points x_a, $Z_{sc}(x_a) = z(x_a)$. Equations 2.7 through 2.8 also hold true for $Z_{sc}(x)$. The last plot in the Figure 2.1 shows the real deposit again and a profile of kriged estimates $Z_k(x)$. This kriged profile is deduced from the available data $Z(x_a)$ of the actual deposit. Notice that at sample points x_a, $Z(x_a) = Z_k(x_a)$. This is due to kriging being an exact estimator; hence , the best estimate of a sample grade is the sample grade itself (Knudsen 1981, pp. 31-33).

Since Z(x) is the real deposit thickness and $Z_k(x)$ is the kriged estimate of the real deposit, the difference between these two profiles, $[Z(x) - Z_k(x)]$, is the kriging error. This kriging error is of special interest to us in conditional simulation because it has an important property which is the key to the theory of conditional simulation. This error, $[Z(x) - Z_k(x)]$, is considered as RF (random function) and it is orthogonal to (independent of) the estimate $Z_k(x)$ (Journel and Huijbregts 1978, p. 495). Using this property, a conditional simulation can be made by simulating the error $[Z(x) - Z_k(x)]$ and add it to the kriged values $Z_k(x)$. To be valid, however, the simulation error would have to be isomorphic to the real error [Z(x) -

$Z_k(x)]$. Two RFs are isomorphic if they have same expectation and same second-order moment, covariance or variogram (Journel et al, 1978).

Once again, the real deposit thickness Z(x) was hypothetical, and it is never known in reality, unless one decided to dig out the entire deposit on an experimental basis. Therefore, the true kriging error $[Z(x) - Z_k(x)]$ is also unknown. Simulation of this unknown error can be done by taking a nonconditional simulation $Z_s(x)$ and constructing a kriged estimate $Z_{sk}(x)$ using the simulated values at the same sample positions, x_a, as the real data.

The true deposit can be written as:

$$Z(x) = Z_k(x) + [Z(x) - Z_k(x)] \qquad 2.10$$

The simulated kriging error $[Z_s(x) - Z_{sk}(x)]$ is independent and isomorphic to the unknown true error $[Z(x) - Z_k(x)]$ and $Z_{sc}(x)$ is isomorphic to Z(x). Therefore, conditionally simulated deposit can be written as:

$$Z_{sc}(x) = Z_k(x) + [Z_s(x) - Z_{sk}(x)] \qquad 2.11$$

Thus the requirements of conditional simulations are satisfied since the following qualifications are met:

1) $Z_{sc}(x)$ has the same expectation as Z(x). This follows from the unbiasedness property of the

kriging estimator. Taking expectation of equation 2.11, we have:

$$E\{Z_{sc}(x)\} = E\{Z_k(x) + [Z_s(x) - Z_{sk}(x)]\}$$
$$= E\{Z_k(x)\} + E\{[Z_s(x) - Z_{sk}(x)]\}$$
$$= E\{Z(x)\}.$$

2) $Z_{sc}(x)$ and $Z(x)$ has same variogram. This because the simulated error $[Z_s(x) - Z_{sk}(x)]$ is isomorphic to the true error $[Z(x) - Z_k(x)]$ and independent of $Z_k(x)$. Also, $Z_{sc}(x)$ is isomorphic to $Z(x)$.

3) Same value at known data points. From properties of kriging we know that kriged values are equal to the real values at known data points, x_a. That is, $Z_k(x_a) = Z(x_a)$ and $Z_{sk}(x_a) = Z_s(x_a)$. Therefore,

$$Z_{sc}(x_a) = Z_k(x_a) + [Z_{sk}(x_a) - Z_s(x_a)]$$
$$= Z(x_a).$$

CHAPTER 3

CONDITIONAL SIMULATION MODEL BUILDING

In this chapter, various features of conditional simulation (CSIM) model building are described. The variable chosen for modeling is in-situ sulfur. The modeling procedure is identical for any other variable such as Btu, ash, or thickness of coal seam.

Prerequisites to Building a CSIM Model

The paramount feature of a CSIM model is that the model must reproduce the most essential statistical characteristics of the real deposit. Specifically, the model should:

1. have the same mean as the real deposit,
2. have the same variance and variogram function,
3. have the same empirical distribution, and
4. be conditioned to the real data.

Therefore, to build a CSIM model one must have three essential elements; 1) data from a real deposit (<u>for</u> which the model is being built), 2) computer softwares (<u>by</u> which the model is built), and 3) computer hardware (<u>on</u> which the model is built).

The data requirements are: 1) real deposit, and 2) sufficient samples measured without error to construct an experimental variogram. Computer programs used to build CSIM models on a Cyber-175 computer were written by Knudsen (1981) at the University of Arizona.

The real deposit simulated in this study is a portion of the Upper Freeport Coal Seam located in western Pennsylvania near the town of Homer City. There are 188 diamond drill holes reporting sulfur values within an area of about 50 square miles. The holes have an average drilling spacing of about 1500 feet, encompassing the Helen Mine property.

Variogram Study of Sulfur

Variogram study can be categorized into two parts, namely, the statistical analysis to understand the geology of the deposit and the variogram computation to quantitatively capture the spatial correlation among values of a particular coal characteristics such as sulfur.

Statistical Analysis

During statistical analysis of Helen mine data, it was found (Kim, Baafi, and Barua, 1981, p. 15) that there is a transition zone in E-seam which splits the Helen property into thick coal (about 80 inches seam thickness) and thin coal (about 49 inches seam thickness). The presence of this apparent discontinuity was subsequently confirmed by the company geologists. Most of the Helen property falls below the transition zone of thin coal as shown in Figure 3.1.

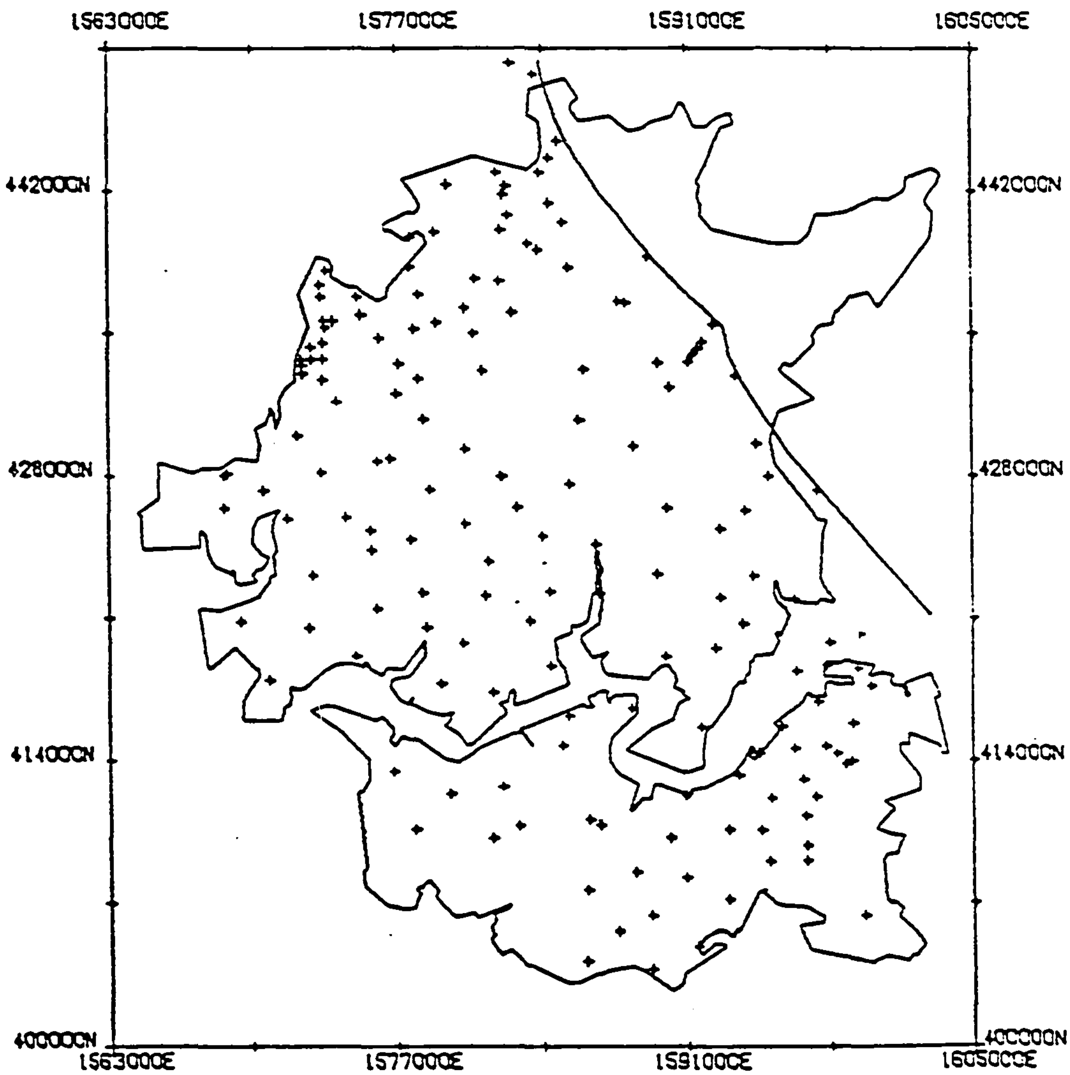


Figure 3.1 Plan map of Upper Freeport coal seam.

The polygonal outline, in this figure, marks the property boundary and pluses indicate locations of drillholes intersecting the coal bed. A statistical summary of coal samples below the transition zone is given in Table 3.1 and the sulfur histogram is shown in Figure 3.2.

The histogram in Figure 3.2 shows several important aspects of the distribution of sulfur. First, the distribution appears to be truncated at about 0.5% sulfur. Secondly, the presence of several modes, a minor one at about 0.7% sulfur, one major one at 2.0% sulfur, and at 3% sulfur. Finally, the data is skewed to the right (skewness = 0.464). This seemingly complex distribution can possibly be accounted for by the relative differences in amounts of sulfur in organic and inorganic matters in coal (knudsen 1981, p. 59).

Plants use sulfur in their growth process. When these plants end up as coal after bacterial decomposition over millions of years, the sulfur remains in the coal as organically bound (Cecil et al., 1978, p. 42). The amount of this sulfur is between 20 to 80% of the total sulfur and cannot be removed from the coal by coal cleaning processes (Gluskoter, 1968).

Inorganic sulfur on the other hand, occurs predominantly as metal sulfides, mainly pyrite. The sulfur compounds found in coal are mainly due to the intrusion of

Table 3.1 Summary of Statistics for Coal Characteristics

Variable	Number of Assays	Sample Mean	Sample Variance	Sample Standard Deviation
Thickness	224	49.00 in	41.00 in^2	6.40 in
Ash	188	16.83 %	17.83 $(\%)^2$	4.20 %
Sulfur	188	2.57 %	1.25 $(\%)^2$	1.11 %

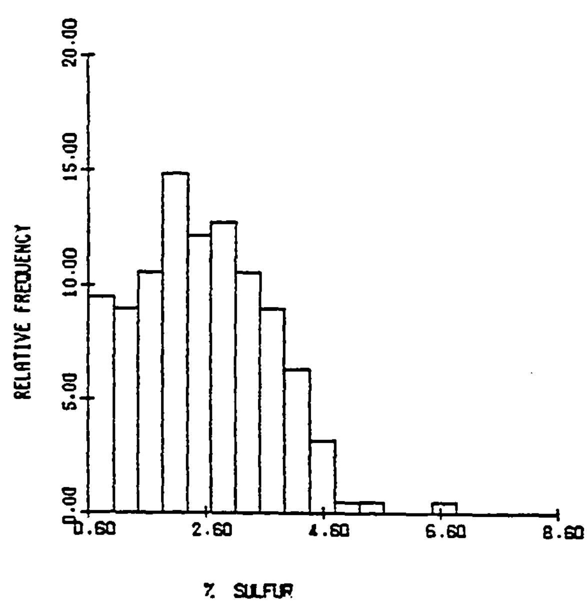


Figure 3.2 Sulfur histogram.

inorganic matters into the coal bed. Because of several distinct origins of sulfur in coal, it can be argued that sulfur from each source is likely to have different distributions and, thus, the combined sulfur distribution may be multi-modal as suggested in the histogram in Figure 3.2.

Normalization of Sulfur Values

The CSIM employs the Turning Band Method, and this method produces only normally distributed values (Matheron/Journel, 1974). If the variable being simulated has any other form of distribution, then a transformation must be found to reproduce the normal distribution, in order to apply CSIM.

As we noted in Figure 3.2, the sulfur exhibits a skewed distribution. The Chi-Square Goodness of Fit Test to check the normality of sulfur values was found unsatisfactory. A logarithmic transformation was tried next, but the transformed values were not well behaved under normal distribution. It was then decided to make the tranformation using a function consisting of Hermite Polynomials (Kim, Myers, and Knudsen, 1977, pp. 60-81). This function essentially guarantees a set of normally distributed values. Figure 3.3 shows the resulting transformation can be used to retransform the normally distributed values back to the original distribution.

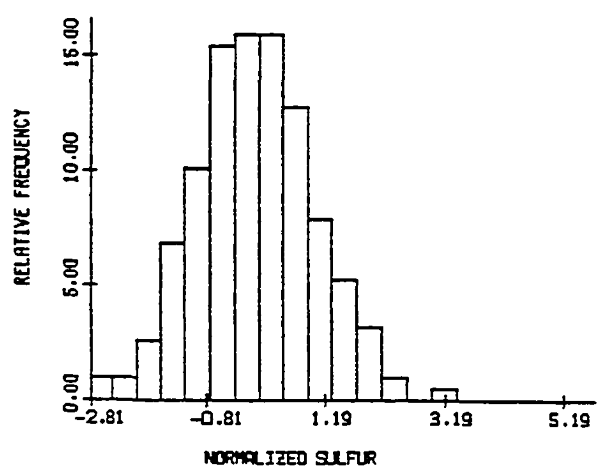


Figure 3.3 Histogram of normalized sulfur.

Variogram Analysis

A variogram is defined as half the average square difference between sample values that are a certain distance apart. It basically measures the variance of the difference between sample values separated by a certain distance. The variogram was calculated for normalized sulfur values and no anisotropy was found. Dotted lines in Figure 3.4 shows the experimental variogram. This variogram effect is quite large (about 30 percent of the total sill). The true nugget may be smaller than indicated, but very few closely spaced data are available which is not adequate to determine the nugget more accurately. The jagged appearance in this variogram is of little concern since most of it lies beyond the range of influence of the variogram.

Spherical variogram models were fitted to the experimental variogram to find the theoretical variogram model parameters (e.g. nugget, sill, and range of influence). Finding the best fit theoretical model is a dual process. It involves visual matching of theoretical model to experimental variogram and scientific verification at known data points by point kriging, often referred to as jack-knifing or cross-validation. Point kriging is simply estimating values at known data points, by using theoretical variogram parameters, and comparing them with actual values at known points. The best fitted model is the one that

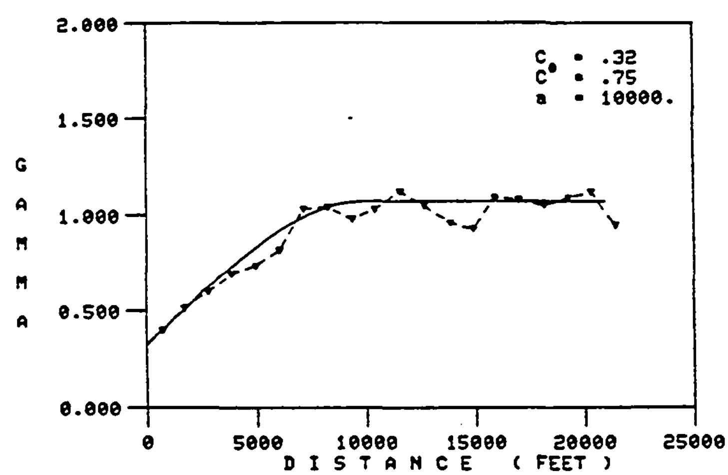


Figure 3.4 Normalized sulfur variogram.

Table 3.2 Parameters of Spherical Variogram Models

Variable	Sill Co + C $(\%)^2$	Nugget Co $(\%)^2$	C-Value C $(\%)^2$	Range a (feet)
Sulfur	1.28	0.37	0.91	10,000
Normalized Sulfur	1.07	0.32	0.75	10,000

shows the best kriging results and reasonably good visual fit to the sample variogram. Figure 3.4 shows the best fit theoretical model (solid line) and the experimental variogram (dotted line). The theoretical model parameters of normalized and actual sulfur values are given in Table 3.2.

Mechanics of CSIM Model Building

In this section, a basic definition of a CSIM model, as conceived by the CSIM system, will be discussed first followed by CSIM model construction.

CSIM Model Definition

A CSIM model consists of an orderly collection of grid points stored in a three-dimensional array where each grid point represents a precise physical volume of ground in the deposit (Kim et al., 1981). The value of each grid point is the simulated attribute, such as the percentage of sulfur present in that volume of ground. The smaller the volume of ground the more detail the model provides, as long as enough sample data are present to give such detail. However, with smaller volume the kriging variance increases. The CSIM model can have its vertical dimension set to unity (1) to effectively convert it to a two-dimensional model which is ideal for modeling flat-lying, tabular coal seams.

Since coal deposits generally cover large areal extent, it becomes necessary to divide the deposit into equal sized blocks for modeling purposes. For a two-dimensional model, each block is represented by 100 by 100 by 1 arrays of grid points (10,000 points). The relationship of grid spacing to a block is shown in Figure 3.5. Since the purpose of the model is to study the quality fluctuation in short term, it is not necessary to use the entire model all at once. Instead, only the portions of the model corresponding to the areas that will be mined in the near future are studied. For instance, if mining will be limited to Block 1 of Figure 3.5 for next year, then only Block 1 need be modeled and be brought to computer core for execution.

Model Construction

The study objective here is to simulate hourly ROM sulfur fluctuation from an underground coal mine. The mine selected for this study was Homer City Owner's Helen mine where the average hourly production during the first half of 1982 was about 16 tons per working face (summarized from company's production report). To that end, a 10' X 10' Smallest Mining Unit (SMU) with an average 49 inches of seam height and 25 (cu.ft/ton) tonnage factor would represent an equivalent hourly production (10' X 10' X 49" ÷ 12 ÷ 25 = 16.34 tons).

A 10' X 10' SMU can be defined by a collection of points inside a 10' X 10' block. The greater the number of

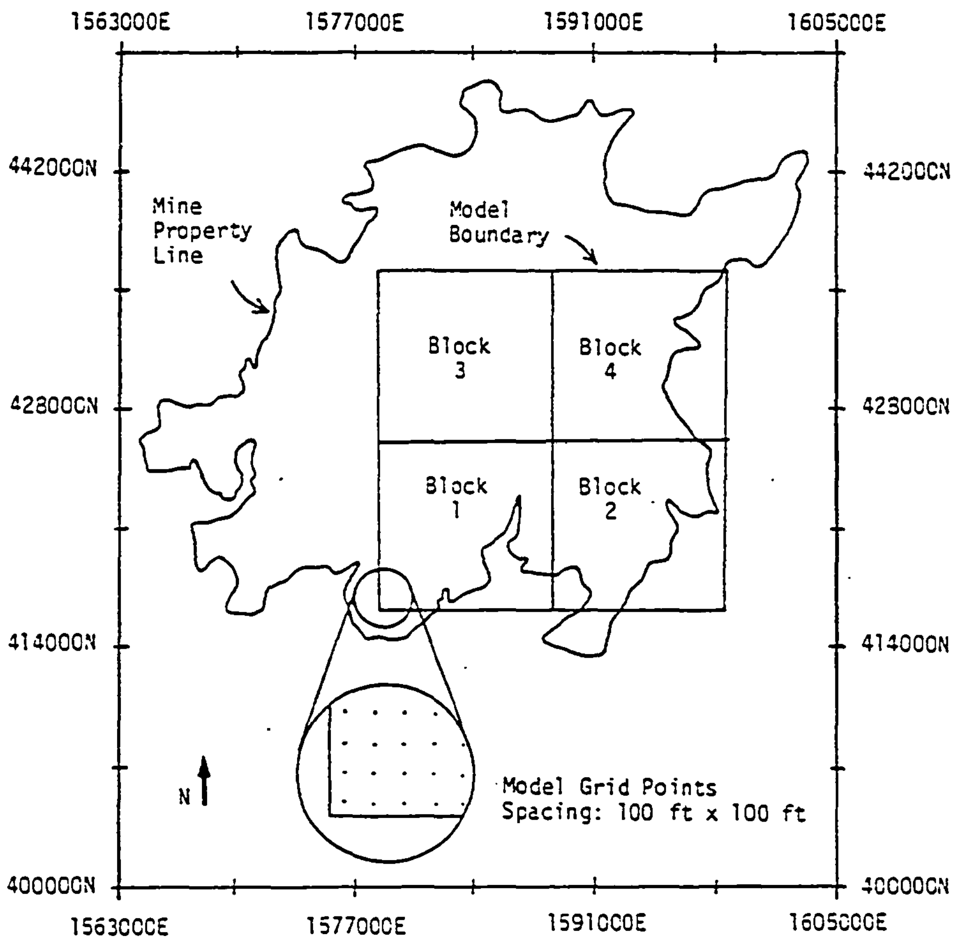


Figure 3.5 Plan view showing block/grid point relationship.

points, the better the definition of SMU is. The arithmetic average of point values is the simulated value of the SMU. The relationship between the number of points used to simulate a 10' X 10' SMU and the corresponding CSIM grid spacing is shown in Table 3.3. With finer grid size, an enormous number of points have to be simulated in the computer to cover the coal deposit in order to generate hourly ROM coal data. In this study, therefore, a 5' X 5' grid spacing was selected, where each SMU value is the average of four (4) simulated point values falling inside that SMU.

Constructing a CSIM model covering about 15,000' X 15,000' area (current extension of Helen Mine workings, see Figure 3.6) with 5' X 5' grid presents two unavoidable practical problems. First, the number of grid points necessary to model the area would be 9 million (3,000 X 3,000) which is so large that the current CSIM system cannot handle it. Secondly, the number of actual data available to condition these large number of simulated values is only 188. To box off these problems, a two stage model building is carried out where 188 drill hole assay values are used to condition the first stage models and simulated values, generated in the first stage models, are used in conditioning the second stage models.

The effect of two stage conditioning may be similar to that of non-conditioning. However, the simulated values

Table 3.3 Relationship Between CSIM Grid Size and Number of Points in a 10' x 10' SMU

CSIM Grid Size	Number of Points in a 10' x 10' SMU
10' x 10'	1
5' x 5'	4
2.5' x 2.5'	16

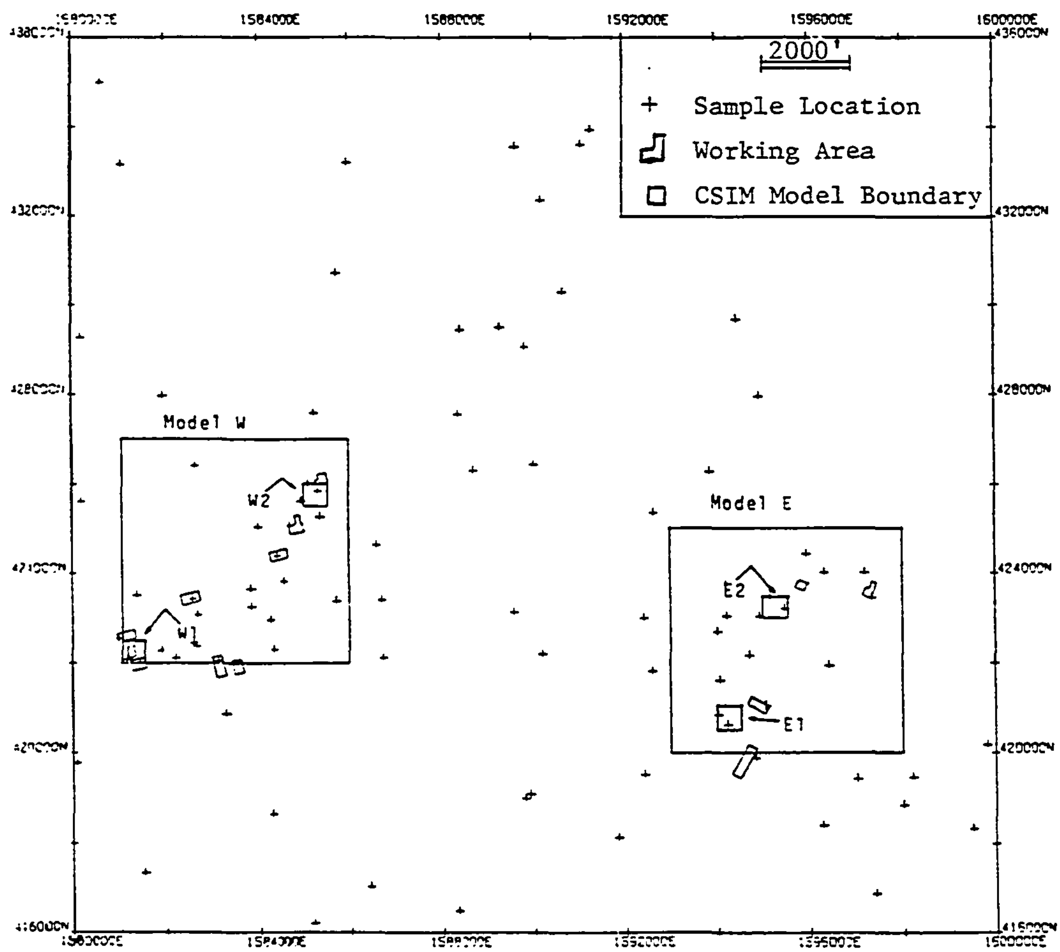
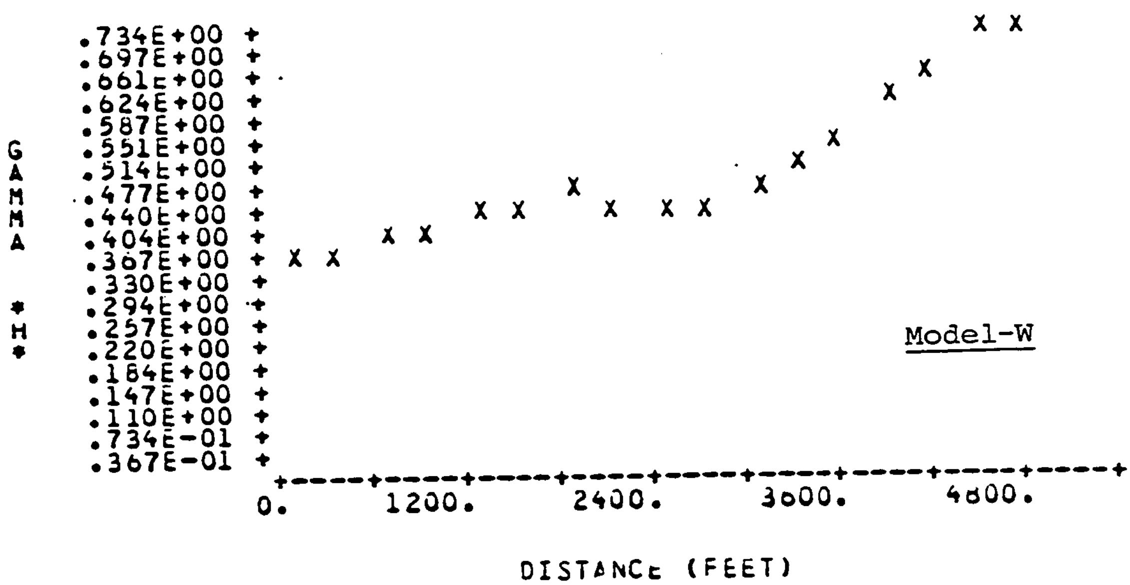


Figure 3.6 Plan map of Helen Mine working areas and CSIM model boundaries.

generated after the first stage conditioning will exhibit, to some degree, the localized variability in those four (4) smaller models because a few drill holes do fall within each smaller model. Hence, after the second stage conditioning, the simulated values of smaller models may show some degree of localized variability in them. Further detail on model building is given below.

During 1981-1982 most of the mining activities of Helen mine were concentrated towards the west and east sides of the Helen property as shown in Figure 3.6. In the first stage of model building, two equal sized areas were selected to build two separate CSIM models. One at the west side (Model-W) and the other at the east side (Model-E). Each model covers an area of 5,000' X 5,000', as shown in the Figure 3.6, and consists of 10,000 simulated values on a 50' X 50' grid. Conditioning of each model was performed by using the actual data falling within the respective model area.

Figure 3.7 shows the variograms of simulated values for Model-W and Model-E. These variograms can be regarded as global variogram of Figure 3.4, as expected. If the horizontal scale of Figure 3.7 is reduced, then the slope of the variograms will be similar to that of Figure 3.4. Also note that, at a given distance, $\gamma(h)$ values are similar. The nugget remained almost same in these three (3)



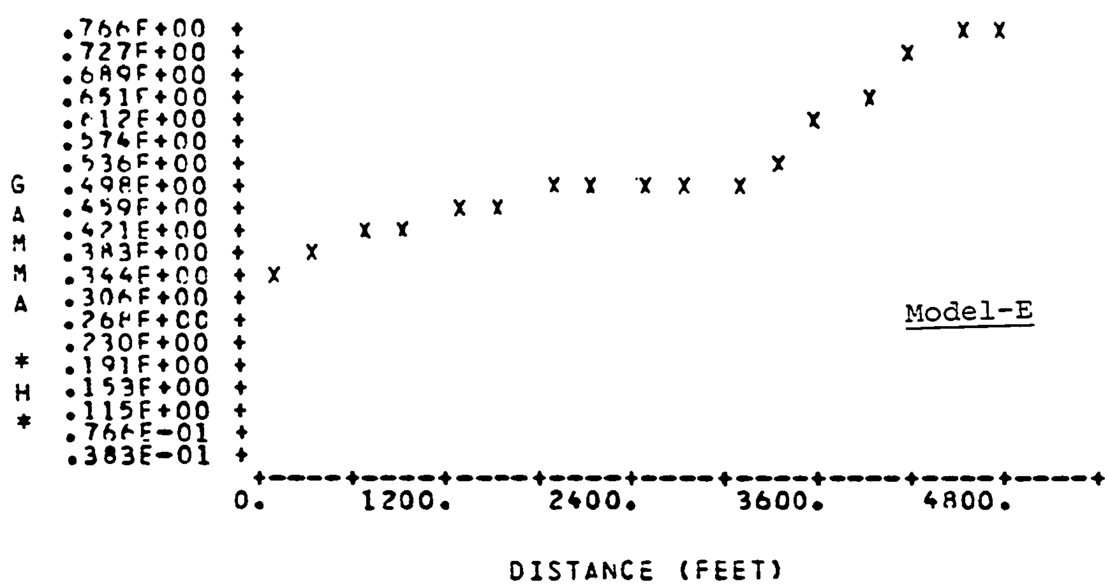


Figure 3.7 Variograms of simulated values for Model-W and Model-E.

variograms. The range of Figure 3.7 variograms could not be obtained because the model size is only 5,000' compared to the global variogram range of 10,000'. Since there is no apparent disagreement between global variogram and first stage model variograms, the global variogram is used in the second stage of model building.

In the second stage, four (4) additional models were built. Two models inside the Model-W (Model-W1 and Model-W2) and two models inside the Model-E (Model-E1 and Model-E2). Each of these four (4) smaller models covers an area of 500' X 500' and consists of 10,000 simulated values on a 5' X 5' grid; thus netting the required grid for hourly production. Conditioning of these smaller models was performed using the simulated values, falling within the respective models. A flowchart of this two stage model building is drawn in Figure 3.8.

Simulated values in these models represent normalized sulfur values. They need to be transformed back to the original distribution of sulfur values. A reverse transformation was carried out next, on each of the four (4) smaller models using the inverse of the transformation function originally used to transform sulfur values to a normal distribution.

Model Results

Each retransformed model contains 10,000 simulated

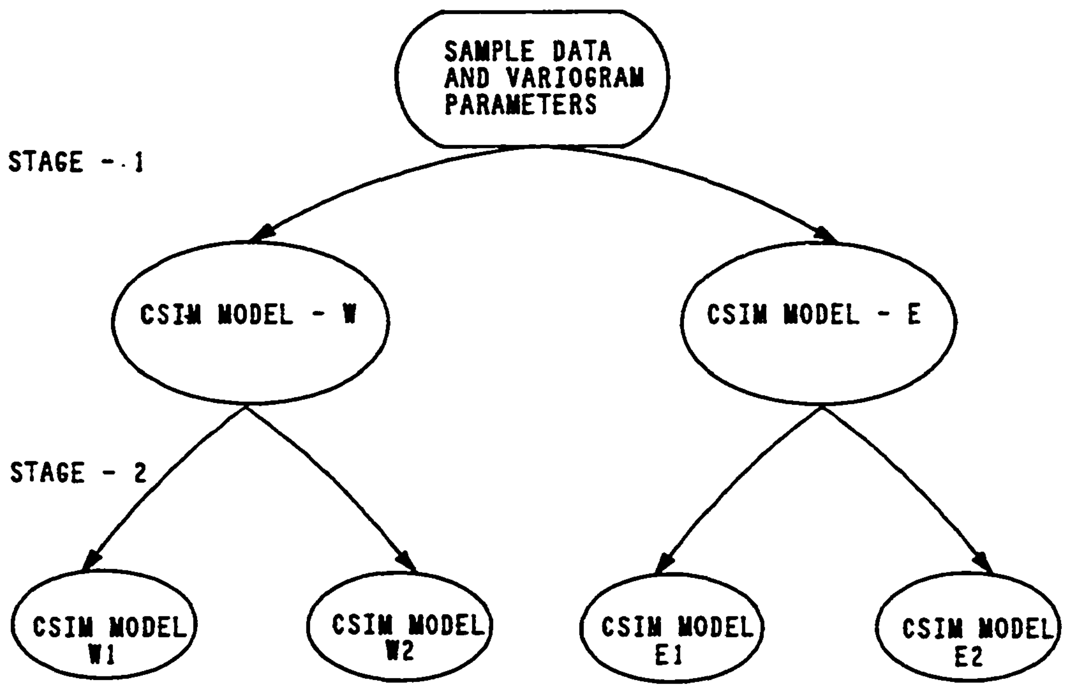


Figure 3.8 Two stage CSIM model buliding.

sulfur values and corresponds to a 500' X 500' area of the coal deposit. Statistical Summary and histogram of these models are shown in Figures 3.9 and 3.10. The mean value of sulfur in these models varies from a low of 2.01% to a high of 2.74% and the variance varies from 0.44 $(\%)^2$ to 0.49 $(\%)^2$. The histograms are all little different from one another. Most show positive skewness except Model-E1. It is skewed slightly negative.

Model Validation

Any solution obtained is only as good as the model it was derived from. Therefore, a thorough model validation must be done before it can be used. The objective of this validation is to check whether the geostatistical hypotheses used to build the model have been respected. In particular, the following geostatiscal calculations must be performed on the model and then compared with the actual deposit:

(1) mean and variance of simulated values,

(2) histogram of simulated values, and

(3) variogram of simulated values.

Using the variogram of the deposit, the variance of a point within a 500' X 500' block was calculated to be σ^2 (o/500' X 500') = 0.4. This value is slightly lower than the variance shown by the simulated values in four (4) smaller models (varies from 0.44 to 0.49). The mean and variogram of the CSIM models can not be compared with the

```
EXECUTION OF PROGRAM CSIM04          TODAYS DATE    11/28/84
FILE NAMES ACCESSED IN THIS RUN
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  SIMULATION MODEL        XMODW1
FILE CREATION DATE   11/27/84
SUMMARY STATISTICS FOR BLOCK      1
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          VARIANCE  =    .45797445E+00
          STD.DEV.  =    .67673810E+00
          SKEWNESS  =    .27343979E+00
          KURTOSIS  =    .25795202E+01
                                                 **HISTOGRAM**

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  1410      .141      .350     .1920E+01
  1736      .174      .523     .2210E+01
  1418      .142      .665     .2500E+01
  1219      .122      .787     .2790E+01
   958      .096      .883     .3080E+01
   641      .064      .947     .3370E+01
   328      .033      .980     .3660E+01
   142      .014      .994     .3950E+01
    46      .005      .999     .4240E+01
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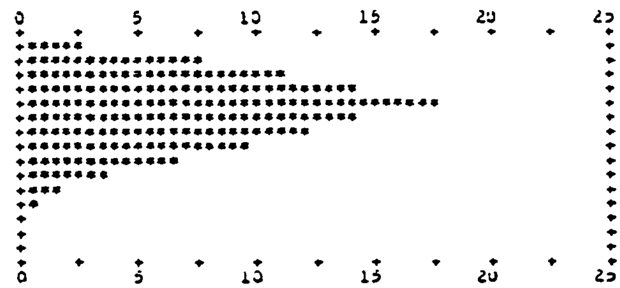

Model-W1

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  SIMULATION MODEL        XMODW2
FILE CREATION DATE   11/27/84
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          VARIANCE  =    .44540415E+00
          STD.DEV.  =    .66738606E+00
          SKEWNESS  =    .43605550E+00
          KURTOSIS  =    .25580466E+01
                                                 **HISTOGRAM**

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  1497      .150      .398     .1757E+01
  1397      .140      .538     .2027E+01
  1352      .135      .673     .2296E+01
  1166      .117      .790     .2565E+01
   848      .085      .875     .2835E+01
   509      .051      .926     .3104E+01
   347      .035      .970     .3373E+01
   187      .019      .989     .3643E+01
    77      .008      .997     .3912E+01
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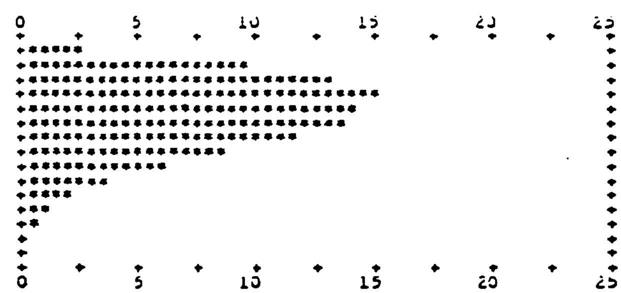

Model-W2

Figure 3.9 Summary statistics of CSIM models W-1 and W-2.

```
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FILE NAMES ACCESSED IN THIS RUN
  MASTER FILE         XMASE1
  SIMULATION MODEL         XMODE1
FILE CREATION DATE  11/27/84
SUMMARY STATISTICS FOR BLOCK       1
          MEAN      =   .25459920E+01
          VARIANCE  =   .49323600E+00
          STD.DEV.  =   .70230707E+00
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          KURTOSIS  =   .25344550E+01
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HISTOGRAM

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705	.070	.116	.1755E+01
1069	.107	.223	.2071E+01
1398	.140	.363	.2383E+01
1667	.167	.530	.2695E+01
1476	.148	.677	.3009E+01
1441	.144	.821	.3321E+01
1010	.101	.922	.3634E+01
496	.050	.972	.3947E+01
205	.021	.993	.4259E+01
62	.006	.999	.4572E+01
10	.001	1.000	.4885E+01
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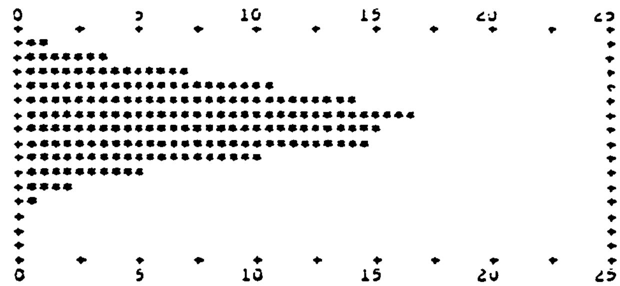

Model-E1

```
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FILE NAMES ACCESSED IN THIS RUN
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  SIMULATION MODEL         XMODE2
FILE CREATION DATE  11/27/84
SUMMARY STATISTICS FOR BLOCK       1
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          VARIANCE  =   .43510722E+00
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          KURTOSIS  =   .25627669E+01
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HISTOGRAM

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1099	.110	.221	.2175E+01
1491	.149	.370	.2510E+01
1823	.182	.552	.2842E+01
1645	.165	.713	.3174E+01
1414	.142	.855	.3505E+01
920	.092	.947	.3836E+01
390	.039	.986	.4170E+01
117	.012	.997	.4502E+01
19	.002	.999	.4834E+01
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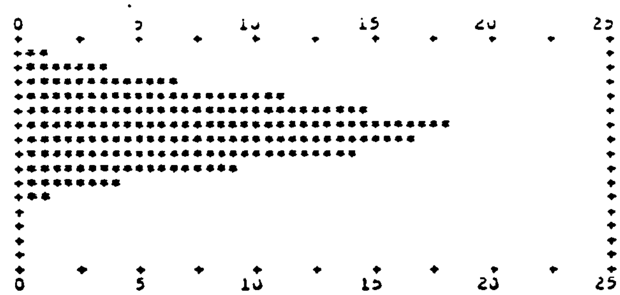


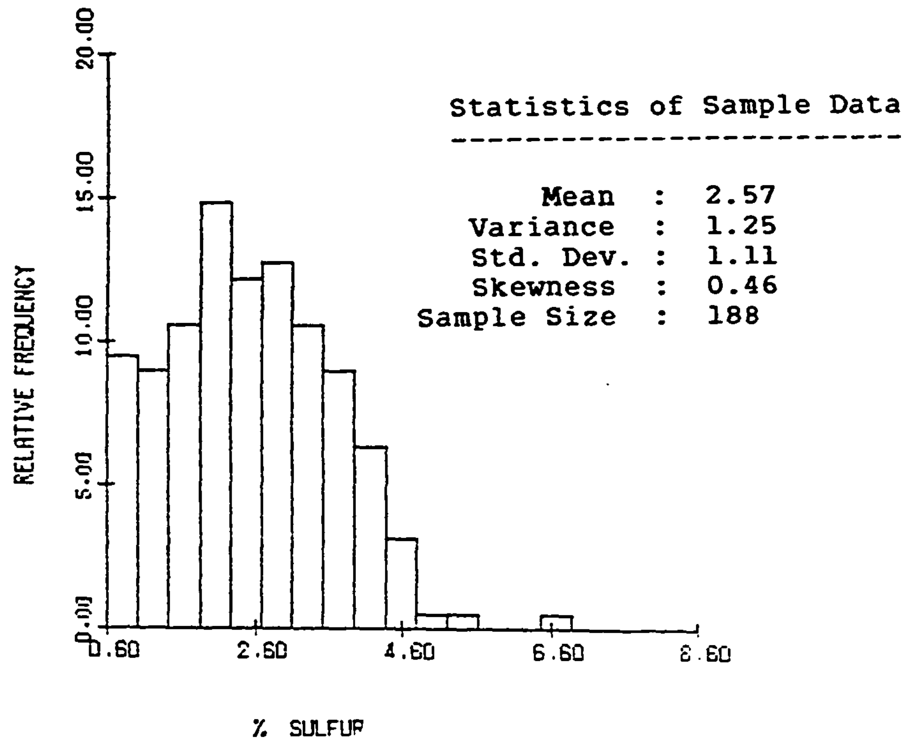
Model-E2

Figure 3.10 Summary statistics of CSIM models E-1 and E-2.

global mean and variogram, respectively, because the global data encompasses an area of about 50 square miles whereas each CSIM model extent is only 500'. Therefore, to make a reasonable comparison between CSIM model and the real deposit and to check the validity of CSIM, a test model covering 15,000' X 15,000' (about 11 square miles) area is built and the comparison is made on this test model.

Figure 3.11 shows the basic statistics and histograms for both the original sample data and the CSIM test model. The mean value of the model, 2.54, is almost the same as the mean value of the sample data, 2.57. The variance of the simulated values (1.13), however, is slightly lower than the variance shown by the sample data (1.25).

Neither of these apparent discrepancies is significant. Smaller variance of simulated values over the sample data is expected because the real deposit is about five times bigger than the test model. Also, the number of simulated values is 10,000 versus 188 samples from the deposit. The variance of simulated values should correspond more closely to the variance of sulfur values within a 11 square mile area, than to the variance of 50 square mile area. Using the variogram model of the deposit, the variance of a sample within a 15,000' X 15,000' area was calculated to be σ^2 (o/15,000' X 15,000') = 1.10. This value



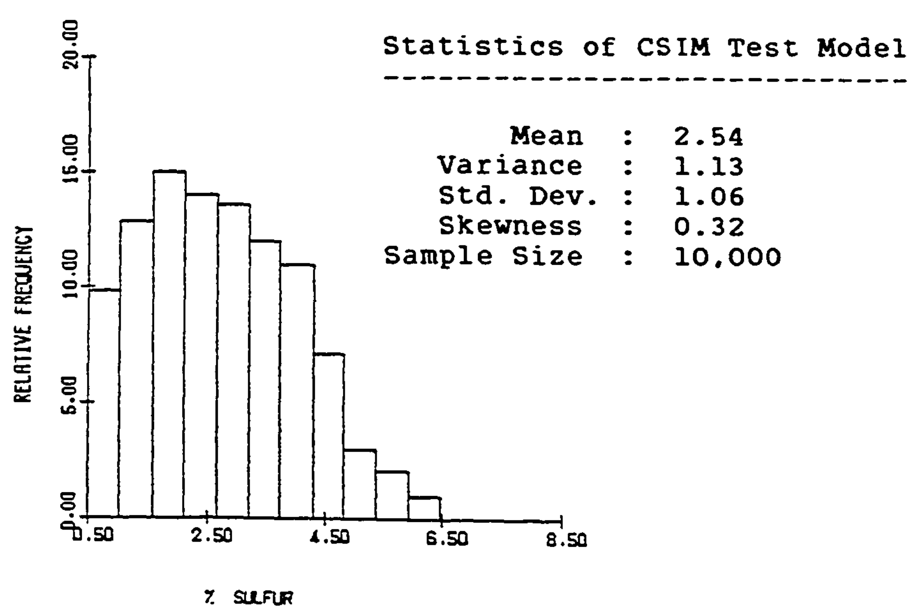


Figure 3.11 Comparison of sample values with simulated values.

is very close to the variance shown by the model, thus, there is good agreement with the test model.

Following a similar line of reasoning, the absolute difference of 0.03 (2.57 - 2.54) between the mean values of model and sample can be tested. Suppose the entire deposit is divided into 15,000' X 15,000' blocks. Each of these blocks would exhibit different mean values and the mean values would be distributed about the overall mean value of the deposit. The variance of the mean value of 15,000' X 15,000' block is σ^2 (15,000' X 15,000'/deposit) = 0.18. Assuming normality in mean values, it follows that about 68% of the values should be within one standard deviation of the overall mean value. Since $\sigma = \sqrt{0.18} = 0.42$, the CSIM test model mean value is well within one standard deviation of the mean of the deposit.

The CSIM histogram bears quite a close resemblance to the histogram of sample values. The test model histogram is a little smoother than the sample histogram. This difference is probably not significant owing to the fact that model area is much smaller than the deposit.

Finally, one of the most important virtues of CSIM model is that it should reproduce the spatial correlations exhibited by the sulfur values. Variograms calculated for the test model are compared against the the variogram calculated from the sample data in Figure 3.12.

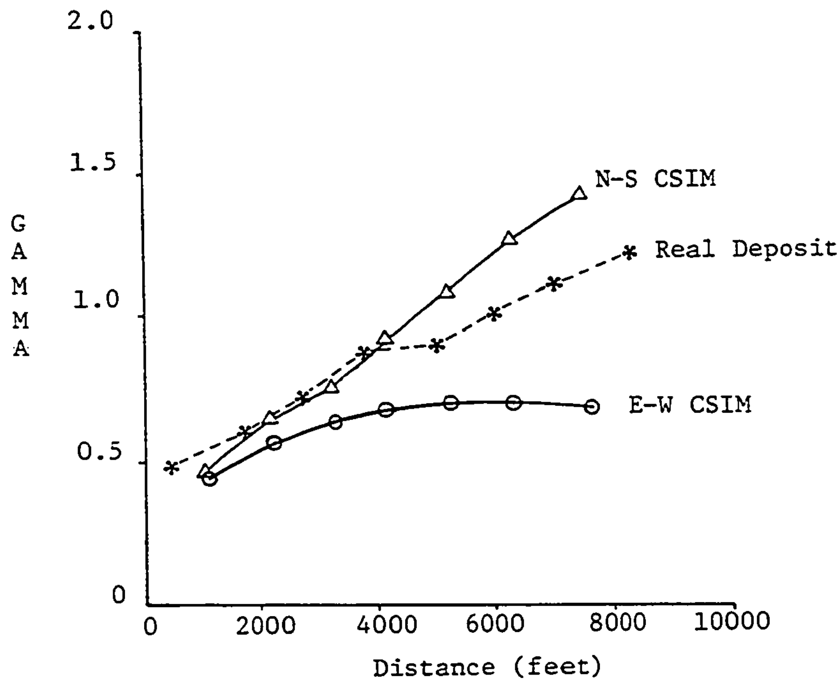


Figure 3.12 Experimental variograms for real data and simulated data.

The N-S variogram of the CSIM model, for about the first 4,000' from the origin of Y(h), almost coincides with the sulfur variogram and beyond 4,000'; the sample variogram falls between N-S and E-W CSIM model variograms. The difference beyond 4,000' from $\gamma(h)$ origin is probably not significant, although no convenient statistical test is available to test the significance of the difference.

Thus, based on the close agreement between the test model and the sample data on the observable statistical characteristics, the conditional simulation model seems to have adequately simulated the real deposit.

CHAPTER 4

RUN OF MINE (ROM) DATA ANALYSIS AND DETERMINATION OF THE MINIMUM SAMPLING FREQUENCY

One of the objectives of this study is to determine ROM coal sampling frequency by employing conditional simulation technique. Sampling strategy is built upon the characteristics, expressed as variability, of ROM coal quality which, as mentioned in chapters one and two, depend mainly on two factors; 1) the in-situ coal characteristics and 2) the nature of blending that occurs during the formation of ROM coal. In-situ coal variables are spatially correlated and this coal eventually becomes ROM coal, which raises several questions about the characteristics of ROM coal. For instance, do in-situ coal characteristics have any effect on ROM coal characteristics? Should any spatial correlation be expected in ROM coal and under what conditions? How can this information be utilized in ROM coal sampling frequency determination? To seek answers to these questions, an indepth investigation is carried out on simulated ROM coal data and the results are discussed in this chapter. But first, ROM coal data is generated by simulating mining methods on the conditionally simulated models developed in the previous chapter.

Mining Method Simulation

The mining methods normally practiced in underground coal mines across eastern U.S. are: (1) Room and Pillar mining, (2) Shortwall mining, and (3) Longwall mining. The Helen mine, however, practices only room and pillar mining and shortwall mining; hence these two methods are tried here.

The objective of mining simulation is to attempt to reproduce chronologically the various mining units mined from all active panels during a given period. The mining simulation described here is macro in nature compared to some of the existing micro mine simulation such as UGMHS of the Pennsylvania State University. The micro models simulate practically all the interrelated underground activities which affect coal mine productivity. It was decided inappropriate, at this study, to consider such micro level simulations as the work involved in interphasing such micro simulation with the CSIM model would be excessive and unnecessary to meet the study objectives. Instead, a more appropriate and simpler approach of macro simulation was used to meet the objective of generating ROM production data.

The macro mining simulation requires three basic steps:

1) Determine the selective mining units (a selective mining unit, SMU, is the smallest size

that can be mined) and develop their cut plans for the mining method in use.

2) Access the (true) grade for each SMU from CSIM model.

3) Generate the production data.

Each of the above steps is discussed below:

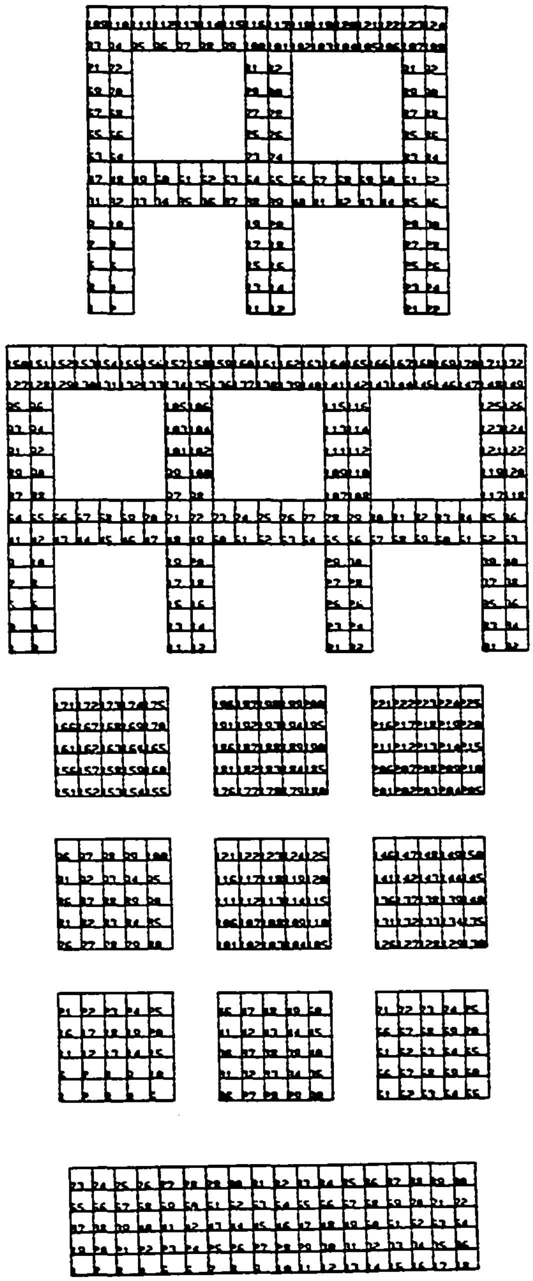
Selective Mining Units (SMUs)

In the Helen mine, coal is taken from nearly twelve different areas (or sections) during a year, using a continuous-miner. These working areas are concentrated on the west and on the east side of the property (see Figure 3.6). Figures 4.1a through 4.1d show four different simulated mining sections. Figures 4.1a and 4.1b are 3-Entry and 4-Entry development sections. Figure 4.1c is Pillar-Extraction section (a part of Room and Pillar mining operation) and Figure 4.1d is Shortwall section shown without development headings.

Each mining section was further divided into SMUs of 10' X 10' which represent one hour of production from that section. In room and pillar mining, the basic dimensions are 50' X 50' pillar with 20' entry. In shortwall, they are 180' wide face with 10' slice cut.

Grade Assignment to SMUs

Every SMU was assigned a grade by superimposing the



a) W1: 3-Entry Development

b) W2: 4-Entry Development

c) E1: Pillar Extraction

d) E2: Shortwall

Figure 4.1 Mining methods used in CSIM models.

cut plans on the developed CSIM models. This is achieved by using a computer program called RPCUT. RPCUT takes a mining cut plan, which consists of a series of SMUs as shown in Figure 4.1, and accesses the CSIM model to find model points within the cut plan. Since the CSIM model grid spacing is 5' X 5' and a SMU size is 10' X 10', four (4) CSIM model points will fall within each SMU. Average value of these four points is assigned to that SMU.

Generation of ROM Data

SMU grades sequentially determined by program RPCUT from four (4) sections (Figure 4.1a through 4.1d) are next merged to obtain hourly ROM coal grade. The average grade of hourly ROM coal is calculated as follows:

$$x_j = (1/n) * \sum_{i=1}^{n} x_{ij} \qquad i = 1,\ldots,n;$$

$$\text{where,} \qquad j = 1,\ldots,k \qquad 4.1$$

x_j = quality of jth hour ROM coal,

x_{ij} = quality of jth hour coal from ith section,

n = number of working sections, and

k = number of production hours.

ROM hourly tonnage is the summation of hourly tonnages from all the sections. In the present case it would be 4 * 16 = 64 tons.

Statistical Analysis of Simulated ROM Data

After obtaining ROM data, statistical analysis on them is performed. Two different approaches are considered, geostatistical and classical.

Geostatical Approach

The objective here is to examine if spatial correlation still exists in ROM coal sulfur, given the spatial correlation of in-situ coal at each section. Since in-situ coal from a three-dimensional deposit becomes the ROM coal after it is mined, a conveyor belt carrying this ROM coal can be seen as an one-dimensional deposit with time (hours or days) being the unit of dimension. The distribution of sulfur in this one-dimensional deposit is shown in histogram of Figure 4.2.

Figure 4.3 shows the one-dimensional sulfur variogram of ROM coal from the simulated Helen deposit. This variogram shows almost pure nugget effect (nugget is about 75% of the total sill). In other words, two observations of ROM coal sulfur, one hour apart, appear to be uncorrelated, as seen by the almost pure nugget effect in the obtained variogram.

Observing almost pure nugget in Figure 4.3 is not entirely a surprise because of the various factors that effected the ROM coal sulfur. Some of these factors are: 1) the nature of in-situ sulfur variogram, 2) the size of SMU,

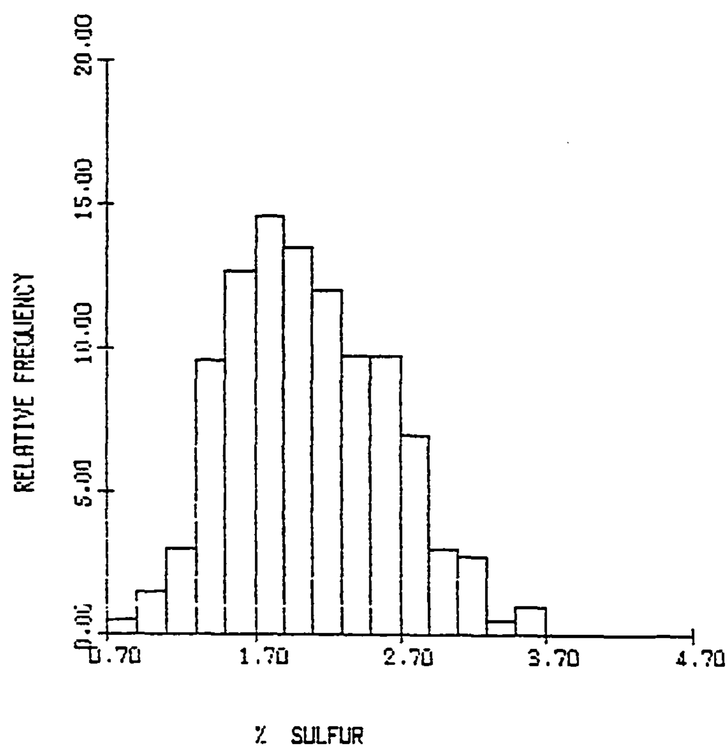


Figure 4.2 Histogram of simulated ROM coal sulfur.

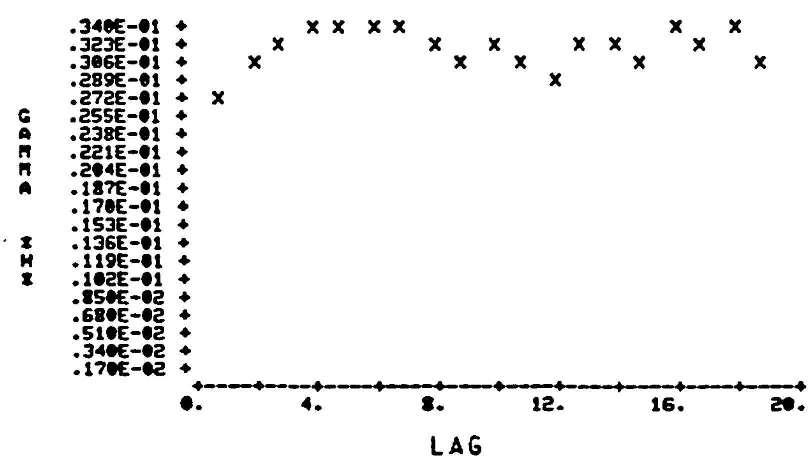


Figure 4.3 1-D variogram of 1-hour grouped ROM sulfur data.

3) relative locations of each section with respect to each other, and 4) number of sections which constituted the ROM coal.

The in-situ sulfur variogram is spherical and the parameters are (from Table 3.2): nugget (Co) = 0.32 $(\%)^2$ as compared to 0.024 $(\%)^2$ of Figure 4.3, sill (Co + C) = 1.07 $(\%)^2$ as compared to 0.034 $(\%)^2$ of the Figure 4.3, and range (a) = 10,000'. The nugget to sill ratio is 30% (0.32 * 100. / 1.07) as compared to 75% of Figure 4.3. This ratio is the percentage of the total variance of the data due to both measurement errors and micro-variabilities of the mineralization. The structure of these micro-variabilities is not accessible from the available data; hence, they appear in the form of nugget effect.

In-situ sulfur range of 10,000' is considerably large in comparison to the SMU size of 10' X 10' (10,000 / 10 = 1,000 times of unit size). Since the ROM coal represents a very small portion of the deposit as compared to the range of the variogram, one can expect a nugget effect in ROM coal sulfur. Combining coals from different mining sections imparts an averaging effect that further reduces any auto-correlation that may have existed among individual sections.

Figure 4.4 shows the one-dimensional ROM coal sulfur variograms of 8-hour, 16-hour, and 24-hour grouped ROM coal data obtained from the simulated Helen deposit. A n-hour

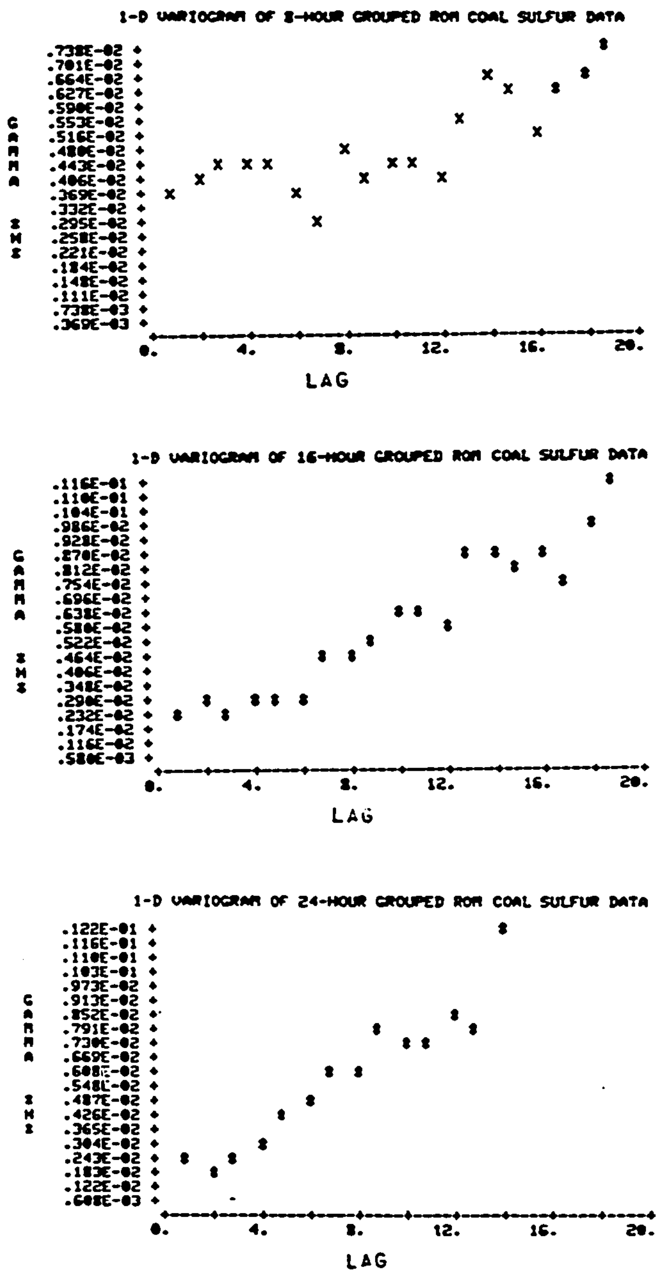


Figure 4.4 ROM coal sulfur variograms.

grouped ROM coal data means, n one-hour sample values from each of the four (4) working sections are taken and averaged (following equation 4.1) to form one observation for that n-hour grouped data. In other words, more averaging is induced into the ROM coal by increasing the volume of the ROM coal represented by the n-hour grouped data. These variograms appear to show a lack of spatial continuity near the origin i.e., the area of interest, which further indicates that hourly to 8 hr ROM data are uncorrelated.

Effect of Structural Phenomenon on ROM Coal Quality

In the previous section, the hourly ROM coal sulfur values appeared to be uncorrelated. This outcome was based on a simulated deposit of an existing mine, under a given set of conditions. One may question if this result can be extended to any deposit. The study was repeated with different deposits in order to arrive at conditions under which one can expect a spatial continuity in hourly ROM coal. Hypothetical coal deposits were simulated, and hourly ROM coal data were generated to investigate this point. These deposits are structurally different from the Helen coal deposit. Their characteristics in terms of variogram parameters are summarized in Table 4.1. The procedures followed to generate ROM data are exactly the same as described in chapter three and the early part of this

Table 4.1 Sulfur Spherical Variogram Parameters of Hypothetical Coal Deposits, CSIM, and SMU Size Used in Modeling These Deposits

Case	Sill Co + C (%)	Nugget Co (%)	C-Value C (%)	Range a (ft)	CSIM Grid (ft)	SMU Size (ft)
1	1.07	0.0	1.07	10,000	5 X 5	10 X 10
2	1.07	0.0	1.07	5,000	5 X 5	10 X 10
3	1.07	0.0	1.07	1,000	5 X 5	10 X 10
4*	1.07	0.32	0.75	10,000	5 X 5	10 X 10
5	1.07	0.32	0.75	5,000	5 X 5	10 X 10
6	1.07	0.32	0.75	1,000	5 X 5	10 X 10
7	1.07	0.535	0.535	10,000	5 X 5	10 X 10
8	1.07	0.535	0.535	5,000	5 X 5	10 X 10
9	1.07	0.535	0.535	1,000	5 X 5	10 X 10
10	1.07	1.07	0.0	10,000	5 X 5	10 X 10
11	1.07	1.07	0.0	5,000	5 X 5	10 X 10
12	1.07	1.07	0.0	1,000	5 X 5	10 X 10

* known deposit

chapter. However, the conditioning step of the first stage model to the existing drill hole data had to be bypassed due to the arbitrary structural phenomena of these deposits. The first stage CSIM model data were used for the second stage CSIM model conditioning as before.

Table 4.2 lists the successes and failures of detecting spatial continuity in ROM coal sulfur values. When the nugget/sill ratio is zero the hourly ROM coal sulfur values show spatial continuity in them. Also, when a nugget/sill ratio is 30% or less and variogram range/SMU size ratio is 500 or less, the ROM coal sulfur from four (4) working sections appear to retain spatial continuity. Because of the large ratio of range over SMU size and because of the double conditioning aspect, the CSIM model values at 5' X 5' grid may be entirely due to an artifact of model building, in case of Helen mine. To expect any spatial continuity in ROM coal quality in short term, the nugget/sill ratio should be close to zero (below 30%) and the variogram range/SMU should be less than 500. A successful ROM coal sulfur variogram from a zero nugget deposit (case #1 in Table 4.1) is shown in Figure 4.5.

Classical Approach

As the ROM coal sulfur values are found to be uncorrelated, the classical approach is employed in the analysis of the hourly ROM coal sulfur values of the

Table 4.2 List of Successes and Failures of Obtaining Spatial Correlation in Simulated ROM Coal Sulfur

Nugget ----- *100 Sill	Number of Workings	Average Distance between Workings	Method to use for Sampling Scheme Variogram Range / SMU Size 100	500	1,000
0%	4	8,000'	GS*	GS	GS
30%	4	8,000'	GS	GS	CS**
50%	4	8,000'	CS	CS	CS
100%	4	8,000'	CS	CS	CS

* geostatistics
** classical statistics

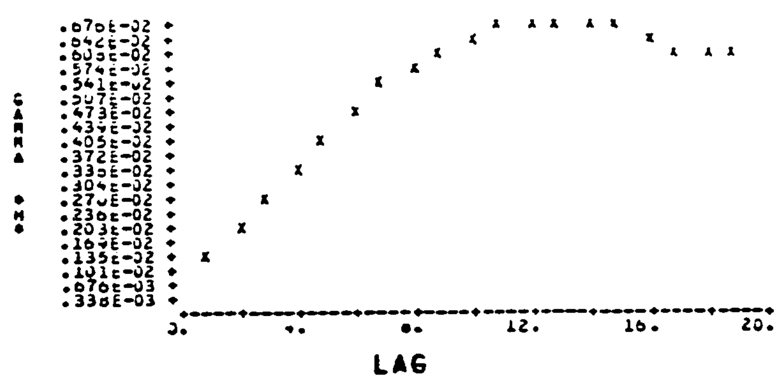


Figure 4.5 1-D variogram of simulated ROM coal sulfur (Case #1 in Table 4.1).

simulated Helen deposit. The hourly ROM coal sulfur values are basically the mean value of 1-hourly obsevations from four (4) different mining sections, i.e., 1-hourly group with four (4) observations. If these four (4) observations are assumed to be drawn from a normal population, then the variance and 95% confidence interval (C. I.) about the sample mean can be estimated as follows:

$$Var(x_{ij}) = \frac{1}{n-1} \sum_{i=1}^{n} (x_{ij} - x_{j})^{2} \qquad 4.2$$

$$C.\ I. \quad = x_{j} + t_{\alpha/2,n-1} * \sqrt{Var(x_{j})} \qquad 4.3$$

A plot of mean values and confidence interval band of 1-hour group data is shown in Figure 4.6a. The fluctuation pattern of ROM coal sulfur values is quite erratic and the confidence band is non-uniform. After the 1-hour group, the fluctuation pattern of an 8-hour group (32 observations), a 16-hour group (64 observations), and a 24-hour group (96 observations) are generated and plotted in Figures 4.6b, 4.6c, and 4.6d respectively.

By looking at Figures 4.6a through 4.6d, it becomes obvious that as the group size increases, i.e. the number of observation per mean value increases, the variability in mean value reduces. This smoothing in ROM coal sulfur variability is due to the well known fact of Central Limit

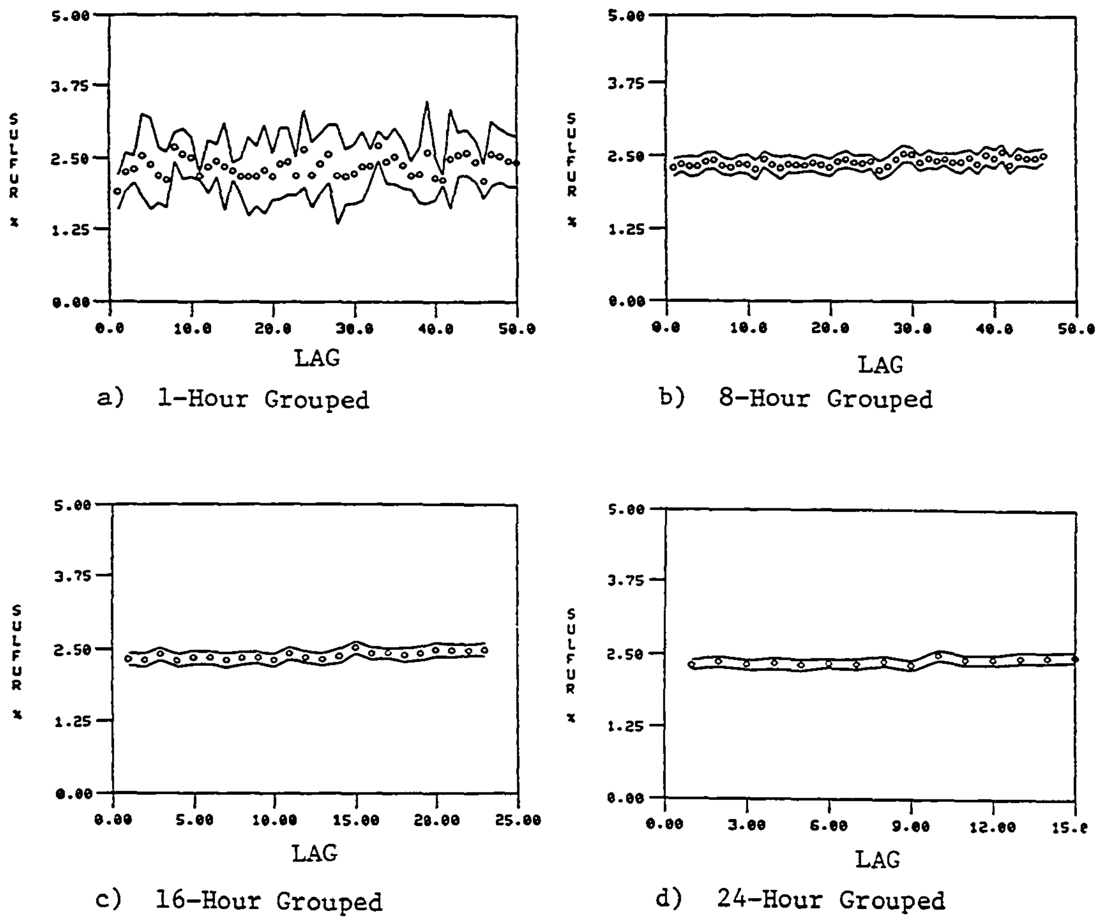


Figure 4.6 ROM coal sulfur fluctuation.

Theorem. With an increase in group size, the tonnage per group also increases as shown in Table 4.3. Therefore, a compromise should be reached, at some point, between the degree of smoothness in ROM coal sulfur fluctuation and the corresponding tonnage. Such a compromise can be achieved by measuring the variability, in terms of standard deviation, of the mean values at different group size and plotting them against the tonnage per group size as shown in Figure 4.7. From the plot, an ideal group size or tonnage can be selected by specifying a desired level of variability. This information is beneficial to the planning engineer during stockpile strategy development, where the information regarding the variability of ROM coal and the tonnage it represents are critical in selecting/designing a stockpile to store this coal. Coal stockpiling aspects of a power plant are discussed in chapter five. From Figures 4.6 and 4.7, the variability in ROM coal sulfur appears to level off at the 8-hour grouped data.

Next, the question of whether or not the ROM coal sulfur fluctuation pattern depends on the interval on which data is collected was investigated. That is, if simulated data are collected every n-th hour interval, is the similar pattern of fluctuation as in Figure 4.6 expected? To answer this question, only every 4-th, 8-th, 12-th, and 24-th hour data from the hourly ROM coal data set are used to perform a similar analysis. The results are shown in Figure 4.8a -

Table 4.3 Simulated ROM Coal Group Tonnage

Group Size	Number of Data points	Average Tons per Data point	Total Tons per Group
1-hour	4	16	64
8-hour	32	16	512
16-hour	64	16	1024
24-hour	96	16	1536

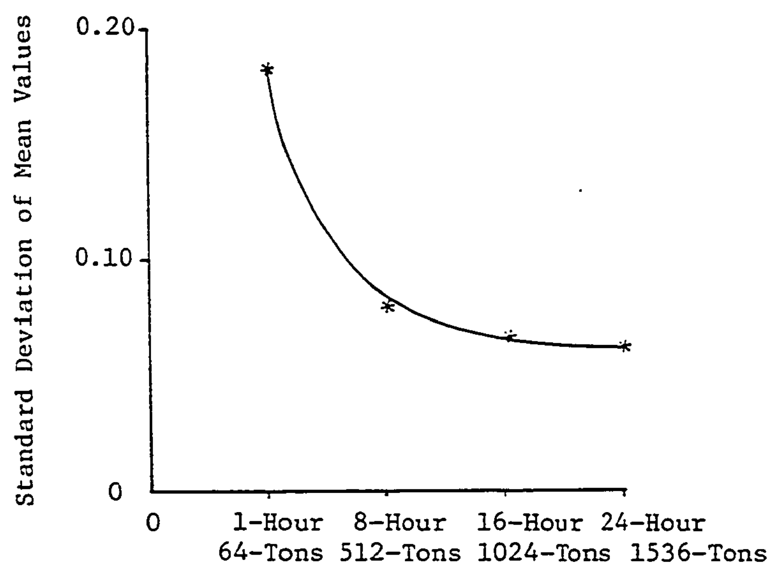
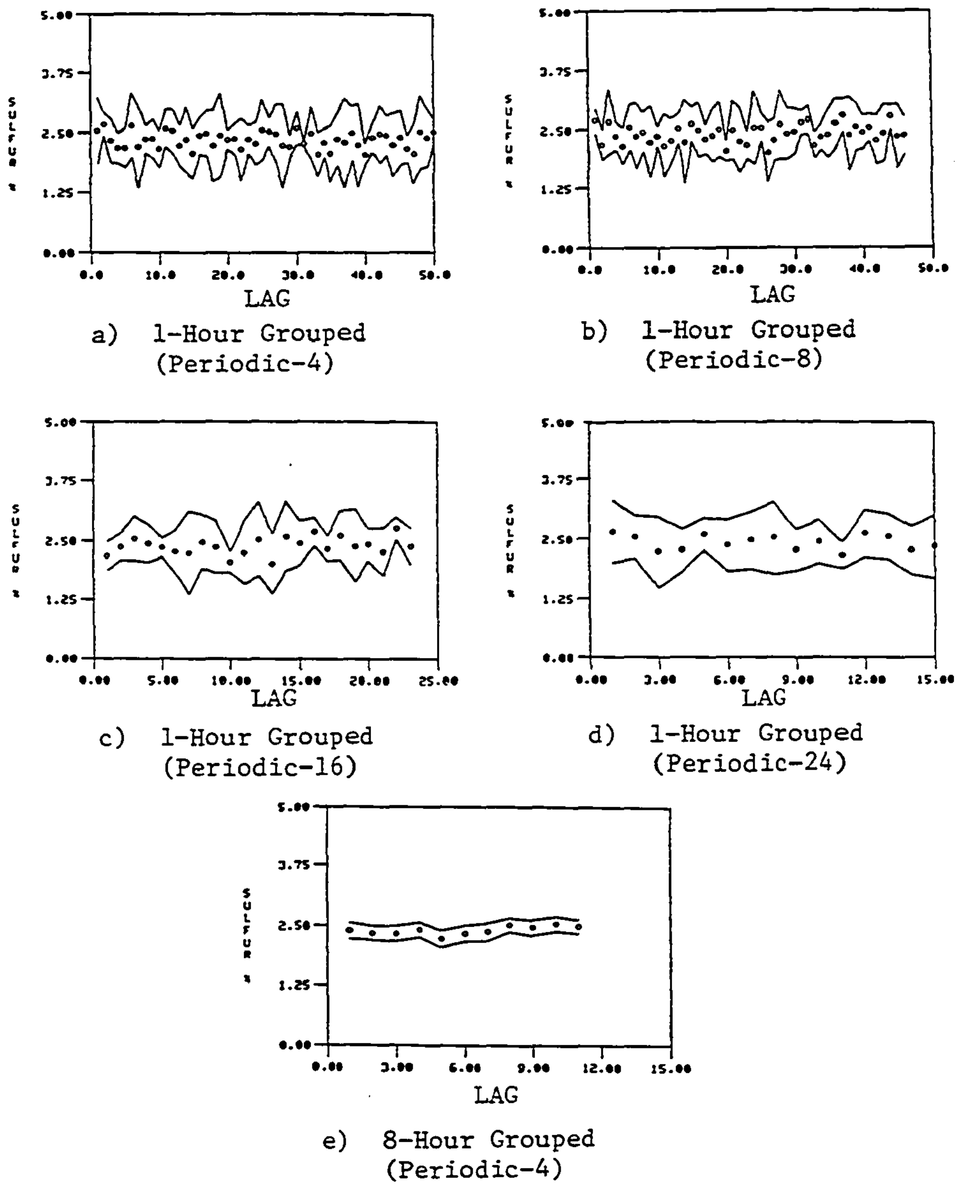


Figure 4.7. Standard deviation of mean values at different group size.



a) 1-Hour Grouped (Periodic-4)

b) 1-Hour Grouped (Periodic-8)

c) 1-Hour Grouped (Periodic-16)

d) 1-Hour Grouped (Periodic-24)

e) 8-Hour Grouped (Periodic-4)

Figure 4.8 ROM coal sulfur fluctuation at different periodic intervals.

4.8d. From these figures, it is clear that the high variability in ROM coal sulfur for 1-hour group still remains. As expected, the variability reduces only when the 1-hourly group data are averaged into 8-hour group data (see Figure 4.8e). Hence it is safe to conclude that the frequency of the sample interval has little impact on the confidence interval, if the volume of the sample represents one hour samples. A more effective way to achieve the reliability of the sample is to obtain 8-hour samples. Similarly, 24-hour samples may represent only a marginal improvement over that of 8-hour samples. The volume of one hour sample can be calculated using Gy's basic sampling equation.

Scheme for ROM Coal Sampling Frequency Determination

The objective of this scheme is to estimate the sampling frequency of ROM coal. As noted in chapter one, most of the mines across the U.S. practice continuous sampling where one composite sample is taken daily. Though it is called continuous sampling, in reality however, small samples are collected intermittently through out the day, by advancing and retracting the primary cutter chute of an automatic sampler.

To illustrate this point, let's look at the plan view of a conveyor belt carrying ROM coal in Figure 4.9. Consider the rectangle ABCD which is a portion of a conveyor

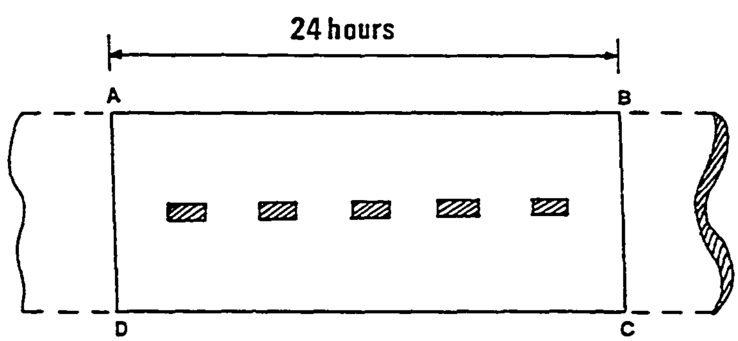


Figure 4.9. A schematic diagram of a conveyor belt carrying 24 hours ROM Coal.

belt representing one day (24 hours) production. An automatic sampler cuts small portions of ROM coal from the belt throughout the day. Hatched areas, inside ABCD, indicate these small portions of ROM coal, but the exact orientation of these small cuts in relation to the conveyor belt may differ. Now the question is, how many times these samll amounts should be collected (i.e., the number of times the automatic sample cutter should advance and retract its cutting chute) in a day? Also, what should be the weight, in pounds or grams, of each of these small samples? How many of these small samples would constitute an hourly sample?

Weights of an hourly sample can be calculated by using Gy's basic sampling equation, as mentioned in chapter two, and the sampling frequency can be estimated by analyzing the variability of ROM coal. Following the results in Table 4.2, two cases are considered. These are: 1) ROM coal quality that exhibits spatial correlation and 2) ROM coal quality that does not exhibit spatial correlation.

Case 1: Spatial Correlation in ROM Coal

The geostatistical tool of estimation variance can be applied here to obtain the number of hourly samples needed, in a day, to make a composite sample such that this composite sample will represent the day's production within the desired level of reliability. Estimation variance σ_E^2

refers to the variance of the error between the true grade Z and the estimated grade Z^* of, say, a block. A detailed theoretical derivation of estimation variance appears in most geostatistical books.

Let's expand the idea of employing estimation variance technique to ROM coal. Rectangle ABCD, in Figure 4.8, is a portion of a conveyor belt carrying the ROM coal from, say, the hypothetical deposit in case #1 representing 24 hours production. This rectangle can be thought of as the size of an one-dimensional deposit. The ROM coal sulfur variogram from this one-dimensional deposit was shown in Figure 4.5. Estimation variance of the mean sulfur value of the deposit ABCD can be calculated by using this variogram and selecting some uniformly spaced fictitious hourly samples across ABCD. By varying the number of these hourly samples a level can be reached where estimation variance of ABCD equals the desired reliability of a composite sample; thus resulting in the needed number of hourly samples across ABCD.

Case 2: Lack of Spatial Correlation in ROM Coal

In Figure 4.7, the variability in ROM coal sulfur appeared to level off at the 8-hour grouped data. The variance of an 8-hour grouped data, i.e., 32-hourly sample point, is listed in Table 4.4, which varies from 0.015 to 0.299 and most of them fall around 0.20. Assuming normality

Table 4.4 Summary Statistics of 8-Hour Grouped Simulated ROM Coal Sulfur Data

THIS GROUP HOUR IS 8

NUMBER	MEAN	VARIANCE	STD. DEV	U-BOUND	L-BOUND	BAND WIDTH
1	2.293	.199	.446	2.450	2.136	.314
2	2.351	.117	.341	2.471	2.231	.240
3	2.310	.238	.488	2.462	2.138	.344
4	2.310	.209	.456	2.470	2.150	.321
5	2.401	.179	.423	2.550	2.252	.298
6	2.424	.172	.415	2.570	2.278	.292
7	2.320	.184	.428	2.471	2.169	.302
8	2.290	.160	.399	2.430	2.149	.281
9	2.354	.178	.422	2.503	2.206	.297
10	2.343	.219	.468	2.508	2.178	.329
11	2.257	.225	.475	2.424	2.090	.334
12	2.432	.152	.390	2.570	2.295	.274
13	2.343	.184	.429	2.494	2.191	.302
14	2.275	.299	.546	2.469	2.084	.385
15	2.350	.183	.428	2.501	2.200	.301
16	2.342	.177	.420	2.489	2.194	.295
17	2.329	.090	.301	2.434	2.223	.212
18	2.379	.186	.431	2.530	2.227	.304
19	2.332	.209	.457	2.493	2.171	.322
20	2.286	.175	.420	2.434	2.138	.296
21	2.399	.159	.399	2.540	2.259	.281
22	2.442	.185	.430	2.593	2.291	.303
23	2.377	.115	.340	2.497	2.257	.239
24	2.360	.174	.418	2.507	2.213	.294
25	2.396	.115	.339	2.515	2.276	.239
26	2.255	.186	.431	2.407	2.103	.303
27	2.317	.222	.471	2.483	2.151	.331
28	2.433	.251	.501	2.614	2.262	.352
29	2.538	.183	.428	2.689	2.387	.301
30	2.519	.140	.375	2.651	2.387	.264
31	2.382	.141	.376	2.514	2.250	.264
32	2.461	.199	.446	2.618	2.304	.314
33	2.413	.153	.392	2.551	2.275	.276
34	2.454	.079	.278	2.552	2.356	.196
35	2.403	.175	.418	2.550	2.256	.294
36	2.400	.270	.520	2.583	2.217	.366
37	2.475	.190	.436	2.629	2.322	.307
38	2.357	.233	.483	2.527	2.197	.340
39	2.521	.213	.461	2.684	2.359	.325
40	2.458	.221	.470	2.623	2.292	.331
41	2.582	.173	.416	2.729	2.436	.293
42	2.355	.168	.409	2.499	2.211	.288
43	2.499	.210	.458	2.659	2.336	.322
44	2.465	.120	.347	2.587	2.343	.244
45	2.459	.221	.470	2.625	2.294	.331
46	2.525	.132	.363	2.653	2.397	.256

in ROM coal sulfur values in each 8-hour group, number of hourly samples per 8-hour group can be estimated using statistical theory.

Consider, for instance, the mean value of sulfur in an 8-hour group is 2.4, variance 0.2, and allowable estimation error (e) about the mean is 10% of the mean (one sided). The problem is to find the sample size, n, such that the sample mean 2.4 fall within the limits 2.4 - 0.24 and 2.4 + 0.24. Sample size n can be estimated as:

$$n = (z_{\alpha/2} * \sigma/e)^2$$

where:

z = specified probability

σ^2 = population variance of 8-hour grouped data

With 95% confidence level, $z_{\alpha/2}$ becomes 1.96 and

$$n = (1.96)^2 * 0.2 / (0.24)^2 = 13.34 \text{ or } 14.$$

As mentioned before, an 8-hour grouped data is consisting of 32 hourly sample points with 512 (32 * 16) tons of ROM coal. Therefore, the number of hourly samples required from this ROM coal is 14.

In chapter two, following Gy's equation (2.1), minimum sample weight at the primary cutting stage was calculated to be 175 (2.5 * 70) kg. Assuming this sample weight to be representative of an hourly sample, the total weight of 14 hourly samples would be 2450 (14 * 175) kg or approximately 3 tons. That is, for every 512 tons of ROM coal 3 tons of coal must be cut from the coal stream by the primary cutter, in order to have the 95% confidence level of the sample result.

In summary, hourly ROM coal data were generated by simulating mining methods on conditionally simulated coal deposit. These hourly ROM coal data were statistically analyzed to determine the minimum frequency of sampling. Two schemes were suggested following the statistical characteristics of the ROM coal: 1), use of geostatistical tool of estimation variance if spatial correlation in ROM coal quality can be established and 2), use of classical statistics if no spatial correlation can be found. The quantity of sample, in both cases, can be calculated using Gy's basic sampling equation.

CHAPTER 5

LINKING ROM COAL TO STOCKPILE AND COAL BLENDING

When ROM coal arrives at the power plant, it is normally stored in a temporary stockpile. The power plant owner must quickly decide a stockpile that is suitable for this incoming coal. The owner's decision would depend on the quality and the quantity of this coal and the design criteria of stockpile. Each stockpile is specifically designed to accept certain quality and quantity of incoming coal. Once coal is stored in a stockpile, it is normally mixed with coal from other stockpiles such that the resultant mix meets the power plant feed requirements in terms of both boiler design specifications and emission regulations.

In this chapter, the role of coal stockpile and coal blending at the power plant will be discussed. An interactive coal stockpile management program, designed to solve stockpiling and blending problems, will also be described.

Role of Coal stockpile

Coal stockpiling is an important part of an overall feed control strategy at a power plant. For the most part, it is essential for any power plant to maintain a proper level of coal inventory in terms of both quality and quantity in various stockpiles. Coal stockpiling ensures a stable supply of coal to the boiler; it allows the planner to design a required blend; and it plays a strategic role for the power plant owner in the event of uncertainities such as strike, sudden change in coal prices, etc.

There are three main factors that govern the coal flow to a stockpile. These are: 1) coal qualities and quantity, 2) stockpile criteria, and 3) stockpile availability. Contingent upon these factors, the right stockpile must be selected for incoming coal. As mentioned in chapter one, once coal is stored in a stockpile, it should not be left unused for a long period of time due to possible oxidation and spontaneous combustion.

Therefore, to maintain a proper level of coal inventory in various stockpiles, a dynamic coal stockpile management system is needed. This system should also provide solutions to coal blending problems.

Coal Blending

The objective here is to solve the power plant coal blending problems due to varying qualities of stockpiled coal. At a power plant, usually there are two situations for which coal blending is done; 1) for boiler feed and 2) for coal cleaning plant feed (Baafi, 1983). Linear goal programming is well suited for solving such blending problems. It is imperative, in the short term, that the blend resulting from the stockpiled coal be calculated regardless of whether or not it satisfies the plant specifications. For planners to recommend a course of action to take, they must know the magnitude of the difference between the target blend and the expected blend over the short term. Goal programming provides this information and it can be used to choose various options, such as purchasing coal on the spot market, coal cleaning, etc.

Computer programs for solving goal programming problems can be found in most goal programming textbooks, such as " Goal programming for Decision Analysis" by S. M. Lee (1972) and "Goal programming and Extensions" by J. P. Ignizio (1976).

Lonergan (1983) utilized the goal programming technique and developed a program specifically to solve coal blending problems somewhat similar to the one described here. However, his program had two major drawbacks: 1) the role of stockpile in the overall feed control strategy was omitted (it was mentioned as a future research topic) and 2) the types of objectives or goals an user can seek were "hardwired" into the program for solving only boiler feed blending problems, thereby restricting its usage.

As mentioned before, the coal stockpile plays a vital role in the overall feed control scenario at a power plant. It is imperative that the stockpile role be considered while preparing a plant feed. A proper level of coal inventory in stockpiles should always be maintained if the power plant feed requirement goals are to be realized most of the time.

During goal programming formulation, the user needs flexibility in choosing his own goals and in formulating them accordingly. This flexibility provides a means for experimentation in seeking solutions for not only the boiler feed blending problems, but for coal cleaning plant feed problems as well. With this in mind, an interactive computer program was developed which brings the basic data management aspects (for coal stockpiling) and goal programming aspects (for coal blending) together in a single program. It was decided to make this program executable on both minicomputer and microcomputer; thus, making its usage extremely economical and practical to any coal-fired power plants.

Description of the Intreactive Coal Stockpile Management Program (CSTOCK)

The coal stockpile management program (CSTOCK) is designed to control coal flows from different sources to a series of stockpiles and subsequently from stockpiles to the power plant in order to maintain a smooth and proper feed to the boiler.

CSTOCK has two functionally distinct, but interconnected parts. The first part creates and updates coal stockpile information in the computer which becomes input to the second part. In the second part, the goal programming technique is utilized to solve the feed blending problems using varying qualities of stockpiled coal.

Part One: Coal Stockpile Information Update Using CSTOCK

This is essentially a simple data management program. The objective here is to design a simple file-handling system for updating information of coal flow to stockpiles with built-in decision making capability for selecting the right stockpile(s) for the incoming coal.

Need for a Data Management Program for Coal Stockpile

Data Base Management System (DBMS) programs are coming on the market at an incredible pace. According to a recent article in PC Magazine (June 12, 1984) there are about 66 DBMS programs available for microcomputers and every week another program appears on the market, promising to surpass every current and future microcomputer DBMSs. If there are so many DBMS programs available then why develop another one?

There are four major reasons for this. First, the data management program developed here is a part of the overall stockpile management program, specifically designed to solve coal stockpiling and coal blending problems of a power plant. As mentioned before, incoming coal is added to a stockpile if it meets the requirements of that stockpile. Each stockpile is specifically designed to accept certain quantity and qualities of coal. It is, therefore, desirable to use a DBMS program that has the above decision making power in it. Unfortunately no marketed DBMS program has such capability. This is because, coal stockpiling is a specific operation of a power plant and the marketed DBMS programs are general business oriented softwares.

Secondly, aside from solving coal stockpiling problems through a simple file-handling system, CSTOCK solves goal programming problems as well. For an interactive goal programming software to solve coal blending problems using stockpiled coal, it must have internal access to the stockpiled coal information. Internal access means that, while executing the program, the user must have easy access to the stockpile file without having to exit from the program. This is because mixing varying qualities of stockpiled coal in order to find a desired power plant feed is an iterative process. The first part of CSTOCK provides an easy access to the stockpile file that the goal programming (the second part of CSTOCK) needs. This is one of the unique features of CSTOCK.

Thirdly, if one of the DBMS programs out of 66 is considered then it will make the blending program dependent on that DBMS program. In other words, the user has to get two different and disjointed softwares instead of one, not to mention the additional software commands that user must learn in order to use them.

Finally, CSTOCK is designed to run both on minicomputer (DEC-10) and microcomputer (IBM-PC). Without some major modifications, none of the microcomputer based DBMS programs are congruous to minicomputers and vice versa.

CSTOCK Capabilities

CSTOCK is a menu-driven program. It has one main menu and various sub-menus to guide the user. The main menu has four items:

1. Check Stockpile Status
2. Update Stockpile File
3. Blend Coal
4. Quit

Items 1 and 2 belong to the first part of CSTOCK, item 3 is the entrance to the second part of CSTOCK, and item 4 is the exit from CSTOCK.

To demostrate the decision making capability of CSTOCK as mentioned before, consider a problem where a certain amount of incoming coal is to be added to any one or more than one of the existing stockpiles of a power plant.

Assume, the power plant operates seven (7) stockpiles and the stockpiled coal information is known and shown in Table 5.1. Assume incoming coal specifications to be 3,000 tons (3 KTons) having a 1.72% sulfur content, a 13.4% ash content, and a unit heating value of 12,000 Btu (12.0 KBtu). As per CSTOCK programming logic, the plant owner has two options; 1) to choose the stockpile as per his wish or 2) to let the program decide the potential stockpile(s) suitable for this incoming coal depending on the stockpile criteria. Stockpile criteria are nothing more than a set of limitations on both quantity and qualities of coal for each stockpile. A sample stockpile criteria file is shown in Table 5.2. If the plant owner decides to choose option two (2), then CSTOCK uses information given in Tables 5.1 and 5.2 and selects stockpile(s) by simply checking the limitation of each variable (quantity and qualities) for every stockpile. CSTOCK results, as they appear on the terminal screen, are shown in Figure 5.1. Following this result, the owner can,select stockpile(s) suitable for the present incoming coal. In this example, stockpile #6 was selected and 3000 tons of incoming coal was added to it. The stockpile information is automatically updated as shown in Table 5.3 (note the quantity, qualities, and date of stockpile #6 of Tables 5.1 and 5.3).

Likewise, during coal removal, CSTOCK checks whether the chosen stockpile can provide the requested amount. If

Table 5.1 Stockpile Infomation File

ID	K-TON	SULFUR	ASH	K-BTU	DESCRP	DATE
1.	14.00	2.50	18.00	11.00	RAW-1	11/ 7/84
2.	10.00	2.60	19.00	11.00	RAW-2	11/ 7/84
3.	5.00	2.90	20.00	10.00	RAW-3	11/ 7/84
4.	5.00	1.98	14.00	12.50	CLEAN-1	11/ 7/84
5.	5.00	1.73	12.08	12.40	CLEAN-2	11/ 7/84
6.	6.00	1.60	10.00	11.90	EXCOAL-1	11/ 7/84
7.	5.00	1.40	13.25	11.70	EXCOAL-2	11/ 7/84

Table 5.2 Stockpile Criteria File

ID	MAX KTON	MIN KTON	MAX SUL	MIN SUL	MAX ASH	MIN ASH	MAX KBTU	MIN KBTU	DESCRIPTION
1.	15.0	1.0	2.55	2.45	30.0	15.0	20.0	0.0	RAW-1
2.	15.0	1.0	2.75	2.56	25.0	15.0	20.0	0.0	RAW-2
3.	15.0	1.0	3.50	2.76	20.0	15.0	20.0	0.0	RAW-3
4.	14.0	0.0	2.44	1.95	15.0	0.0	20.0	7.0	CLEAN-1
5.	14.0	0.0	1.94	1.73	15.0	0.0	20.0	7.0	CLEAN-2
6.	10.0	0.0	1.72	1.50	15.0	0.0	20.0	10.0	EXCOAL-1
7.	10.0	0.0	1.49	0.00	15.0	0.0	20.0	10.0	EXCOAL-2

```
INCOMING COAL SPECIFICATIONS
----------------------------

     K-TON   =        3.00
     SULFUR  =        1.72
     ASH     =       13.40
     K-BTU   =       12.00

BASED ON STOCKPILE CRITERIA, FOLLOWING STOCKPILES
ARE SELECTED FOR THE ABOVE INCOMING COAL

   VARIABLE           STOCKPILE NUMBER

--------------------------------------------------
     K-TON   :        2  3  4  5  6  7
     SULFUR  :        6
     ASH     :        4  5  6  7
     K-BTU   :        1  2  3  4  5  6  7

--------------------------------------------------
```

Figure 5.1. A Sample Output from CSTOCK on Stockpile Selection.

Table 5.3 Updated Stockpile Information File

ID	K-TON	SULFUR	ASH	K-BTU	DESCRPT	DATE
1.	14.00	2.50	18.00	11.00	RAW-1	11/ 7/84
2.	10.00	2.60	19.00	11.00	RAW-2	11/ 7/84
3.	5.00	2.90	20.00	10.00	RAW-3	11/ 7/84
4.	5.00	1.98	14.00	12.50	CLEAN-1	11/ 7/84
5.	5.00	1.73	12.08	12.40	CLEAN-2	11/ 7/84
6.	9.00	1.64	11.13	11.93	EXCOAL-1	11/16/84
7.	5.00	1.40	13.25	11.70	EXCOAL-2	11/ 7/84

the stockpile can not provide the requested amount of coal due to tonnage limitation, then a warning message is displayed and the user is asked to select different stockpile(s).

Besides stockpiling, CSTOCK has other capabilities which apply to coal blending problems. These include the selection of objectives and the assignment of priorities and weights to those objectives. CSTOCK also has the capability to modify the initial problem formulation interactively such that sensitivity analyses can be performed quickly at one terminal session.

CSTOCK Shortcomings

At the moment, the interactive aspect of CSTOCK to solve goal programming problems is not a general purpose goal programming software, but restricted to coal blending problems only. However, via batch mode of execution, the second part of CSTOCK can be used for general purpose goal programming problems. CSTOCK also lacks the special features of many DBMS programs such as graphics, charts, etc.

Part Two: Coal Blending Using CSTOCK

This part uses the stockpile information generated in part one to solve coal blending problems. It can be accessed through the main menu by selecting item 3 on this menu.

A Short Term Coal Blending Example

Consider a short term coal blending problem of the same power plant, mentioned earlier in this chapter, where it operates seven (7) coal stockpiles (see Table 5.3). Due to limited supply of superior quality (low sulfur and high Btu) coal from external sources, the planner wants to avoid the use of coal from stockpile #6 and #7 in the daily blend. Utilizing this information the planner wishes to determine the appropriate quantities to be used from each of the five remaining stockpiles on a daily basis such that the boiler feed requirements are met. These requirements are assumed to be 5,000 tons (5 KTons) of coal per day having a 1.95% sulfur content, a 14.0% ash content, and a unit heating value of 12,500 Btu (12.5 KBtu). The owner has outlined the following goals in an ordinal ranking:

1. Satisfy power plant tonnage requirements.
2. Use at least 1,000 tons of coal from stockpile #2.
3. Minimize the sulfur content and ash content of the power plant feed. Minimization of sulfur content is twice as important as minimization of ash content.
4. Maximize the heating value of the power plant feed.

The second priority goal may be management's order to use this coal daily, irrespective of its quality. This coal can be viewed as coming from the dedicated mine or from a dormant stockpile which must be put to use to avoid possible oxidation and spontaneous combustion.

To solve this blending problem using CSTOCK, the planner must formulate it in a goal programming fashion. Detailed formulation of steps for this problem is presented in Appendix A. The goal programming equations obtained from this formulation are shown below:

Find $\{x_1, x_2, x_3, x_4, x_5\}$ so as to

minimize $a = \{(n_1+p_1), n_2, (2p_3+p_4), n_5\}$ such that

$$x_1 + x_2 + x_3 + x_4 + x_5 + n_1 - p_1 = 5.0$$

$$x_2 + n_2 - p_2 = 1.0$$

$$2.50x_1 + 2.60x_2 + 2.90x_3 + 1.98x_4 + 1.73x_5 + n_3 - p_3 = 9.75$$

$$18.0x_1 + 19.0x_2 + 20.0x_3 + 14.0x_4 + 12.1x_5 + n_4 - p_4 = 70.0$$

$$11.0x_1 + 11.0x_2 + 10.0x_3 + 12.5x_4 + 12.4x_5 + n_5 - p_5 = 62.5$$

$$\bar{x}, \bar{n}, \bar{p} > \bar{0}$$

where the left hand side coefficients are stockpiled coal information gathered from Table 5.1. 9.75 is the tons of sulfur in the feed in thousands at the target grade of 1.95% (1.95 * 5.0 = 9.75). Likewise, 70.0 = 14.0 * 5.0 for ash and 62.5 = 12.5 * 5.0 for thousand Btu.

The solution to this problem must not indicate more tonnage from any participating stockpile than that stockpile is capable of providing. This check is performed interactively by the user during program execution.

The solution resulting from CSTOCK is shown in Figure 5.2. Note that the power plant tonnage, tonnage-limitation, and sulfur requirement goals are met which reflects the importance of these goals to the planner. Ash and Btu target values of feed quality could not be satisfied simultaneously due to the nature of the coal provided by the participating stockpiles. However, ash and Btu values were well within 95% of their respective targets. No coal was used from stockpile #1 and #3 owing to the high values of sulfur in them and usage of these coals were not considered as separate goals.

If the planner finds this blend satisfactory then he can enter the first part of CSTOCK via main menu and can carry out necessary stockpile file updating to reflect his decision. If, on the other hand, the blending solution is found unsatisfactory, the planner can reformulate the problem by rearranging his preference structure to influence the resultant optimal blend. Reformulation includes one or more of the following:

1. Modify priority structure.
2. Change goal targets (RHS).

VARIABLE ANALYSIS

VARIABLE	AMOUNT
2	1.00000
5	3.08000
4	.92000

TARGET ACHIEVEMENT ANALYSIS

GOAL	GOAL ITEM	TARGET (RHS)	LHS ABOVE TARGET	LHS BELOW TARGET
1	TONNAGE	5.00	.00	.00
2	TON-LIMIT STKPL 2	1.00	.00	.00
3	SULFUR	9.75	.00	.00
4	ASH	70.00	.00	.91
5	BTU	62.50	.00	1.81

ANALYSIS OF THE OBJECTIVE

PRIORITY	UNDER-ACHIEVEMENT
4	1.80800
3	.00000
2	.00000
1	.00000

FINAL RESULTS OF THIS RUN

STOCKPILE NUMBER	TONNAGE
1	.00
2	1.00
3	.00
4	.92
5	3.08

Figure 5.2. CSTOCK results of a coal blending problem.

3. Add or drop a goal.

4. Add or drop a stockpile.

CSTOCK allows an easy access to carry out these modifications.

In summary, Program CSTOCK was developed for both minicomputer and microcomputer to handle stockpiling and coal blending problems. The program source code is divided into nineteen subroutines, each of which performs a specific task. Nine subroutines are for part one and the remaining ten are for part two. Since both parts are interconnected, some of the subroutines are shared by both parts. Figure 5.3 contains a list of the major subroutines and their functions. The goal programming algorithm (subroutine GOAL in Table 5.6) was taken from S. M. Lee's (1972) text book and modified to suite CSTOCK programming logic. All other subroutines were designed and written under this study. Listing of thses subroutines can be found in Appendix B.

STATUS	:	Checks the status of stockpile file.
UPDATE	:	Updates or creates stockpile by calling subroutine ADD.
ADD	:	Adds coal to a stockpile.
TAKOUT	:	Removes coal from a stockpile.
CRITER	:	Checks stockpile criteria file and logically selects stockpile/s suitable for incoming coal.
DATE20	:	Obtains current date for file updating. It needs an assembly language program ACSV20, which is a part of FORLIB.PLUS package.
BLENDC	:	Accesses the goal programming part.
BATCHM	:	Provides batch mode operation for goal programming.
INACTM	:	Provides interactive mode operation for goal programming.
GOAL	:	Solves goal programming problem using modified simplex algorithm.
CHKOUT	:	Displays output on the terminal screen.
CHECK2	:	Checks user input before accepting it.

Figure 5.3 List of major subroutines in CSTOCK.

CHAPTER 6

CONCLUSIONS

The major objectives of this study were 1), to review the adequacy of the existing in-house ROM coal sampling technique; 2), to determine the relationship between estimated in-situ coal and the ROM coal qualities using conditional simulation; 3), to determine the required sampling frequency of ROM coal which will provide the desired level of reliability on the ROM coal quality determination; and finally 4), to solve coal stockpile and coal blending problems at a power plant.

Most in-house ROM coal sampling techniques do not consider the short term fluctuation in ROM coal quality. To make the in-house ROM coal sampling more adequate, the variability of coal qualities in ROM coal must be considered in sampling technique. The nature of this variability can be measured, prior to actual mining, by using the simulation technique, as described in this dissertation. With a prior knowledge of the variability in ROM coal qualities, the required sampling frequency and the amount of sample of ROM coal which will provide the desired level of reliability can be calculated as demonstrated in chapter five.

Employing the conditional simulation technique, different coal deposits, shown in Table 4.1, were simulated by a computer to arrive at conditions under which one can expect a spatial continuity in hourly ROM coal quality, given the in-situ coal quality. The results from Table 4.2 show that, when in-situ variogram nugget/sill ratio is zero or very close to zero, the ROM coal quality is likely to show spatial correlation. Also, the ROM coal quality appears to retain spatial correlation when in-situ variogram nugget/sill ratio is 30% or less and the varigram range/SMU size ratio is 500 or less.

To determine the sampling frequency of ROM coal, ROM coal data was first generated by simulating mining methods on conditionally simulated coal deposit. ROM coal data was next statistically analyzed to determine the sampling frequency. Two schemes were suggested.

1. Use of the geostatistical estimation variance if the spatial correlation in ROM coal quality can be established.
2. Use of classical statistics if the spatial correlation in ROM coal quality can not be established. An example of this was presented in chapter five.

An interactive computer program was developed that uses the ROM coal and coal from other sources to solve coal stockpiling and coal blending problems at a coal-fired power plant. Simple file-handling and multi-objective goal programming techniques provided solutions to these problems. Menu-driven and interactive capabilities give this program a high level of flexibility that is needed to analyze and solve the stockpiling and blending problems.

Suggestions for Future Research

Simulated ROM coal sulfur of Helen Mine appeared to show no sptial correlation. This is due to high nugget/sill and varigram range/SMU size ratios of insitu sulfur variogram. This insitu sulfur variogram is a global variogram of the coal deposit, whereas, daily ROM coal constitutes a very small portions of the entire coal deposit. Therefore, to examine the true variability of coal quality in ROM coal, a study of localized variogram is required which should also include the effect of out-of-seam dilution. A 10' X 10' SMU was defined by the average value of four (4) 5' X 5' grid points of a CSIM model. A finer definition, say 16 or 25 points, for a 10' X 10' SMU may produce some local variabilities that may exist in reality.

The cost of sampling was not included in this study. For an operating mine to follow the sampling schemes suggested in this research, there should first be a cost benefit study to justify the use of such schemes. Recently, "on-line" coal analyzers have been developed which provide information of a coal stream fast enough (within minutes) to make the necessary processing decision on coal flow. But, an on-line coal analyzer is very expensive (1.5 to 2.0 million dollars; GAMMA METRICS: Continuous Flow-Thru Coal Analyzer) and smaller coal operators may face financial difficulties in acquiring it.

A coal stockpile management program was designed for microcomputer as well as minicomputer to solve coal stockpiling and coal blending problems at a power plant. The data management part of this program lacks special features of any data base management program such as graphics, charts, etc. A further study is needed to incorporate these features into the coal stockpile management program.

APPENDIX A

GOAL PROGRAMMING FORMULATION

In a goal programming formulation, the following steps are followed:

1. determination of decision variables,
2. formulation of objective functions,
3. assigning priorities and weights to objectives, and
4. formulation of the achievement function.

These steps are discussed individually below:

Determination of Decision Variables. A decision variable is any variable over which the decision maker has control. For coal blending problem, decision variables will be the quantities of coal from each stockpile that will comprise the resultant blended end product.

Formulation of Objective Functions. In a goal programming formulation every constraint, unlike LP, becomes an objective of the problem. Each objective is formulated as a function of decision variables with a target (Right-Hand-Side) value. This value can define a lower bound or an upper bound for possible solutions to the objective function, or it can be a specific target that the objective function must achieve.

A negative and a positive deviation variables are associated with each objective. These variables account for the degree to which the objective function value meets the target RHS value based on a specific set of decision variables. Mathematically, formulation of objective functions can be described as follows:

$\bar{x}$ = vector of decision variables $x_1, x_2, \ldots, x_j$

c_{ij} = the coefficient associated with variable j in the i^{th} objective

b_i = i^{th} target or RHS value.

n_i = negative deviation variable associated with the i^{th} objective.

p_i = positive deviation variable associated with the i^{th} objective.

The form of objective function in a linear goal programming is:

$$c_{ij}x_j + n_i - p_i = b_i \qquad i = 1,2,\ldots\ldots,m$$

where m = the total number of objectives.

<u>Assigning Priorities and Weights to Objectives.</u> In a goal programming formulation, chosen objectives must be ranked from high priority to low priority by sequential

numbering with number one referring to top priority.

Objectives can be grouped into one priority level provided they are commensurable, that is, have a common unit of measure. Each objective within a priority level can be assigned a weighting factor to indicate the relative importance of that objective within the given priority level. The higher the weight the greater the importance.

Formulation of the Achievement Function. The achievement function ($\bar{a}$) is defined as an ordered vector of a dimension equal to the number of priorities within the problem. To formulate the achievement function one must analyze each objective function and its associated right-hand-side value. Consider a typical objective function as shown below:

$$f_i(\bar{x}) + n_i - p_i = b_i$$

If b_i is an upper bound value, then overachievement of this value is not possible and the goal is to minimize the amount of underachievement. This situation is formulated by assuming $p_i = 0$ (overachievement impossible) and minimizing n_i (minimize the underachievement as measured by the negative deviation from b_i). Conversely, if b_i is a lower bound value, the situation is formulated by assuming $n_i = 0$ (underachievement impossible) and minimizing p_i (minimize the overachievement as measured by the positive deviation from b_i). Finally, if the objective function is absolute, then the value b_i must be satisfied exactly. In this case the sum of $(n_i + p_i)$ must be minimized.

Once the deviation variables which are to be minimized for each objective are decided upon, the results are summarized in the achievement function or vector a by

$$\min \bar{a} = \{a_i,\ a_2, \ldots, a_k\}$$

where a_i = the linear combination of deviation variables to be minimized for all objectives at priority level i.

k = total number of priority levels.

The results of these four steps can be combined to produce the following general model of a linear goal programming problem:

$$\text{Find } \bar{x} = \{x_1,\ x_2, \ldots, x_j\} \text{ so as to minimize} \tag{A.1}$$

$$\bar{a} = \{a\ ,\ a\ , \ldots, a\ \} \text{ such that} \tag{A.2}$$

$$c_{i,j}x_j + n_i - p_i = b_i \quad i = 1,2,\ldots,m \text{ and} \tag{A.3}$$

$$\bar{x}, \bar{n}, \bar{p} \geq \bar{0} \tag{A.4}$$

Equation (A.2) is the achievement function for k priority levels. Equations (A.3) are the m objective functions and Equations (A.4) are implicity nonnegativity constraints on decision variables and deviation variables.

Method of Solution

Solving the blending problem modeled as a goal programming problem involves the use of a modified simplex algorithm. This algorithm utilizes a series of tableaus in determining the optimal solution to the problem. A tableau is simply a convenient representation of the variable coefficients and right-hand-side values of any linear goal program (Ignizio, 1976, p. 41). The general form of the tableau used by this modified simplex algorithm is presented in Figure A.1.

The headings and elements within this tableau are defined as follows according to Ignizio (1976, pp. 43-44):

Headings:

p_k = the k^{th} priority level, $k = 1,\ldots,k$

V = problem variables, both decision and deviational. The variables to the right of V (x_j and p_i) are the initial set of nonbasic variables. The variables below V (n_i) are the initial set of basic variables.

$\bar{b}$ = the elements below $\bar{b}$ are the b_i's, i.e., the right-hand-side values of each obj.

Elements:

$j = 1,2,\ldots,j$; $i = 1,\ldots,m$; $s = 1,\ldots,j$; $k = 1,\ldots,k$

$e_{i,s}$ = element in the i^{th} row, under the s^{th} nonbasic variable. That is, $e_{i,s}$ is the

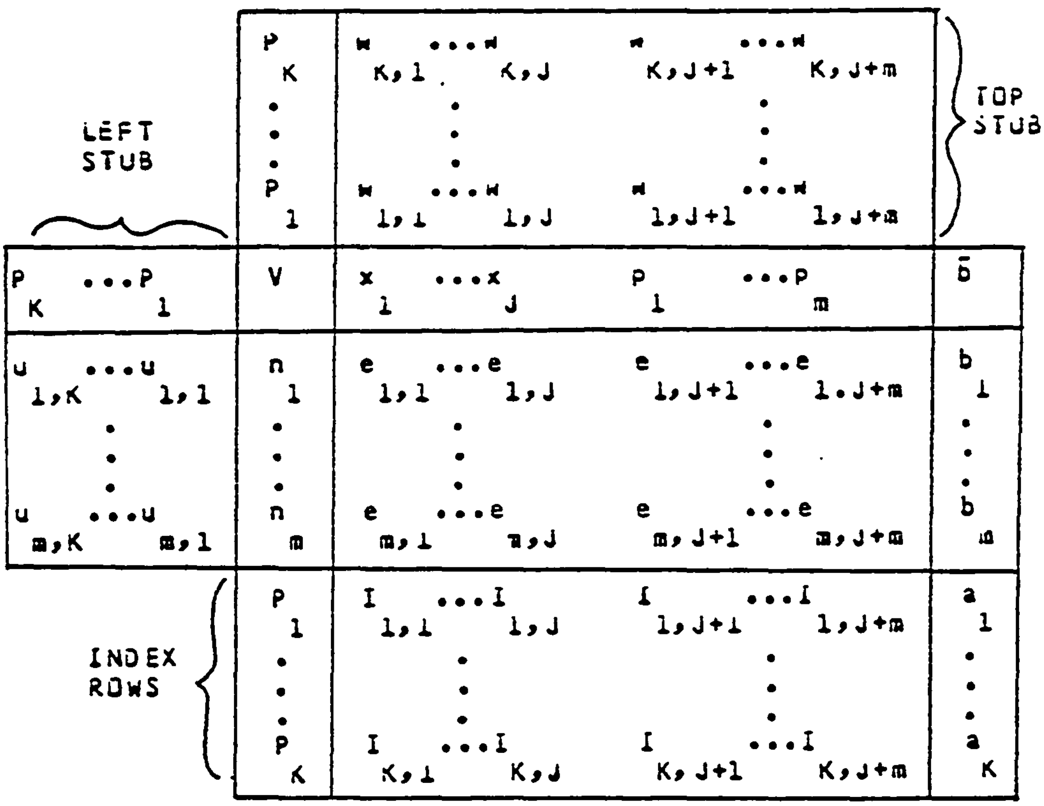


Figure A.1 General form of modified simplex tableau.

coefficient of the s^{th} nonbasic variable in objective i.

$w_{k,s}$ = weighting factor of priority k (P_k) associated with the s^{th} nonbasic var.

$u_{i,k}$ = weighting factor of priority k (P_k) associated with the i^{th} basic variable.

$I_{k,s}$ = index number for priority k under the s^{th} nonbasic variable.

a_k = level of achievement of priority k where $a = \{a_1, a_2, \ldots, a_k\}$.

All elements except $I_{k,s}$ and a_k are obtained from the problem formulation. Values for $I_{k,s}$ and a_k are computed as follows:

$$I_{k,s} = (e_{i,s} * u_{i,k}) - w_{k,s} \tag{A.5}$$

$$a_k = b_i * u_{i,k} \tag{A.6}$$

The modified simplex algorithm is designed to alter the tableau by exchanging a present nonbasic variable for a basic variable if such an exchange will improve the present solution. This process is repeated until no further improvement is possible. The solution to the problem, at any stage, is given by the values of the basic variables which are stored in the b vector. Values for $a_1, a_2, \ldots, a_k$ represent the level of achievement for the k different priority levels. The lower the value of a_k, the better the current solution, since the achievement function is of a minimization form. If a_k equals 0, then the set of objectives at this particular priority level (level k) has been completely achieved. The set of index numbers serve to indicate whether or not the present solution is optimal. If it is not, these index numbers identify the proper exchange between a basic and a nonbasic variable for solution improvement.

Each priority level is optimized in turn. When seeking to optimize lower priority levels the algorithm ensures that no degradation of the previously determined achievements at higher priority levels occurs in the process.

APPENDIX B

FORTRAN SOURCE LISTING OF CSTOCK

```
C
C       CSTOCK IS AN INTERACTIVE STOCKPILE MANAGEMENT PROGRAM
C
C                      WRITTEN BY
C
C                    SUKHENDU L. BARUA
C
C       DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING
C               THE UNIVERSITY OF ARIZONA
C                   TUCSON, ARIZONA
C                   DECEMBER, 1984
C
C       VERSION: I
C
C       PURPOSE: CSTOCK IS DESIGNED TO CONTROL COAL FLOWS FROM DIFFERENT
C                SOURCES TO A SERIES OF STOCKPILES AND SUBSEQUENTLY FROM
C                STOCKPILES TO THE POWER PLANT FOR COAL BURN.
C
C                CSTOCK HAS TWO FUNCTIONALLY DISTINCT, BUT INTERCONNECTED
C                PARTS.  THE FIRST PART CREATES AND UPDATES STOCKPILE
C                INFORMATION IN THE COMPUTER WHICH BECOMES INPUT TO THE
C                SECOND PART.  IN THE SECOND PART GOAL PROGRAMMING
C                TECHNIQUE IS UTILIZED TO SOLVE THE FEED BLENDING PROBLEMS
C                USING VARYING QUALITIES OF STOCKPILED COAL.
C
C                GOAL PROGRAMMING LOGIC IS GIVEN IN SUBROUTINES GOAL, START,
C                AND FINISH.  THESE THREE SUBROUTINES WERE MODIFIED FROM
C                S. M. LEE'S TEXT BOOK: "GOAL PROGRAMMING FOR DECISION
C                ANALYSIS", 1972.
C
C----------------------------------------------------------------------------
        COMMON /FILES/ICON,MST1,MST2,MST3
        COMMON /COUNT/ICOUNT,KOUNT
C
        CHARACTER *10 DAY
        ICON=0
        MST1=1
        MST2=2
        MST3=3
C
        KOUNT=0
        ICOUNT=0
        N=0
        IDATE=9
        CALL DATE20
        OPEN(IDATE,FILE='DATE20.DAT',ACCESS='SEQUENTIAL',STATUS='OLD')
        READ(IDATE,1001)DAY
 1001   FORMAT(A10)
        WRITE(ICON,1002)DAY
 1002   FORMAT(//15X,'TODAY'S DATE:   ',A10/)
        CLOSE(IDATE)
C
        WRITE(ICON,1000)
 1000   FORMAT(/5X,'WELCOME TO THE COAL STOCKPILE MANAGEMENT PROGRAM'//)
 10     WRITE(ICON,100)
 100    FORMAT(/2X,'MENU:  SELECT ONE BY TYPING AN INTEGER #'/,
     $  /5X,'1.   CHECK STOCKPILE STATUS'/,
     $  5X,'2.   UPDATE STOCKPILE FILE'/,
     $  5X,'3.   BLEND COAL'/,
     $  5X,'4.   QUIT'//,
     $  5X,'YOUR SELECTION ==> ',\)
     $  5X,'4.   BLEND TO FEED POWER PLANT'/,
C     $  5X,'5.   GENERATE SUMMARY TYPE RESULTS'/,
C     $ 5X,'6.   GENERATE DETAIL RESULTS'/,
```

```
C
      READ(ICON,5)IS
5     FORMAT(BN,I5)
      IF(IS.LT.1 .OR. IS.GT.4)WRITE(ICON,105)
      IF(IS.LT.1 .OR. IS.GT.4)GO TO 10
105   FORMAT(/5X,'COULD NOT RECOGNIZED YOUR SELECTION.  SELECT'/,
     $ 5X,'AGAIN BY TYPING PROPER INTEGER NUMBER'/)
C
      IF(IS.EQ.1)CALL STATUS(N)
      IF(IS.EQ.2)CALL UPDATE(N)
      IF(IS.EQ.3)CALL BLENDC(N)
C     IF(IS.EQ.4)CALL BLENDP
C     IF(IS.EQ.5)CALL OUTS
C     IF(IS.EQ.6)CALL OUTD
      IF(IS.EQ.4)CALL QUITT
C
      IF(IS.NE.4)GO TO 10
      END
C
      SUBROUTINE QUITT
      COMMON /FILES/ICON,MST1,MST2,MST3
      WRITE(ICON,100)
100   FORMAT(/5X,'BYE NOW, HAVE A NICE DAY!'//)
      RETURN
      END
C
      SUBROUTINE STATUS(N)
C-------------------------------------------------------------------
C     THIS SUBROUTINE CREATES AND CHECKS STATUS OF STOCKPILE FILES
C
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /FN/HEAD1(7)
      COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
      COMMON /COUNT/ICOUNT,KOUNT
C
C     DOUBLE PRECISION A(6),HEAD1
      DIMENSION A(5)
      CHARACTER NDAY*10,DESCR*10,NAME1*11,NAME2*11,NAME3*11,
     $ IFRMT1*70,IFRMT2*70,IFRMT3*70,HEAD1*6
      DATA A/5*0.0/
      DATA NDAY/'          '/
      DATA DESCR/'          '/
      IFRMT1='(F3.0,1X,F6.2,3X,F5.2,3X,F5.2,2X,F5.2,4X,2A10)'
      IFRMT2='(F3.0,8F7.2,2X,A10)'
      IFRMT3='(1X,A2,2X,A5,3X,A6,3X,A3,3X,A5,4X,A6,7X,A4)'
      IF(KOUNT.GT.0)GO TO 35
      WRITE(ICON,110)
110   FORMAT(/5X,'***  STOCKPILE FILE INFORMATION  ***'///,
     $ 5X,'PROGRAM CSTOCK REQUIRES A STOCKPILE FILE WHICH CONTAINS'/,
     $ 5X,'NECESSARY STOCKPILE INFORMATION.  CSTOCK TREATS THIS FILE'/,
     $ 5X,'AS AN ORIGINAL STOCKPILE FILE (OSF) AND CREATES A NEW'/,
     $ 5X,'STOCKPILE FILE (NSF) WHICH IS THE DUPLICATE OF OSF.  ANY'/,
     $ 5X,'UPDATING ON STOCKPILE DUE TO EITHER ADDITION OF REMOVAL'/,
     $ 5X,'OF COAL IS CARRIED OUT ON THE NSF AND OSF IS KEPT ASIDE'/,
     $ 5X,'AS A MEMOIR.')
9     WRITE(ICON,111)
111   FORMAT(/5X,'DO YOU HAVE A STOCKPILE FILE?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 18
      IF(IFLAG.EQ.0)RETURN
      GO TO 9
18    WRITE(ICON,114)
114   FORMAT(/5X,'NAME OF ORIGINAL STOCKPILE FILE '/,
     $ 5X,'(NO MORE THAN 11 CHARACTERS LONG) ==> ',\)
      READ(ICON,205)NAME1
205   FORMAT(A11)
```

```
      WRITE(ICON,117)
117   FORMAT(/5X,'NAME OF NEW STOCKPILE FILE'/,
     $ 5X,'(NO MORE THAN 11 CHARACTERS LONG) ==> ',\)
      READ(ICON,205)NAME2
25    WRITE(ICON,116)NAME1,NAME2
116   FORMAT(/5X,'NAMES READ ARE:'/,
     $ 15X,'ORIGINAL FILE:   ',A11/,
     $ 15X,'NEW FILE:        ',A11/,
     $ 5X,'ARE THESE NAMES CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 30
      IF(IFLAG.EQ.0)GO TO 18
      GO TO 25
C-----  OPEN TWO FILES:
C-----  ORIGINAL FILE - SEQUENTIALLY ACCESSED
C-----  NEW FILE -      DIRECT ACCESSED
30    OPEN(MST1,FILE=NAME1,ACCESS='SEQUENTIAL',STATUS='OLD')
      OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $ STATUS='NEW',RECL=80)
      READ(MST1,IFRMT3,ERR=91)HEAD1
      WRITE(ICON,230)
230   FORMAT(/5X,'THE ORIGINAL STOCKPILE FILE'/)
      WRITE(ICON,IFRMT3)HEAD1
      WRITE(MST2,IFRMT3,REC=1)HEAD1
      I=2
22    READ(MST1,IFRMT1,END=90)A,DESCR,NDAY
      WRITE(ICON,IFRMT1)A,DESCR,NDAY
      WRITE(MST2,IFRMT1,REC=I)A,DESCR,NDAY
      I=I+1
      GO TO 22
90    N=I-2
      CLOSE(MST1)
      CLOSE(MST2)
35    IF(KOUNT.EQ.0)GO TO 39
36    WRITE(ICON,118)
118   FORMAT(/5X,'DO YOU WISH TO SEE THE STOCKPILE FILES ?'/,
     $ 5X,'ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.2)GO TO 36
      IF(IFLAG.EQ.1)CALL STFILE(N,1)
39    KOUNT=1
      RETURN
91    WRITE(ICON,120)
120   FORMAT(/5X,'ORIGINAL STOCKPILE FILE OPEN/READ ERROR')
      RETURN
92    WRITE(ICON,125)
125   FORMAT(/5X,'NEW STOCKPILE FILE OPEN/READ ERROR')
      RETURN
      END
      SUBROUTINE UPDATE(N)
C------------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /COUNT/ICOUNT,KOUNT
      IF(KOUNT.EQ.0)CALL STATUS(N)
      IF(N.LE.0)RETURN
40    IERR=0
      WRITE(ICON,120)
120   FORMAT(/5X,'SELECT ONE OF THE FOLLOWING'/,
     $ /5X,'1   ADD COAL TO A STOCKPILE',/,
     $ 5X,'2   TAKE OUT COAL FROM A STOCKPILE',/,5X,'3   DO NOTHING'//,
     $ 5X,'YOUR SELECTION ==> ',\)
      READ(ICON,5)ISEL
5     FORMAT(BN,I5)
      IF(ISEL.LT.1.OR.ISEL.GT.3)IERR=1
      IF(IERR.EQ.1)WRITE(ICON,145)
      IF(ISEL.EQ.1)CALL ADD(N)
```

```
      IF(ISEL.EQ.2)CALL TAKOUT(N)
C     IF (ISEL.EQ.3)RETURN
      IF(IERR.EQ.1)GO TO 40
145   FORMAT(/5X,'YOU MADE A MISTAKE MY FRIEND! '/,
     $ 5X,'SELECT A NUMBER BETWEEN 1 AND 3')
C
61    CALL MENU2(IC,N)
C     IF(IC.LT.3)GO TO 61
      RETURN
      END
C
      SUBROUTINE TAKOUT(N)
C-----------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /FN/HEAD1(7)
      COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
      COMMON /IVAR/NVAR,NVAR2
C
      DIMENSION A(5)
      CHARACTER NDAY*10,DESCR*10,NAME1*11,NAME2*11,NAME3*11,
     $ IFRMT1*70,IFRMT2*70,IFRMT3*70,HEAD1*6,DAY*10
      DATA A/5*0.0/
      DATA NDAY/'          '/
      DATA DESCR/'          '/
      IFRMT1='(F3.0,1X,F6.2,3X,F5.2,3X,F5.2,2X,F5.2,4X,2A10)'
      IFRMT2='(F3.0,8F7.2,2X,A10)'
      IFRMT3='(1X,A2,2X,A5,3X,A6,3X,A3,3X,A5,4X,A6,7X,A4)'
      IDATE=9
C
C-----  CALL SUBROUTINE DATE20 TO REPORT UPDATED DATE
C
      CALL DATE20
      OPEN(IDATE,FILE='DATE20.DAT',ACCESS='SEQUENTIAL',STATUS='OLD')
      READ(IDATE,1001)DAY
1001  FORMAT(A10)
      CLOSE(IDATE)
C
40    IERR=0
25    WRITE(ICON,125)
125   FORMAT(/5X,'FROM WHICH STOCKPILE?  ENTER INTEGER # ==> ',\)
      READ(ICON,5)IS
5     FORMAT(BN,I5)
      WRITE(ICON,127)
127   FORMAT(/5X,'HOW MANY K-TONS?  ENTER WITH DECIMAL ==> ',\)
      READ(ICON,6)STON
6     FORMAT(BZ,F10.0)
26    WRITE(ICON,126)IS,STON
126   FORMAT(/5X,'STOCKPILE NUMBER = ',I3,/,
     $ 5X,'TONNAGE REMOVED  = ',F10.2,/,
     $ 5X,'ARE THESE VALUES CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 27
      IF(IFLAG.EQ.0)GO TO 25
      GO TO 26
27    IF(IS.LT.1.OR.IS.GT.N)IERR=1
      IF(IERR.EQ.1)WRITE(ICON,130)
130   FORMAT(/5X,'THIS STOCKPILE DOES NOT EXIST, TRY ANOTHER ONE')
      IF(IERR.EQ.1)GO TO 40
      IST=IS+1
      OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $ STATUS='OLD',RECL=80)
      READ(MST2,IFRMT1,REC=IST,ERR=92)A,DESCR,NDAY
      SUB=A(2)-STON
      IF(SUB.GT.0.)GO TO 50
      IF(SUB.LT.0)WRITE(ICON,135)STON,A(2)
      IF(SUB.LT.0)GO TO 25
```

```
      DO 49 I=2,NVAR2
      A(I)=0.
49    CONTINUE
135   FORMAT(/5X,' YOU DO NOT HAVE ',F10.2,' TONS OF MATERIAL IN',/,
     $ 5X,' THE CURRENT STOCKPILE.  YOU ONLY HAVE ',F10.2,' K-TONS.',/,
     $ 5X,' SO SELECT A DIFFERENT STOCKPILE OR DIFFERENT TON OR BOTH.')
50    A(2)=SUB
      NDAY=DAY
      WRITE(MST2,IFRMT1,REC=IST)A,DESCR,NDAY
      CLOSE(MST2)
      RETURN
92    WRITE(ICON,140)
140   FORMAT(/5X,'FILE OPEN/READ ERROR IN ROUTINE TAKOUT')
      RETURN
      END
      SUBROUTINE MENU2(ISEL,N)
C-----------------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
40    IERR=0
      WRITE(ICON,100)
100   FORMAT(/5X,'SELECT ONE'/,
     $ 5X,'1   SEE STOCKPILE FILE'/,
     $ 5X,'2   SEE STOCKPILE CRITERIA FILE'/,
     $ 5X,'3   GO BACK TO MAIN MENU'//,
     $ 5X,'YOUR SELECTION ==> ',\)
C
      READ(ICON,5)ISEL
5     FORMAT(BN,I5)
      IF(ISEL.LT.1.OR.ISEL.GT.3)IERR=1
      IF(IERR.EQ.1)WRITE(ICON,145)
      IF(IERR.EQ.1)GO TO 40
145   FORMAT(/5X,'YOU MADE A MISTAKE MY FRIEND! '/,
     $ 5X,'SELECT A NUMBER BETWEEN 1 AND 3')
      IF (ISEL.EQ.3)RETURN
      CALL STFILE(N,ISEL)
      IF(ISEL.EQ.0)GO TO 40
      RETURN
      END
C
      SUBROUTINE STFILE(N,II)
C-----------------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /COUNT/ICOUNT,KOUNT
      COMMON /FN/HEAD1(7)
      COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
      DIMENSION A(5),B(9)
      CHARACTER NDAY*10,DESCR*10,NAME1*11,NAME2*11,NAME3*11,
     $ IFRMT1*70,IFRMT2*70,IFRMT3*70,HEAD1*6,HEAD*80
      DATA A/5*0.0/
      DATA NDAY/'          '/
      DATA DESCR/'          '/
      IFRMT1='(F3.0,1X,F6.2,3X,F5.2,3X,F5.2,2X,F5.2,4X,2A10)'
      IFRMT2='(F3.0,8F7.2,2X,A10)'
      IFRMT3='(1X,A2,2X,A5,3X,A6,3X,A3,3X,A5,4X,A6,7X,A4)'
C
      IF(II.EQ.2)GO TO 40
      IF(II.EQ.4)GO TO 20
15    IERR=0
      WRITE(ICON,100)
100   FORMAT(/5X,'WHICH ONE ?'/,
     $ 5X,'1  ORIGINAL STOCKPILE FILE'/,5X,'2  UPDATED STOCKPILE FILE'/
     $ ,5X,'3  BOTH FILES'//,
     $ 5X,'YOUR SELECTION ==> ',\)
```

```
      READ(ICON,5)IS
5     FORMAT(BN,I5)
      IF(IS.LT.1.OR.IS.GT.3)IERR=1
      IF(IERR.EQ.1)WRITE(ICON,101)
      IF(IERR.EQ.1)GO TO 15
101   FORMAT(/5X,'YOU MADE A MISTAKE MY FRIEND! '/,
     $ 5X,'SELECT A NUMBER BETWEEN 1 AND 3')
      IF(IS.EQ.2)GO TO 20
C
      OPEN(MST1,FILE=NAME1,ACCESS='SEQUENTIAL',STATUS='OLD')
      WRITE(ICON,131)
131   FORMAT(5X,'THE ORIGINAL STOCKPILE FILE'/)
      READ(MST1,IFRMT3,ERR=93)HEAD1
      WRITE(ICON,IFRMT3)HEAD1
      I=1
10    READ(MST1,IFRMT1,END=90)A,DESCR,NDAY
      WRITE(ICON,IFRMT1)A,DESCR,NDAY
      I=I+1
      GO TO 10
C90   N=I-1
90    CLOSE(MST1)
      IF(IS.EQ.1)GO TO 30
C
20    OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $ STATUS='OLD',RECL=80)
      READ(MST2,IFRMT3,REC=1,ERR=92)HEAD1
      WRITE(ICON,130)
130   FORMAT(/5X,'THE UPDATED STOCKPILE FILE'/)
      WRITE(ICON,IFRMT3)HEAD1
      J=2
35    READ(MST2,IFRMT1,REC=J)A,DESCR,NDAY
      WRITE(ICON,IFRMT1)A,DESCR,NDAY
      J=J+1
      IF(J.GT.(N+1))GO TO 91
      GO TO 35
C91   N=J-2
91    CLOSE(MST2)
      GO TO 30
40    IF(ICOUNT.GT.0)GO TO 41
60    WRITE(ICON,140)
140   FORMAT(/5X,'DO YOU HAVE A STOCKPILE CRITERIA FILE?'/,
     $ 5X,'ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.2)GO TO 60
      IF(IFLAG.EQ.1)GO TO 65
      II=0
      RETURN
C
65    WRITE(ICON,150)
150   FORMAT(/5X,'NAME OF THIS FILE?'/,
     $ 5X,'NO MORE THAN 11 CHARACTERS LONG ==> ',\)
      READ(ICON,200)NAME3
200   FORMAT(A11)
70    WRITE(ICON,155)NAME3
155   FORMAT(/5X,'NAME READ IS:   ',A11/,
     $ 5X,'IS THIS NAME CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 31
      IF(IFLAG.EQ.0)GO TO 65
      GO TO 70
31    ICOUNT=1
41    WRITE(ICON,160)
160   FORMAT(/5X,'THE STOCKPILE CRITERIA FILE'/)
      OPEN(MST3,FILE=NAME3,ACCESS='SEQUENTIAL',STATUS='OLD')
      READ(MST3,206,ERR=94)HEAD
206   FORMAT(A80)
```

```
        WRITE(ICON,206)HEAD
        I=2
45      READ(MST3,IFRMT2,END=30)B,DESCR
        WRITE(ICON,IFRMT2)B,DESCR
        I=I+1
        GO TO 45
        CLOSE(MST3)
30      RETURN
93      WRITE(ICON,165)
165     FORMAT(/5X,'OSF OPEN/READ ERROR IN ROUTINE STFILE')
        RETURN
92      WRITE(ICON,166)
166     FORMAT(/5X,'NSF OPEN/READ ERROR IN ROUTINE STFILE')
        RETURN
94      WRITE(ICON,167)
167     FORMAT(/5X,'CRITERIA FILE OPEN/READ ERROR IN ROUTINE STFILE')
        RETURN
        END
        SUBROUTINE CHECK2(IFLAG)
C-----------------------------------------------------------------------
        COMMON /FILES/ICON,MST1,MST2,MST3
C
        CHARACTER *1  IANS,UY,LY,UN,LN
        UY='Y'
        LY='y'
        UN='N'
        LN='n'
        IFLAG=2
        READ(ICON,200)IANS
200     FORMAT(A1)
C
        IF(IANS.EQ.UN .OR. IANS.EQ.LN)IFLAG=0
        IF(IANS.EQ.UY .OR. IANS.EQ.LY)IFLAG=1
        IF(IFLAG.LE.1)GO TO 20
        WRITE(ICON,105)
105     FORMAT(/5X,'COULD NOT RECOGNIZED YOUR RESPONSE')
20      RETURN
        END
        SUBROUTINE CRITER(VAR,NVAR,N)
C-----------------------------------------------------------------------
        COMMON /COUNT/ICOUNT,KOUNT
        COMMON /FILES/ICON,MST1,MST2,MST3
        COMMON /FN/HEAD1(7)
        COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
        DIMENSION A(5),B(9),VAR(8)
        DIMENSION ITON(20),ISUL(20),IASH(20),IBTU(20)
        CHARACTER NDAY*10,DESCR*10,NAME1*11,NAME2*11,NAME3*11,
     $  IFRMT1*70,IFRMT2*70,IFRMT3*70,HEAD1*6,HEAD*80
        DATA A/5*0.0/
        DATA NDAY/'          '/
        DATA DESCR/'          '/
        IFRMT1='(F3.0,1X,F6.2,3X,F5.2,3X,F5.2,2X,F5.2,4X,2A10)'
        IFRMT2='(F3.0,8F7.2,2X,A10)'
        IFRMT3='(1X,A2,2X,A5,3X,A6,3X,A3,3X,A5,4X,A6,7X,A4)'
C
C
C       ONCE STOCKPILE CRITERIA FILE IS OPENED NO NEED TO OPEN AGAIN
        IF(ICOUNT.GT.0)GO TO 30
10      WRITE(ICON,100)
100     FORMAT(/5X,'DO YOU HAVE A STOCKPILE CRITERIA FILE?'/,
     $  5X,'ENTER Y OR N ==> ',\)
        CALL CHECK2(IFLAG)
        IF(IFLAG.EQ.2)GO TO 10
        IF(IFLAG.EQ.1)GO TO 15
```

```
      WRITE(ICON,105)
105   FORMAT(/5X,'YOU MAST HAVE A STOCKPILE CRITERIA FILE IF YOU'/,
     $ 5X,'WANT THE PROGRAM TO SELECT THE STOCKPILE')
      RETURN
C
15    WRITE(ICON,110)
110   FORMAT(/5X,'NAME OF THIS FILE?'/,
     $ 5X,'NO MORE THAN 11 CHARACTERS LONG ==> ',\)
      READ(ICON,200)NAME3
200   FORMAT(A11)
25    WRITE(ICON,115)NAME3
115   FORMAT(/5X,'NAME READ IS:   ',A11,/,
     $ 5X,'IS THIS NAME CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 30
      IF(IFLAG.EQ.0)GO TO 15
      GO TO 25
30    ICOUNT=1
      WRITE(ICON,116)
116   FORMAT(/5X,'THE STOCKPILE CRITERIA FILE'/)
      OPEN(MST3,FILE=NAME3,ACCESS='SEQUENTIAL',STATUS='OLD')
      READ(MST3,205,ERR=94)HEAD
      WRITE(ICON,205)HEAD
205   FORMAT(A80)
C     OPEN THE UPDATED STOCKPILE FILE
      OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $ STATUS='OLD',RECL=80)
C
C     GO THROUGH THE STOCKPILE CRITERIA FILE AND STOCKPILE FILE
C     TO SELECT STOCKPILE FOR MATERIAL ADDITION
      IC=1
      IB=1
      IDD=1
      IE=1
      DO 45 I=1,N
      IP1=I+1
      READ(MST3,IFRMT2,END=50)B,DESCR
      READ(MST2,IFRMT1,REC=IP1)A,DESCR,NDAY
      WRITE(ICON,IFRMT2)B,DESCR
      SUMTON=A(2)+VAR(1)
      IF(SUMTON.GT.B(2))GO TO 41
      ITON(IC)=I
      IC=IC+1
41    IF(VAR(2).LT.B(5))GO TO 42
      IF(VAR(2).GT.B(4))GO TO 42
      ISUL(IB)=I
      IB=IB+1
42    IF(VAR(3).LT.B(7))GO TO 43
      IF(VAR(3).GT.B(6))GO TO 43
      IASH(IDD)=I
      IDD=IDD+1
43    IF(VAR(4).LT.B(9))GO TO 45
      IF(VAR(4).GT.B(8))GO TO 45
      IBTU(IE)=I
      IE=IE+1
45    CONTINUE
50    IC=IC-1
      IB=IB-1
      IDD=IDD-1
      IE=IE-1
C
      WRITE(ICON,120)
120   FORMAT(/5X,'INCOMING COAL SPECIFICATIONS'/,
     $ 5X,'----------------------------'/)
      DO 55 I=1,NVAR
      IP1=I+1
```

```
      WRITE(ICON,121)HEAD1(IP1),VAR(I)
121   FORMAT(8X,A8,' = ',F10.2)
55    CONTINUE
      WRITE(ICON,122)
122   FORMAT(/5X,'BASED ON STOCKPILE CRITERIA, FOLLOWING STOCKPILES'/,
     $ 5X,'ARE SELECTED FOR THE ABOVE INCOMING COAL'//,
     $ 8X,'VARIABLE',10X,'STOCKPILE NUMBER')
      WRITE(ICON,128)
128   FORMAT(/5X,'--------------------------------------------------')
C
      IP1=2
      IF(IC.GT.0)WRITE(ICON,123)HEAD1(IP1),(ITON(J),J=1,IC)
123   FORMAT(8X,A8,' : ',5X,20I3)
      IF(IC.LE.0)WRITE(ICON,124)HEAD1(IP1)
124   FORMAT(8X,A8,' : ',7X,'NONE')
      IP1=IP1+1
      IF(IB.GT.0)WRITE(ICON,123)HEAD1(IP1),(ISUL(J),J=1,IB)
      IF(IB.LE.0)WRITE(ICON,124)HEAD1(IP1)
      IP1=IP1+1
      IF(IDD.GT.0)WRITE(ICON,123)HEAD1(IP1),(IASH(J),J=1,IDD)
      IF(IDD.LE.0)WRITE(ICON,124)HEAD1(IP1)
      IP1=IP1+1
      IF(IE.GT.0)WRITE(ICON,123)HEAD1(IP1),(IBTU(J),J=1,IE)
      IF(IE.LE.0)WRITE(ICON,124)HEAD1(IP1)
      WRITE(ICON,128)
C
      CLOSE(MST2)
      CLOSE(MST3)
      RETURN
92    WRITE(ICON,166)
166   FORMAT(/5X,'NSF OPEN/READ ERROR IN ROUTINE STFILE')
      RETURN
94    WRITE(ICON,167)
167   FORMAT(/5X,'CRITERIA FILE OPEN/READ ERROR IN ROUTINE STFILE')
      END
      SUBROUTINE ADD(N)
C-----------------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /FN/HEAD1(7)
      COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
      COMMON /IVAR/NVAR,NVAR2
      DIMENSION A(5),VAR(8)
      CHARACTER NDAY*10,DESCR*10,NAME1*11,NAME2*11,NAME3*11,
     $ IFRMT1*70,IFRMT2*70,IFRMT3*70,HEAD1*6,DES*10,DAY*10
      DATA A/5*0.0/
      DATA NDAY/'          '/
      DATA DESCR/'          '/
      IFRMT1='(F3.0,1X,F6.2,3X,F5.2,3X,F5.2,2X,F5.2,4X,2A10)'
      IFRMT2='(F3.0,8F7.2,2X,A10)'
      IFRMT3='(1X,A2,2X,A5,3X,A6,3X,A3,3X,A5,4X,A6,7X,A4)'
      IDATE=9
C
C-----  CALL SUBROUTINE DATE20 TO REPORT UPDATED DATE
C
      CALL DATE20
      OPEN(IDATE,FILE='DATE20.DAT',ACCESS='SEQUENTIAL',STATUS='OLD')
      READ(IDATE,1001)DAY
1001  FORMAT(A10)
      CLOSE(IDATE)
C
      NVAR=4
      NVAR2=NVAR+1
C     CALL DATE(DAY)
```

```
25        WRITE(ICON,135)(HEAD1(JK),JK=2,NVAR2)
135       FORMAT(/5X,'ENTER AMOUNTS OF ',4(A6,' , ')/,
     $    5X,'WITH DECIMAL AND SEPARATED BY A COMMA OR A BLANK'/,
     $    5X,'==> ',\)
          READ(ICON,*)(VAR(I),I=1,NVAR)
          WRITE(ICON,137)
137       FORMAT(/5X,'VALUES READ ARE:'/)
          DO 26 I=1,NVAR
          IP2=I+1
          WRITE(ICON,136)HEAD1(IP2),VAR(I)
136       FORMAT(10X,A8,' = ',F10.2)
26        CONTINUE
27        WRITE(ICON,110)
110       FORMAT(/5X,'ARE THESE VALUES CORRECT?  ENTER Y OR N ==> ',\)
          CALL CHECK2(ICH)
          IF(ICH.EQ.1)GO TO 45
          IF(ICH.EQ.0)GO TO 25
          GO TO 27
45        WRITE(ICON,140)
140       FORMAT(/5X,'SELECT ONE '/,
     $    5X,'1    LET THE PROGRAM SELECT THE STOCKPILE DEPENDING'/,
     $    5X,'        ON THE STOCKPILE CRITERIA'/,
     $    5X,'2    USER SELECTS THE STOCKPILE REGARDLESS OF THE'/,
     $    5X,'        STOCKPILING CRITERIA'/,
     $    5X,'3    CHANGE OF HEART - DO NOT ADD COAL'//,
     $    5X,'YOUR SELECTION ==> ',\)
          READ(ICON,5)ISEL
5         FORMAT(BN,I5)
          IF(ISEL.EQ.1)GO TO 60
          IF(ISEL.EQ.2)GO TO 65
          IF(ISEL.EQ.3)RETURN
          WRITE(ICON,145)
145       FORMAT(/5X,'YOU MADE A MISTAKE MY FRIEND! '/,
     $    5X,'SELECT A NUMBER BETWEEN 1 AND 3')
          GO TO 45
C----     CHECK STOCKPILE CRITERIA FILE
60        CALL CRITER(VAR,NVAR,N)
62        WRITE(ICON,150)
150       FORMAT(/5X,'DO YOU WANT TO ADD COAL?  ENTER Y OR N ==> ',\)
          CALL CHECK2(IFLAG)
          IF(IFLAG.EQ.2)GO TO 62
          IF(IFLAG.EQ.1)GO TO 65
          RETURN
C
65        IFLAG=0
          IERR=0
          WRITE(ICON,151)
151       FORMAT(/5X,'TO WHICH STOCKPILE YOU WANT TO ADD? ==> ',\)
          READ(ICON,5)IS
          IF(IS.LT.1.OR.IS.GT.N)IERR=1
          IF(IERR.EQ.0)GO TO 70
          WRITE(ICON,155)
155       FORMAT(/5X,'THIS STOCKPILE DOES NOT EXIST.  WOULD YOU WISH TO'/,
     $    5X,'CREATE A NEW STOCKPILE ?   ENTER Y OR N ==> ',\)
          CALL CHECK2(IFLAG)
          IF(IFLAG.EQ.0)GO TO 65
          IS=N+1
          WRITE(ICON,162)IS
162       FORMAT(/5X,'THE NEW STOCKPILE NUMBER IS',I3)
          WRITE(ICON,160)
160       FORMAT(/5X,'DECRIPTION OF THIS NEW STOCKPILE?'/,
     $    5X,'NO MORE THAN 10 CHARACTERS LONG ==> ',\)
```

```
         READ(ICON,200)DES
200      FORMAT(A10)
         N=N+1
70       OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $   STATUS='OLD',RECL=80)
         IS=IS+1
         IF(IFLAG.LT.1)GO TO 74
         DO 72 I=2,5
         A(I)=0.
72       CONTINUE
         WRITE(MST2,IFRMT1,REC=IS,ERR=92)A,DESCR,NDAY
74       READ(MST2,IFRMT1,REC=IS,ERR=92)A,DESCR,NDAY
         A2=A(2)
         A3=A(3)
         A4=A(4)
         A5=A(5)
         NDAY=DAY
         A(2)=A(2)+VAR(1)
         IF(A(2).LE.0.)GO TO 75
         A(3)=(A3*A2+VAR(2)*VAR(1))/A(2)
         A(4)=(A4*A2+VAR(3)*VAR(1))/A(2)
         A(5)=(A5*A2+VAR(4)*VAR(1))/A(2)
75       IF(IFLAG.EQ.1)DESCR=DES
         IF(IFLAG.EQ.1)A(1)=FLOAT(N)
         WRITE(MST2,IFRMT1,REC=IS)A,DESCR,NDAY
         CLOSE(MST2)
         RETURN
92       WRITE(ICON,165)
165      FORMAT(/5X,'NSF OPEN/READ ERROR IN ROUTINE ADD')
         RETURN
         END


C>
         SUBROUTINE BLENDC(NNN)
C-------------------------------------------------------------
         COMMON /INOUT/IRD,IOUT,ISR,IDBG
         COMMON /FILES/ICON,MST1,MST2,MST3
         IRD=4
         ISR=5
         IOUT=6
         IDBG=7
C
         WRITE(ICON,100)
100      FORMAT(//5X,'WELCOME TO THE BLENDING PART OF THIS STOCKPILE',/,
     $   5X,'MANAGEMENT PROGRAM.  YOU HAVE 2 OPTIONS HERE:'//,
     $   5X,'     1)  BATCH MODE EXECUTION'/,
     $   5X,'     2)  INTERACTIVE MODE EXECUTION'//,
     $   5X,'BEFORE YOU DECIDE, WOULD YOU LIKE TO READ A BRIEF'/,
     $   5X,'INFORMATION ON THESE MODES?')
5        WRITE(ICON,105)
105      FORMAT(5X,'ENTER Y OR N ==> ',\)
         CALL CHECK2(IFLAG)
         IF(IFLAG.EQ.1)GO TO 10
         IF(IFLAG.EQ.0)GO TO 20
         GO TO 5
10       WRITE(ICON,110)
110      FORMAT(/5X,'BATCH MODE:'/,
     $   8X,'THE MULTI-OBJECTIVE PROGRAM FORMULATION MUST BE DONE'/,
     $   8X,'OUTSIDE OF THIS PROGRAM AND KEPT IN A DATA FILE.'/,
```

```
     $  8X,'THE FORMAT FOR PROGRAM FORMULATION IS GIVEN IN THE'/,
     $  8X,'PROGRAM MANUAL.'//,
     $  5X,'INTERACTIVE MODE:'/,
     $  8X,'IN THIS MODE, THE PROGRAM WILL USE THE COAL STOCKPILE'/,
     $  8X,'FILE CREATED OR UPDATED PREVIOUSLY: THUS, RESTRICTING'/,
     $  8X,'THIS MODE FOR SOLVING COAL BLENDING PROBLEMS ONLY,'/,
     $  8X,'WHERE AS IN THE BATCH MODE ANY LINEAR GOAL PROGRAMMING'/,
     $  8X,'PROBLEM CAN BE SOLVED.'/)
C
20      IERR=0
        WRITE(ICON,115)
115     FORMAT(/5X,'SELECT ONE BY ENTERING EITHER 1, 2, OR 3'/,
     $  8X,'1   BATCH MODE'/,
     $  8X,'2   INTERACTIVE MODE'/,
     $  8X,'3   DO NOTHING:  SEND ME BACK TO MAIN MENU'//,
     $  5X,'YOUR SELECTION ==> ',\)
        READ(ICON,6)ISEL
6       FORMAT(BN,I5)
        IF(ISEL.LT.1.OR.ISEL.GT.3)IERR=1
        IF(IERR.EQ.1)WRITE(ICON,120)
        IF(IERR.EQ.1)GO TO 20
120     FORMAT(/5X,'YOU MADE A MISTAKE MY FRIEND! '/,
     $  5X,'SELECT A NUMBER BETWEEN 1 AND 3')
        ISEND=0
        IF(ISEL.EQ.1)CALL BATCHM(ISEND)
        IF(ISEND.GT.0)GO TO 20
        IF(ISEL.EQ.2)CALL INACTM(NNN)
        RETURN
        END
        SUBROUTINE BATCHM(ISEND)
C-----------------------------------------------------------------------
        COMMON /FILES/ICON,MST1,MST2,MST3
        COMMON /INOUT/IRD,IOUT,ISR,IDBG
        COMMON /FNAME/BNAME,OTNAME,DBNAME,INAME
        CHARACTER *11 BNAME,OTNAME,DBNAME,INAME
5       WRITE(ICON,100)
100     FORMAT(/5X,'DO YOU HAVE A FILE THAT CONTAINS PROGRAM ',
     $  'FORMULATION?'/,5X,'ENTER Y OR N ==> ',\)
        CALL CHECK2(IFLAG)
        IF(IFLAG.EQ.1)GO TO 20
        IF(IFLAG.EQ.0)GO TO 10
        GO TO 5
10      WRITE(ICON,105)
105     FORMAT(/5X,'YOU MUST HAVE SUCH A FILE FOR BATCH MODE EXECUTION')
        ISEND=1
        RETURN
C
20      WRITE(ICON,110)
110     FORMAT(/5X,'NAME OF YOUR FORMULATION FILE'/,
     $  5X,'(NO MORE THAN 11 CHARACTERS) ==> ',\)
        READ(ICON,200)BNAME
200     FORMAT(A11)
25      WRITE(ICON,115)BNAME
115     FORMAT(/5X,'NAME READ IS:  ',A11/,
     $  5X,'IS THIS NAME CORRECT?  ENTER Y OR N ==> ',\)
        CALL CHECK2(IFLAG)
        IF(IFLAG.EQ.1)GO TO 30
        IF(IFLAG.EQ.0)GO TO 20
        GO TO 25
C
30      OPEN(IRD,FILE=BNAME,ACCESS='SEQUENTIAL',STATUS='OLD')
        CLOSE(IRD)
        CALL CHKIN(IDBUG)
        CALL PRGOAL(BNAME,IDBUG,1)
        CALL CHKOUT(IDBUG)
        RETURN
```

```
90      WRITE(ICON,120)
120     FORMAT(/5X,'THE FILE NAME YOU SELECTED DOES NOT EXIST!')
        GO TO 5
        END
        SUBROUTINE PRGOAL(DNAME,IDBUG,IBATCH)
C-----------------------------------------------------------------
        DIMENSION PRDT(60),KPCK(60)
        COMMON /FILES/ICON,MST1,MST2,MST3
        COMMON /INOUT/IRD,IOUT,ISR,IDBG
        CHARACTER *11 DNAME
C
        OPEN(IRD,FILE=DNAME,ACCESS='SEQUENTIAL',STATUS='OLD')
        CALL START(N,M,L,PRDT,KPCK,TEST,KEROR,IDBUG)
        IF(KEROR.GT.0)GO TO 10
        CALL GOAL(N,M,L,PRDT,KPCK,TEST,IBATCH,IDBUG)
10      CLOSE(IRD)
        CLOSE(IOUT)
        CLOSE(IDBG)
        RETURN
        END
C
        SUBROUTINE GOAL(N,M,L,PRDT,KPCK,TEST,IBATCH,IDBUG)
        DIMENSION Y(60),PRDT(60),AMT(60),ZVAL(60),DOD(60),DUD(60),
     $  X(125),D(60,125)
        COMMON /PARA/KEPT(60),RHS1(60),VALY(60,10),
     $  C(60,125),VALX(10,125),RVLX(10,125)
        COMMON /INOUT/IRD,IOUT,ISR,IDBG
C
C       GOAL PROGRAMMING
C
C
C
        DO 21 J=1,M
21      X(J)=J
        DO 20 J=1,N
20      Y(J)=J
        DO 25 K=1,L
        DO 25 J=1,N
        VALY(J,K)=VALX(K,J)
25      CONTINUE
        ITAB=0
        ITER=0
C
C-----  BRING IN NEW VARIABLE AND CALCULATE NET CONTRIBUTION OF
C-----  EACH VARIABLE (RVLX(K,J))
C
31      L1=0
32      K3=L-L1
33      IF(K3.LT.1)GO TO 800
40      DO 60 K=1,K3
        DO 60 J=1,M
        SUMP=0.
        DO 50 I=1,N
        P=VALY(I,K)*C(I,J)
        SUMP=SUMP+P
50      CONTINUE
        RVLX(K,J)=SUMP-VALX(K,J)
60      CONTINUE
        ITER=ITER+1
C
C----   BRING IN X(K2)
C
        ZMAX=0.
        DO 90 J=1,M
        IF(K3.GE.L)GO TO 70
        K4=K3+1
```

```
      DO 91 K=K4,L
      IF(RVLX(K,J).LT.O.)GO TO 90
91    CONTINUE
70    RZ=RVLX(K3,J)-ZMAX
      IF(RZ.LE.O.)GO TO 90
      ZMAX=RVLX(K3,J)
      K2=J
90    CONTINUE
95    IF(ZMAX.LE.O.)GO TO 790
C
C-----  WHICH VARIABLE IS REMOVED FROM THE BASIS
C-----  CALCULATE LIMITING AMT FOR EACH BASIS VARIABLE
C
      DO 150 I=1,N
      IF(PRDT(I).GE.O.)GO TO 120
      IF(IDBUG.GT.O)WRITE(IDBG,13)PRDT(I)
13    FORMAT(8F9.0)
      GO TO 830
120   IF(C(I,K2).GT.O.)GO TO 140
      AMT(I)=-1.0
      GO TO 150
140   AMT(I)=PRDT(I)/C(I,K2)
150   CONTINUE
C
C-----  SELECT SMALLEST POSITIVE LIMITING AMT
C
      I=1
160   IF(AMT(I).GE.O.)GO TO 210
      I=I+1
      IF(I.LE.N)GO TO 160
      IF(IDBUG.GT.O)WRITE(IDBG.13)AMT(N)
      GO TO 830
210   ZMIN=AMT(I)
      K1=I
220   I=I+1
      IF(I.GT.N)GO TO 300
      IF(AMT(I).LT.O.)GO TO 220
      IF(ZMIN-AMT(I))220.220.210
C
C-----  REMOVE Y(K1)
C
300   Y(K1)=X(K2)
      DO 310 K=1.L
      VALY(K1,K)=VALX(K,K2)
310   CONTINUE
C
C-----  CALCULATE NEW R.H.S.
C
      DO 400 I=1,N
      PRDT(I)=PRDT(I)-ZMIN*C(I,K2)
400   CONTINUE
      PRDT(K1)=ZMIN
C
C-----  CALCULATE NEW SUBSTITUTION RATES
C
      DO 500 J=1,M
      DO 500 I=1,N
      D(I,J)=C(I,J)-C(K1,J)*(C(I,K2)/C(K1,K2))
500   CONTINUE
      DO 510 J=1.M
      D(K1,J)=C(K1,J)/C(K1,K2)
510   CONTINUE
      DO 520 J=1,M
      DO 520 I=1,N
      C(I,J)=D(I,J)
520   CONTINUE
```

```
C
C-----  WRITE ALL TABLES OR JUST OPTIMAL TABLE
C
        IF(ITAB.LE.0)GO TO 40
C
C-----  WRITE EACH TABLE
C
        IF(IDBUG.EQ.0)GO TO 40
        DO 610 I=1,N
        WRITE(IDBG,13)Y(I),PRDT(I)
610     CONTINUE
        DO 620 I=1,N
        WRITE(IDBG,12)(C(I,J),J=1,M)
12      FORMAT(10F8.3)
620     CONTINUE
        GO TO 40
C
C-----  MOVE TO NEXT LOWER PRORITY LEVEL
C
790     L1=L1+1
        GO TO 32
C
C-----  WRITE FINAL RESULTS
C
        IF(IDBUG.EQ.0)GO TO 819
800     WRITE(IDBG,1014)ITER
1014    FORMAT(10X,'NUMBER OF ITERATIONS.....',I5)
C       WRITE(IDBG,1015)
        WRITE(IDBG.5000)
5000    FORMAT(//25X,'THE SIMPLEX SOLUTION'//)
        WRITE(IDBG,5001)
5001    FORMAT(' THE RIGHT HAND SIDE'/)
801     DO 810 I=1,N
        WRITE(IDBG,13)Y(I),PRDT(I)
810     CONTINUE
        WRITE(IDBG.5002)
5002    FORMAT(' THE SUBSTITUTION RATES '/)
811     DO 812 I=1,N
        WRITE(IDBG,12)(C(I,J).J=1,M)
812     CONTINUE
        WRITE(IDBG.5003)
5003    FORMAT(' THE ZJ-CJ MATRIX'/)
813     DO 814 K=1,L
        WRITE(IDBG,12)(RVLX(K.J),J=1,M)
814     CONTINUE
C
C-----  EVALUATE OBJECTIVE FUNCTION
C
819     DO 820 K=1,L
        ZVAL(K)=0.
        DO 820 I=1,N
        ZVAL(K)=ZVAL(K)+PRDT(I)*VALY(I,K)
820     CONTINUE
        IF(IDBUG.GT.0)WRITE(IDBG,5004)
5004    FORMAT(' AN EVALUATION OF THE OBJECTIVE FUNCTION'/)
        DO 821 K=1.L
        KK=L-K
        IF(TEST.EQ.1.0)GO TO 89
        KK=KK+1
89      IF(IDBUG.GT.0)WRITE(IDBG.15)KK.ZVAL(K)
15      FORMAT(I3.F12.2)
821     CONTINUE
        CALL FINISH(PRDT,L,KPCK,Y.N,TEST,IBATCH)
830     RETURN
        END
```

```
      SUBROUTINE START(NROWS,NVAR,NPRT,RHS,KPCK,TEST,KEROR,IDBUG)
C-----------------------------------------------------------------------
C     THE START SUBROUTINE IS DESIGNED TO TAKE INFORMATION IN A
C     SPECIFIED FORMAT AND TRANSFORMED IT INTO A SERIES OF
C     USABLE MATRICES.
C-----------------------------------------------------------------------
      DIMENSION EQUALS(60),RHS(60)
      COMMON /PARA/KEPT(60),RHS1(60),VALY(60,10),
     $ C(60,125),VALX(10,125),RVLX(10,125)
      COMMON /INOUT/IRD,IOUT.ISR,IDBG
      CHARACTER *80 TITLE
      CHARACTER *1 EQUALS,B,E,G,L
      CHARACTER *4 DATA,OBJ,PROB,RGHT,ANAME,POS,NEG
C
      DATA POS,NEG/'  P ','  N '/
      DATA DATA,OBJ,PROB,B,E,G,L/'DATA','OBJ ','PROB','B','E',
     $ 'G','L'/
      DATA RGHT/'RGHT'/
      TEST=0.0
      NV=125
      NR=60
C
C------ READ THE PROBLEM CARD FOR THE NUMBER OF ROWS, VARIABLES,
C------ AND OTHER PARAMETERS
C
      READ(IRD,3)TITLE
3     FORMAT(A80)
10    READ(IRD,1)ANAME,NROWS.NVAR,NPRT
1     FORMAT(A4.3I3)
      LISP=NPRT+1
      IF(NVAR.LE.0 .OR. NPRT.LE.0 .OR. NROWS.LE.0)GO TO 1020
      IF(ANAME.NE.PROB)GO TO 901
C
C------ READ THE SIGN CARD.
C------ IT WILL CONTAIN ONE OF THE FOLLOWING LETTERS FOR EACH ROW
C------ FOR EQUALS                      E
C------ FOR LESS THAN OR EQUAL TO       L
C------ FOR GREATER THAN OR EQUAL TO    G
C------ FOR BOTH DEVIATIONS             B
C
      READ(IRD,11)(EQUALS(I),I=1,NROWS)
11    FORMAT(60A1)
      NART=0.0
C
C-----  COUNT THE NUMBER OF POSITIVE SLACK VARIABLES
C
      NFLDS=0
      DO 12 I=1,NROWS
      IF(EQUALS(I).EQ.B)NFLDS=NFLDS+1
      IF(EQUALS(I).EQ.G)NFLDS=NFLDS+1
12    CONTINUE
C
C------ TEST FOR SIZE
C
      NSIZE=NFLDS+NROWS+NVAR
      IF(NROWS.GT.NR)GO TO 911
      IF(NSIZE.GT.NV)GO TO 911
C
C------ CLEAR ALL MATRICES
C
      KDUD=NPRT+1
      DO 16 J=1,NSIZE
      DO 16 I=1,NROWS
      KEPT(I)=0
      IF(I.GT.KDUD)GO TO 17
```

```
      K=I
      RVLX(K,J)=0.0
      VALX(K,J)=0.0
17    IF(I.EQ.J)C(I,J)=1.
      VALY(I,K)=0.0
      IF(I.NE.J)C(I,J)=0.0
16    CONTINUE
      KPCK=0
       K=KDUD
C
C------ ADJUST THE SLACK VARIABLES AND OBJECTIVE FUNCTION TO MEET
C       THE REQUIRMENTS OF THE SIGN
C
      DO 13 I=1,NROWS
      IF(EQUALS(I).EQ.E)GO TO 14
      IF(EQUALS(I).EQ.G)GO TO 15
      IF(EQUALS(I).EQ.L)GO TO 13
      IF(EQUALS(I).EQ.B)GO TO 18
      GO TO 910
14    J=I
      VALX(K,J)=1.0
      NART=NART+1
      TEST=1.0
      KEPT(I)=J
      GO TO 13
15    KPCK=KPCK+1
      J=NROWS+KPCK
      C(I,J)=-1.0
      KEPT(I)=J
       J=I
      VALX(K,J)=1.0
      NART=NART+1
      TEST=1.0
      GO TO 13
18    KPCK=KPCK+1
      J=KPCK+NROWS
      C(I,J)=-1.0
      KEPT(I)=J
13    CONTINUE
C
C------ READ IN THE OBJECTIVE FUNCTION
C
      READ(IRD,21)ANAME
21    FORMAT(A4,2I5,F16.0)
19    I=0
      IF(ANAME.NE.OBJ)GO TO 920
20    READ(IRD,21)ANAME,I,M,TEMP
      IF(ANAME.EQ.DATA)GO TO 30
      IF(M.LE.0)GO TO 1022
      K=LISP-M
      IF(J.LE.0)GO TO 1022
      IF(K.GT.NPRT)GO TO 1024
      IF(ANAME.EQ.NEG)GO TO 26
      IF(ANAME.EQ.POS)GO TO 25
      GO TO 27
26    J=I
      VALX(K,J)=TEMP
      GO TO 20
25    J=KEPT(I)
      IF(KEPT(I).EQ.0)GO TO 1026
      VALX(K,J)=TEMP
      GO TO 20
27    IF(TEMP.EQ.0.)GO TO 20
```

```
C
C------ READ THE DATA MATRIX IN
C
30      READ(IRD,21)ANAME,I,J,TEMP
        IF(ANAME.EQ.RGHT)GO TO 40
        IF(I.LE.0)GO TO 1090
        IF(J.EQ.0)GO TO 1090
        J=KPCK+NROWS+J
        C(I,J)=TEMP
        GO TO 30
C
C------ READ THE RIGHT HAND SIDE
C
40      READ(IRD,44)(RHS(I),I=1,NROWS)
44      FORMAT(8F10.0)
C
C------ WRITE THE ABOVE RESULTS
C
        IF(IDBUG.GT.0)WRITE(IDBG,5015)
5015    FORMAT(//25X,'THE RIGHT HAND SIDE-INPUT'/)
        DO 41 I=1,NROWS
        IF(RHS(I))941,42,43
42      RHS(I)=0.00001
43      RHS1(I)=RHS(I)
        IF(IDBUG.GT.0)WRITE(IDBG,1111)I,RHS(I)
1111    FORMAT(25X,I3,2X,F15.5)
41      CONTINUE
C        IF(IDBUG.GT.0)WRITE(IDBG,620)
        IF(IDBUG.GT.0)WRITE(IDBG,5016)
5016    FORMAT(/25X,'THE SUBSTITUTION RATES-INPUT'/)
        DO 1112 I=1,NROWS
        IF(IDBUG.GT.0)WRITE(IDBG,2519)I
2519    FORMAT(1X,'ROW',I5)
1112    IF(IDBUG.GT.0)WRITE(IDBG,1113)(C(I,J),J=1,NSIZE)
1113    FORMAT(2(10F10.3/))
C        IF(IDBUG.GT.0)WRITE(IDBG,620)
        IF(IDBUG.GT.0)WRITE(IDBG,5017)
5017    FORMAT(/25X,'THE OBJECTIVE FUNCTION-INPUT'/)
        DO 1114 K=1,NPRT
        M=LISP-K
        IF(IDBUG.GT.0)WRITE(IDBG,2150)M
2150    FORMAT(25X,' PRIORITY',I5)
1114    CONTINUE
C        IF(IDBUG.GT.0)WRITE(IDBG,620)
        IF(IDBUG.GT.0)WRITE(IDBG,5018)
5018    FORMAT(/25X,'SUMMARY OF INPUT INFORMATION '/)
        NVAR=NSIZE
        IF(IDBUG.GT.0)WRITE(IDBG,2017)NROWS,NVAR,NPRT,NART
2017    FORMAT(10X,'NUMBER OF ROWS',11X,I5/,10X,'NUMBER OF VARIABLES',
     $  6X,I5,/,10X,'NUMBER OF PRIORITIES',5X,I5,/,10X,
     $  'ADDED PRIORITIES',9X,I5)
        IF(NART.GT.0)NPRT=NPRT+1
        RETURN
910     WRITE(IOUT,914)
914     FORMAT(' PROGRAM CONTAINS AN ERROR EITHER IN THE NUMBER OF',/,
     $  'ROWS OR IN THE SIGN CARD.  THE VALUE IS SOMETHING OTHER',/,
     $  'THAN E, G, OR L')
        KEROR=1
        GO TO 999
1090    WRITE(IOUT,1091)
1091    FORMAT(' IMPROPER DATA COLUMN OR ROW DEFINITION')
        KEROR=1
        GO TO 999
920     WRITE(IOUT,921)TEMP
921     FORMAT(' AN OBJECTIVE CARD WITH THE VALUE',F16.3,'IS FOUND'/,
     $  ' BUT INSTRUCTIONS AS TO WHICH DEVIATION HAS BEEN',/,
     $  ' NEGLECTED.  EXAMINE YOUR DATA')
```

```
      KEROR=1
      GO TO 999
1020  WRITE(IOUT,1021)
1021  FORMAT(' COLUMN VALUE OR PRIORITIES CANNOT BE EQUAL TO ZERO'/,
     $ ' UNDER ANY CIRCUMSTANCES')
      KEROR=1
      GO TO 999
1022  WRITE(IOUT,1023)
1023  FORMAT(' COLUMN VALUE OR PRIORITY VALUE IS EQUAL TO OR LESS'/,
     $ ' THAN ZERO')
      KEROR=1
      GO TO 999
911   WRITE(IOUT,912)
912   FORMAT(' THE NUMBER OF VARIABLES NEEDED TO COMPUTE THIS'/,
     $ ' PROGRAM IS TOO GREAT UNDER PRESENT DIMENSIONS.'/,
     $ ' CHANGE THIS RESTRICTION TO MEET YOUR NEEDS')
      KEROR=1
      GO TO 999
1026  WRITE(IOUT,1027)
1027  FORMAT(' ATTEMPT IS MADE TO MINIMIZE NON EXISTANT POSITIVE'/,
     $ 'DEVIATION')
      KEROR=1
      GO TO 999
1024  WRITE(IOUT,1025)
1025  FORMAT(' OBJ. FUNCTION PRIORITY EXCEEDS STATED NUMBER OF'/,
     $ ' PRIORITIES')
      KEROR=1
      GO TO 999
901   WRITE(IOUT,902)
902   FORMAT(' PROBLEM CARD MISSING OR MISTYPED')
      KEROR=1
      GO TO 999
926   WRITE(IOUT,927)
927   FORMAT(' A CARD IN THE OBJ. SECTION DEFINED SOME VALUE FOR'/,
     $ ' THE OBJ. FUNCTION BUT FAILED TO DEFINE WHETHER THIS'/,
     $ ' WAS TO APPLY TO THE POSITIVE OR NEGATIVE DEVIATION')
941   WRITE(IOUT,942)
942   FORMAT(' NEGATIVE VALUES ARE NOT ALLOWED ON THE R.H.S.'/,
     $ ' CORRECT PROBLEM BY MULTIPLYING ENTIRE CONSTRAINT'/,
     $ ' THROUGH BY MINUS ONE.')
      KEROR=1
999   RETURN
      END
      SUBROUTINE FINISH(RHS,NPRT,KPCK,Y,NROWS,TEST,IBATCH)
C-----------------------------------------------------------------------
      REAL NEGSLK
      DIMENSION ZVAL(10),RHS(60),Y(60),APSLK(60),ANSLK(60)
      COMMON /PARA/KEPT(60),RHS1(60),VALY(60,10),
     $ C(60,125),VALX(10,125),RVLX(10,125)
      COMMON /INOUT/IRD,IOUT,ISR,IDBG
      COMMON /TARG/NTUL,ITEM(60),LSTK(60),IDSTK(60),LG(60),
     $ NC,TV2(60)
      COMMON /TARG2/AITEM(10)
      CHARACTER *10 AITEM
C
C------ RHS1 IS THE RESERVED VECTOR OF RHS VALUES FROM THE BEGINNING.
C------ THE ENDING RHS VALUES ARE SUBTRACTED FROM THE BEGINNING ONES
C------ AND THE RESULT IS PLACED INTO THE APPROPRIATE SLACK COLUMN.
C------ THE REMAINDER OF THE VALUES ARE PRINTED ON PAGE TWO OF THE
C------ RESULTS.
C
C------ SLACK ANLYSIS
C
      DO 797 I=1,60
      TV2(I)=0.0
797   CONTINUE
```

```
      NEGSLK=0.0
      DO 19 I=1,NROWS
      NEGSLK=0.0
      POSSLK=0.0
       DO 11 J=1,NROWS
      M=Y(J)
      IF(I.EQ. M)GO TO 10
      IF(M.EQ.KEPT(I))GO TO 12
11    CONTINUE
      GO TO 13
10    NEGSLK=RHS(J)
      GO TO 13
12    POSSLK=RHS(J)
13    APSLK(I)=POSSLK
      ANSLK(I)=NEGSLK
C13    WRITE(IOUT,14)I,RHS1(I),POSSLK,NEGSLK
C14    FORMAT(10X,I3,3F20.5)
19    CONTINUE
C
C-----  VARIABLE AMOUNTS
C
      WRITE(IOUT,44)
44    FORMAT(//25X,'VARIABLE ANALYSIS'/)
      WRITE(IOUT,45)
45    FORMAT(20X,'VARIABLE',15X,'AMOUNT',//)
      DO 41 I=1,NROWS
      NCHCK=Y(I)-KPCK-NROWS
      IF(NCHCK.LE.0)GO TO 41
      WRITE(IOUT,43)NCHCK,RHS(I)
      DO 35 K=1,NC
      IF(NCHCK.EQ.K)TV2(K)=RHS(I)
35    CONTINUE
43    FORMAT(22X,I2,5X,F20.5)
41    CONTINUE
      IF(IBATCH.EQ.2)WRITE(IOUT,100)
100   FORMAT(//25X,'TARGET ACHIEVEMENT ANALYSIS'//,
     $ 1X,'GOAL',3X,'GOAL ITEM',10X,'TARGET (RHS)',3X,'LHS ABOVE ',
     $ 'TARGET',3X,'LHS BELOW TARGET'/)
      IF(IBATCH.EQ.1)WRITE(IOUT,105)
105   FORMAT(//25X,'TARGET ACHIEVEMENT ANALYSIS'//,
     $ 5X,'GOAL',5X,'TARGET (RHS)',5X,'LHS ABOVE ',
     $ 'TARGET',5X,'LHS BELOW TARGET'/)
      DO 200 I=1,NROWS
      IF(IBATCH.EQ.1)GO TO 195
      IF(ITEM(I).EQ.9)GO TO 210
      WRITE(IOUT,135)I,AITEM(ITEM(I)),RHS1(I),APSLK(I),ANSLK(I)
135   FORMAT(2X,I2,4X,A10,9X,F10.2,8X,F10.2,8X,F10.2)
      GO TO 200
210   DO 215 J=1,NTUL
      IF(LG(J).NE.I)GO TO 215
      WRITE(IOUT,136)I,AITEM(9),LSTK(J),RHS1(I),APSLK(I),ANSLK(I)
136   FORMAT(2X,I2,4X,A10,' STKPL ',I2,F10.2,8X,F10.2,8X,F10.2)
215   CONTINUE
      GO TO 200
195   WRITE(IOUT,140)I,RHS1(I),APSLK(I),ANSLK(I)
140   FORMAT(4X,I2,5X,F10.2,10X,F10.2,11X,F10.2)
200   CONTINUE
C
      WRITE(IOUT,50)
50    FORMAT(//,25X,'ANALYSIS OF THE OBJECTIVE',
     $ //20X,'PRIORITY',10X,'UNDER-ACHIEVEMENT'/)
      DO 77 K=1,NPRT
      ZVAL(K)=0.0
      DO 51 I=1,NROWS
51    ZVAL(K)=ZVAL(K)+VALY(I,K)*RHS(I)
```

```
      LISP=NPRT+1
      KK=LISP-K
      IF(TEST.EQ.0.0)GO TO 52
      KK=NPRT-K
      IF(KK.GT.0)GO TO 52
      IF(IDBUG.GT.0)WRITE(IDBG,78)ZVAL(K)
78    FORMAT(/,20X,'ARTIFICIAL',F20.5)
      GO TO 77
52    WRITE(IOUT,53)KK,ZVAL(K)
53    FORMAT(/,22X,I2,5X,F20.5)
77    CONTINUE
      RETURN
      END
      SUBROUTINE CHKOUT(IDBUG)
C-----------------------------------------------------------------
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /INOUT/IRD,IOUT,ISR,IDBG
      COMMON /FNAME/BNAME,OTNAME,DBNAME,INAME
      CHARACTER *11 BNAME,OTNAME,DBNAME,INAME
      CHARACTER *80 DUMMY
C
12    WRITE(ICON,100)
100   FORMAT(/5X,'DO YOU WISH TO SEE THE OUTPUT FILE?')
      WRITE(ICON,130)
130   FORMAT(/5X,'ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.0)GO TO 15
      IF(IFLAG.EQ.1)GO TO 14
      GO TO 12
14    OPEN(IOUT,FILE=OTNAME,ACCESS='SEQUENTIAL',STATUS='OLD')
5     READ(IOUT,110,END=10,ERR=90)DUMMY
      WRITE(ICON,110)DUMMY
110   FORMAT(A80)
      GO TO 5
10    CLOSE(IOUT)
15    IF(IDBUG.EQ.0)GO TO 30
22    WRITE(ICON,120)
120   FORMAT(/5X,'DO YOU WISH TO SEE THE DEBUG FILE?')
      WRITE(ICON,130)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 20
      IF(IFLAG.EQ.0)GO TO 30
      GO TO 22
20    OPEN(IDBG,FILE=DBNAME,ACCESS='SEQUENTIAL',STATUS='OLD')
25    READ(IDBG,110,END=26,ERR=91)DUMMY
      WRITE(ICON,110)DUMMY
      GO TO 25
26    CLOSE(IDBG)
30    RETURN
90    WRITE(ICON,140)OTNAME
140   FORMAT(/5X,'ERROR IN OPENING/READING OUTPUT FILE: ',A11)
      WRITE(ICON,145)
145   FORMAT(5X,'PROBABLE CAUSE: 1.  FILE NAME ERROR, OR'/,
     $ 21X,'2.  FILE NEVER CREATED!')
      RETURN
91    WRITE(ICON,150)DBNAME
150   FORMAT(/5X,'ERROR IN OPENING/READING DEBUG FILE: ',A11)
      WRITE(ICON,145)
      RETURN
      END
      SUBROUTINE INACTM(NNN)
C-----------------------------------------------------------------
      DIMENSION TECH(20,20),A(5)
      COMMON /FILES/ICON,MST1,MST2,MST3
      COMMON /INOUT/IRD,IOUT,ISR,IDBG
```

```
      COMMON /FNAME/BNAME,OTNAME,DBNAME,INAME
      COMMON /FRM/IFRMT1,IFRMT2,IFRMT3,NAME1,NAME2,NAME3
      COMMON /HERE1/NR,NP,NTAF,JPR(60),PWTS(60),TV(60),NRD(60)
      COMMON /TARG/NTUL,ITEM(60),LSTK(60),IDSTK(60),LG(60),
     $ NC,TV2(60)
      COMMON /TARG2/AITEM(10)
      COMMON /HERE2/TYDEV(60),DSIGN(60)
      CHARACTER *1 TYDEV,DSIGN
      CHARACTER *10 AITEM
      CHARACTER *11 BNAME,OTNAME,DBNAME,INAME,NAME2,NAME1,NAME3
      CHARACTER *80 DUMMY,TITLE
      CHARACTER *70 IFRMT1,IFRMT2,IFRMT3
      AITEM(1)='TONNAGE   '
      AITEM(2)='SULFUR    '
      AITEM(3)='ASH       '
      AITEM(4)='BTU       '
      AITEM(5)='MOISTURE  '
      AITEM(6)='VOLATILE M'
      AITEM(7)='FIXED-C   '
      AITEM(8)='COST/TON  '
      AITEM(9)='TON-LIMIT '
      AITEM(10)='          '
C
C
20    WRITE(ICON,100)
100   FORMAT(/5X,'INTERACTIVE INPUT DATA WILL BE STORED IN A FILE'/,
     $ 5X,'FOR POSSIBLE FUTURE USE.  NAME OF THIS FILE?'/,
     $ 5X,'(NO MORE THAN 11 CHARACTERS) ==> ',\)
      READ(ICON,'(A)')INAME
25    WRITE(ICON.115)INAME
115   FORMAT(/5X,'NAME READ IS:   ',A11/,
     $ 5X,'IS THIS NAME CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 30
      IF(IFLAG.EQ.0)GO TO 20
      GO TO 25
30    WRITE(ICON,118)
118   FORMAT(//14X,'PLEASE ENTER VALUES AS REQUESTED AND'/,
     $ 14X,'PLEASE READ ALL INSTRUCTIONS CAREFULLY.'/,
     $ 14X,'WHEN YOU SEE THE SYMBOL (D) PLEASE ENTER'/,
     $ 14X,'    THE VALUE WITH A DECIMAL POINT'//)
      WRITE(ICON,120)
120   FORMAT(/5X,'ENTER TITLE OF RUN ==> ',\)
      READ(ICON,'(A)')TITLE
C
C----  ALL CONSTRAINTS AND OBJECTIVE FUNCTION WILL BE TREATED AS GOALS
C----  NUMBER OF GOALS = NUMBER OF ROWS IN THE PROBLEM
C
31    WRITE(ICON,126)
126   FORMAT(/5X,'ENTER NO. OF COAL SUPPLIERS (I.E. NO. OF'/,
     $ 5X,'STOCKPILES) TO BE USED IN THE FORMULATION ==> ',\)
      READ(ICON,5)NC
14    WRITE(ICON,160)
160   FORMAT(/5X,'NEXT INPUT ITEM IS THE STOCKPILE ID #.  WOULD YOU'/,
     $ 5X,'QUICKLY LIKE TO SEE THE STOCKPILE FILES BEFORE YOU DECIDE?',
     $ /5X,'ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 18
      IF(IFLAG.EQ.0)GO TO 19
      GO TO 14
18    CALL STFILE(NNN,4)
19    WRITE(ICON,162)
162   FORMAT(/5X,'ENTER THE STOCKPILE ID #'/,
     $ 5X,'SEPERATED BY COMMA OR BLANK ==> ',\)
      READ(ICON,*)(IDSTK(I),I=1,NC)
C
```

```
33      WRITE(ICON,125)
125     FORMAT(/5X,'ENTER NO. OF GOALS (ROWS) ==> ',\)
        READ(ICON,5)NR
5       FORMAT(BN,I5)
        WRITE(ICON,161)
161     FORMAT(/5X,'GOAL ITEMS:  1  TONNAGE',13X,'2  SULFUR'/,
     $  18X,'3  ASH',17X,'4  BTU'/,18X,'5  MOISTURE',
     $  12X,'6  VOLATILE MATTER'/,18X,'7  FIXED CARBON',
     $  8X,'8  COST/TON'/,18X,'9  TONNAGE USAGE LIMITATION'//,
     $  5X,'ENTER GOAL ITEMS (INTEGER NO.) TO BE CONSIDERED IN'/,
     $  5X,'THIS FORMULATION IN ORDER OF PREFERENCE.')
        WRITE(ICON,116)
116     FORMAT(5X,'IF YOUR FORMULATION HAS MORE THAN ONE TONNAGE'/,
     $  5X,'USAGE LIMITATION GOAL THEN ENTER THE INTEGER 9 IN THE'/,
     $  5X,'RESPECTIVE PREFERENCE ORDER.  (# GOAL ITEMS = # GOALS)'/)
        WRITE(ICON,119)
119     FORMAT(5X,'ENTER VALUES SEPERATED BY COMMA OR BLANK ==> ',\)
        READ(ICON,*)(ITEM(I),I=1,NR)
        WRITE(ICON,128)
128     FORMAT(/5X,'ENTER THE CORRESPONDING TARGET (R.H.S) VALUES (D)'/,
     $  5X,'(NO. OF TARGET VALUES = NO. OF GOALS) ==> ',\)
        READ(ICON,*)(TV(I),I=1,NR)
C
        NTUL=0
        DO 12 I=1,NR
        IF(ITEM(I).NE.9)GO TO 12
        NTUL=NTUL+1
        LG(NTUL)=I
        WRITE(ICON,166)I
166     FORMAT(/5X,'GOAL',I3,' IS TONNAGE USAGE LIMITATION GOAL'/,
     $  5X,'ENTER THE RESPECTIVE STOCKPILE NUMBER ==> ',\)
        READ(ICON,5)LSTK(NTUL)
12      CONTINUE
        WRITE(ICON,129)
129     FORMAT(/5X,'GOAL DEVIATION SIGN'/,
     $  5X,'E  FOR EXACTLY EQUAL.  NO DEVIATION IN EITHER DIRECTION.'/,
     $  5X,'G  FOR GREATER THAN.  ONLY THE POSITIVE DEVIATION FROM'/,
     $  5X,'   THE RIGH HAND SIDE.'/,
     $  5X,'L  FOR LESS THAN.  ONLY THE NEGETIVE DEVIATION FROM'/,
     $  5X,'   THE RIGHT HAND SIDE.'/,
     $  5X,'B  BOTH DIRECTIONS ARE POSSIBLE.  IT ALLOWS THE MINIMIZA',
     $  'TION'/,5X,'   OF EITHER OR BOTH THE NEGATIVE AND POSITIVE ',
     $  'DEVIATIONS'/,5X,'   FROM THE GOAL.'/)
        DO 32 I=1,NR
        WRITE(ICON,131)I
131     FORMAT(5X,'DEVIATION SIGN FOR GOAL ',I2,' ==> ',\)
        READ(ICON,7)DSIGN(I)
7       FORMAT(A1)
32      CONTINUE
C
        WRITE(ICON,130)NR,NC,(IDSTK(I),I=1,NC)
130     FORMAT(/5X,'YOUR INPUT SO FAR IS SUMMARIZED BELOW'//,
     $  5X,'NUMBER OF GOALS          = ',I10/,
     $  5X,'NUMBER OF SUPPLIERS      = ',I10/,
     $  5X,'SUPPLIERS ID NUMBER      = ',10I5)
        WRITE(ICON,133)
133     FORMAT(/5X,'GOAL',5X,'GOAL ITEM',9X,'DEVIATION SIGN',5X,
     $  'TARGET VALUE'/)
        DO 35 I=1,NR
        IF(ITEM(I).EQ.9)GO TO 36
        WRITE(ICON,135)I,AITEM(ITEM(I)),DSIGN(I),TV(I)
135     FORMAT(6X,I2,6X,A10,13X,A1,14X,F10.2)
        GO TO 35
36      DO 37 J=1,NTUL
        IF(LG(J).NE.I)GO TO 37
```

```
      WRITE(ICON,136)I,AITEM(9),LSTK(J),DSIGN(I),TV(I)
136   FORMAT(6X,I2,6X,A10,' STKPL ',I2,4X,A1,14X,F10.2)
37    CONTINUE
35    CONTINUE
34    WRITE(ICON,137)
137   FORMAT(/5X,'ARE THESE CORRECT?  ENTER Y OR N ==> ',\)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.0)GO TO 31
      IF(IFLAG.EQ.1)GO TO 45
      GO TO 34
C
C---- ACHIEVEMENT FUNCTION INPUT
C
45    WRITE(ICON,140)
140   FORMAT(/5X,'ACHIEVEMENT FUNCTION INPUT INFORMATION'//,
     $ 5X,'INPUT REQUIREMENTS ARE:'/,
     $ 5X,' 1)  NO. OF PRIORITY LEVELS,'/,
     $ 5X,' 2)  NO. OF TERMS IN ACHIEVEMENT FUNCTION, AND'/,
     $ 5X,' 3)  FOR EACH TERM THE FOLLOWING FOUR VALUES'/,
     $ 5X,'        i)  TYPE OF DEVIATION (N FOR NEGATIVE; P FOR ',
     $ 'POSITIVE)'/,
     $ 5X,'       ii)  GOAL (ROW) IN WHICH THIS DEVIATION APPEARS'/,
     $ 5X,'      iii)  PRIORITY LEVEL ASSOCIATED WITH THIS DEVIATION'/,
     $ 5X,'       iv)  WEIGHTING FACTOR FOR THIS DEVIATION')
C
      WRITE(ICON,127)
127   FORMAT(/5X,'ENTER NO. OF PRIORITY LEVELS ==> ',\)
      READ(ICON,5)NP
      WRITE(ICON,142)
142   FORMAT(/5X,'NO. OF TERMS IN ACHIEVEMENT FUNCTION ==> ',\)
      READ(ICON,*)NTAF
      IF(NTAF.GT.0)GO TO 50
      WRITE(ICON,141)
141   FORMAT(/5X,'NO. OF TERMS IN ACHIEVEMENT FUNCTION MUST BE'/,
     $ 5X,'GREATER THAN ZERO.')
      GO TO 45
50    DO 60 I=1,NTAF
      WRITE(ICON,143)I
143   FORMAT(/5X,'TYPE OF DEVIATION (P OR N) FOR TERM ',I2,' ==> ',\)
      READ(ICON,7)TYDEV(I)
      WRITE(ICON,144)
144   FORMAT(5X,'GOAL, PRIORITY, AND WEIGHT (D) ASSOCIATED WITH',
     $' THIS DEVIATION'/,5X,'VALUES SEPERATED BY COMMA OR BLANK ==> ',\)
      READ(ICON,*)NRD(I),JPR(I),PWTS(I)
C     WRITE(ICON,147)
C147  FORMAT(5X,'PRIORITY ASSOCIATED WITH THIS DEVIATION ==> ',\)
C     READ(ICON,*)JPR(I)
C     WRITE(ICON,148)
C148  FORMAT(5X,'WEIGHTS ASSOCIATED WITH THIS DEVIATION ==> ',\)
C     READ(ICON,*)PWTS(I)
8     FORMAT(BZ,F10.2)
60    CONTINUE
C
      WRITE(ICON,145)NP
145   FORMAT(/5X,'ACHIEVEMENT FUNCTION INPUT SUMMARY '//,
     $ 5X,'NUMBER OF PRIORITY      = ',I10,
     $ /5X,'TERM',3X,'DEVIATION',3X,'GOAL',3X,'PRIORITY',3X,'WEIGHTS'/)
      DO 65 I=1,NTAF
      WRITE(ICON,146)I,TYDEV(I),NRD(I),JPR(I),PWTS(I)
146   FORMAT(6X,I2,8X,A1,8X,I2,7X,I2,F12.2)
65    CONTINUE
C
46    WRITE(ICON,137)
      CALL CHECK2(IFLAG)
      IF(IFLAG.EQ.1)GO TO 47
      IF(IFLAG.EQ.0)GO TO 45
```

```
      GO TO 46
C
47    OPEN(ISR,FILE=INAME,ACCESS='SEQUENTIAL',STATUS='NEW')
C
      WRITE(ISR,150)TITLE
150   FORMAT(A80)
      WRITE(ISR,151)NR,NC,NP
151   FORMAT('PROB',3I3)
      WRITE(ISR,152)(DSIGN(I),I=1,NR)
152   FORMAT(20A1)
      WRITE(ISR,153)NTAF
153   FORMAT('OBJ',I7)
      DO 70 I=1,NTAF
      WRITE(ISR,154)TYDEV(I),NRD(I),JPR(I),PWTS(I)
154   FORMAT(2X,A1,3X,I3,2X,I3,1X,F10.2)
70    CONTINUE
      WRITE(ISR,157)
157   FORMAT('DATA')
      OPEN(MST2,FILE=NAME2,ACCESS='DIRECT',FORM='FORMATTED',
     $ STATUS='OLD',RECL=80)
      TE=1.0
      DO 72 I=1,NR
      IF(ITEM(I).EQ.9)GO TO 71
      DO 75 J=1,NC
      IREC=IDSTK(J)+1
      READ(MST2,IFRMT1,REC=IREC,ERR=91)A
      TECH(I,J)=A(1+ITEM(I))
      IF(ITEM(I).EQ.1)TECH(I,J)=1.0
C
C---- WRITE THE TECHNOLOGICAL COEFFICIENTS FROM STOCKPILE FILE
C
      WRITE(ISR,155)I,J,TECH(I,J)
155   FORMAT(4X,2I5,F10.2)
75    CONTINUE
      GO TO 72
71    DO 74 K=1,NTUL
      IF(LG(K).NE.I)GO TO 74
      WRITE(ISR,155)LG(K),LSTK(K),TE
74    CONTINUE
72    CONTINUE
C
      WRITE(ISR,156)(TV(I),I=1,NR)
156   FORMAT('RGHT'/,10F10.2)
C
      CLOSE(ISR)
      CLOSE(MST2)
80    WRITE(ICON,175)
175   FORMAT(/5X,'WHAT YOU WISH TO DO NOW?'//,
     $ 5X,'1   ADD OR DROP A SUPPLIER'/,
     $ 5X,'2   ADD OR DROP A GOAL'/,
     $ 5X,'3   MODIFY ACHIEVEMENT FUNCTION'/,
     $ 5X,'4   RUN THE PROGRAM FOR SOLUTION'/,
     $ 5X,'5   GO BACK TO MAIN MENU'/,
     $ 5X,'6   TERMINATE THIS SESSION'//,
     $ 5X,'YOUR SELECTION ==> ',\)
      READ(ICON,*)NSL
      IF(NSL.EQ.1)GO TO 31
      IF(NSL.EQ.2)GO TO 33
      IF(NSL.EQ.3)GO TO 45
      IF(NSL.GT.4)GO TO 82
      CALL CHKIN(IDBUG)
      CALL PRGOAL(INAME,IDBUG,2)
      CALL CHKOUT(IDBUG)
      WRITE(ICON,176)
176   FORMAT(/5X,'FINAL RESULTS OF THIS RUN'//,
     $ 5X,'STOCKPILE NUMBER',10X,'TONNAGE'/)
```

```
        DO 85 I=1,NC
        WRITE(ICON,177)IDSTK(I),TV2(I)
177     FORMAT(12X,I2,14X,F10.2)
85      CONTINUE
        GO TO 80
82      IF(NSL.EQ.6)CALL QUITT
        RETURN
90      WRITE(ICON,*)'INPUT FILE OPEN ERROR'
        RETURN
91      WRITE(ICON,*)'STOCKPILE FILE OPEN ERROR'
        RETURN
        END
        SUBROUTINE CHKIN(IDBUG)
C-----------------------------------------------------------------------
        COMMON /FILES/ICON,MST1,MST2,MST3
        COMMON /INOUT/IRD,IOUT,ISR,IDBG
        COMMON /FNAME/BNAME,OTNAME,DBNAME,INAME
        CHARACTER *11 BNAME,OTNAME,DBNAME,INAME
35      WRITE(ICON,116)
116     FORMAT(/5X,'OUTPUT FILE NAME ==> ',\)
        READ(ICON,'(A)')OTNAME
40      WRITE(ICON,115)OTNAME
115     FORMAT(/5X,'NAME READ IS:   ',A11/,
     $  5X,'IS THIS NAME CORRECT?  ENTER Y OR N ==> ',\)
        CALL CHECK2(IFLAG)
        IF(IFLAG.EQ.1)GO TO 45
        IF(IFLAG.EQ.0)GO TO 35
        GO TO 40
45      OPEN(IOUT,FILE=OTNAME,ACCESS='SEQUENTIAL',STATUS='NEW')
46      WRITE(ICON,117)
117     FORMAT(/5X,'DO YOU WANT DEBUG OUTPUT ?  ENTER Y OR N ==> ',\)
        CALL CHECK2(IDBUG)
        IF(IDBUG.EQ.0)RETURN
        IF(IDBUG.EQ.1)GO TO 50
        GO TO 46
50      WRITE(ICON,118)
118     FORMAT(/5X,'DEBUG FILE NAME ==> ',\)
        READ(ICON,'(A)')DBNAME
55      WRITE(ICON,115)DBNAME
        CALL CHECK2(IFLAG)
        IF(IFLAG.EQ.1) GO TO 60
        IF(IFLAG.EQ.0)GO TO 50
        GO TO 55
60      OPEN(IDBG,FILE=DBNAME,ACCESS='SEQUENTIAL',STATUS='NEW')
        RETURN
        END
```

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