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A MODEL TO ANALYZE THE COSTS OF STRIP MINING AND RECLAMATION

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A MODEL TO ANALYZE THE COSTS OF STRIP MINING AND RECLAMATION

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I. INTRODUCTION

The recent energy supply-demand imbalance has thrust coal into the forefront as a major energy source. Substantial quantities of the U.S. coal reserves are available through strip mining. Stripping with mobile equipment may be one method to expand the capacity of the coal mining industry in the short run and satisfy increasingly more rigid reclamation regulations as well. Data on the comparative cost of strip mining using different equipment in various pit and overburden situations are a fundamental requirement in evaluating new mining techniques and in making the decision by an operator to open a new mine.

The purpose of this paper is to describe a user oriented computer program for calculating the cost of mining and reclamation with various materials handling techniques and procedures in different pit configurations. Section II provides a basic overview of the strip mining process and problems encountered. Section III describes the mining cost program with emphasis on input data and procedures, the computation algorithm and the output. Section IV presents illustrative results from the analysis of the use of scrapers in various pit configurations. Finally, Section V summarizes the study and identifies other problems and policy issues that can be evaluated with the cost analysis program.

II. THE PROCESS OF STRIP MINING

Strip mining involves three basic processes - land acquisition and set up, mining and reclamation and surface revegatation. Although the following discussion will concentrate on the materials handling problems encountered in the mining and reclamation process, this broader view of strip mining is essential because government regulations as well as surface property right holders will force strip miners to consider the implications of different materials handling methods for future productivity of the surface. Consequently, we view strip mining as a systematic process of simultaneously removing overburden and coal and replacing the overburden in such a manner as to enable use of the surface in the production of agricultural or forest products.

As a materials handling problem, strip mining involves several tasks--removing topsoil, removing shale, removing and loading coal, replacing topsoil, etc. Several different machines, each with technical and economic advantages and disadvantages, may be used to perform the same task. Thus, removing overburden can be accomplished by a dozer, dragline, or power shovel. Furthermore, the same basic machine may perform several tasks--a bulldozer may remove trees, prepare a drill bench, rip rock, or level spoil. Hourly production and operating costs for the same machine will vary among different applications. Thus, total mining costs can be most accurately estimated by determining individual machine costs on a task by task basis. Criteria for the optimal mining plan and equipment set include minimizing the total task cost and maximizing equipment utilization.

In the simplest mining condition where one machine is used to remove all overburden, three steps are required to predict mining cost per ton of coal removed. First, tons of coal uncovered or volume of overburden moved per hour must be determined. Second, both hourly owning (fixed) costs and operating (variable) costs to operate the machine in each task must be determined. Finally, the per hour owning and operating cost for the machine must be divided by the tons of coal produced per hour to determine the machine cost per ton of coal produced. As additional operations or pieces of equipment are required, stripping and loading machine production must be matched to the capacity of support or haul vehicles. Machines should be matched to minimize total mining cost for the operations.

The optimal equipment combination must be selected from several matched feasible sets. This is accomplished by selecting the combination which provides the desired production under the most prevalent mining condition at the least cost, yet still has the capability to maintain production under the most adverse conditions encountered.

The cost of mining for a specific operator depends upon the overburden characteristics and pit configuration as well as the machine efficiency and operating characteristics in his mine. To facilitate accurate analysis of the unique problems encountered by different operators in different sites, a user oriented computer program to calculate mining and reclamation costs for different machines, pit configurations, and overburden characteristics has been developed. The process flow chart of Figure 1 outlines the logic and calculations which are used to evaluate various mining plans and materials handling procedures and determine their cost. The following discussion will review the basic structure of the model with emphasis on the input, computation algorithm and output procedures.

III. THE MINING COST PROGRAM

Input Data and Procedures

Two categories of input information are required to use the program. User specified information includes parameters unique to the user's problem--information on the mining plan such as proposed mine layout and haul roads, overburden characteristics, number of operators and shifts, and information on equipment to be considered. Program data base information includes technical specifications on equipment which is permanently stored in matrices and files. Overburden information such as densities and swell factors are also included in the program data base. Data necessary for calculations are recalled from this data base when needed. Table 1 identifies the required user specified input data and program data base information included in the model.[1]

The operator must identify the equipment he wants to evaluate and provide user input information on basic overburden characteristics. Program data base information on machines to be evaluated that are not already stored in matrices must also be inputted.

Output reliability is directly dependent on the accuracy of the mine plan and layout. For mine plans using mobile equipment, the mining engineer must provide information on haul roads, segment lengths, grades, and rolling resistances which portray actual mining conditions as accurately as possible. Different road segments and grades can be specified for each overburden strata removed by mobile units. For dragline or shovel operations, the maximum overburden thickness, pit width and casting distance must be specified within the actual capabilities of the machine to be evaluated.

The mine operator may input data on investment, machine life, fuel consumption, lubricant consumption and cycle time of his machines, if available. These values are super-imposed on the data stored in the program data base. Data base information is used as default values if user information is not specified.

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[1]Input forms are available for use upon request.

Figure 1. Process Flow Diagram

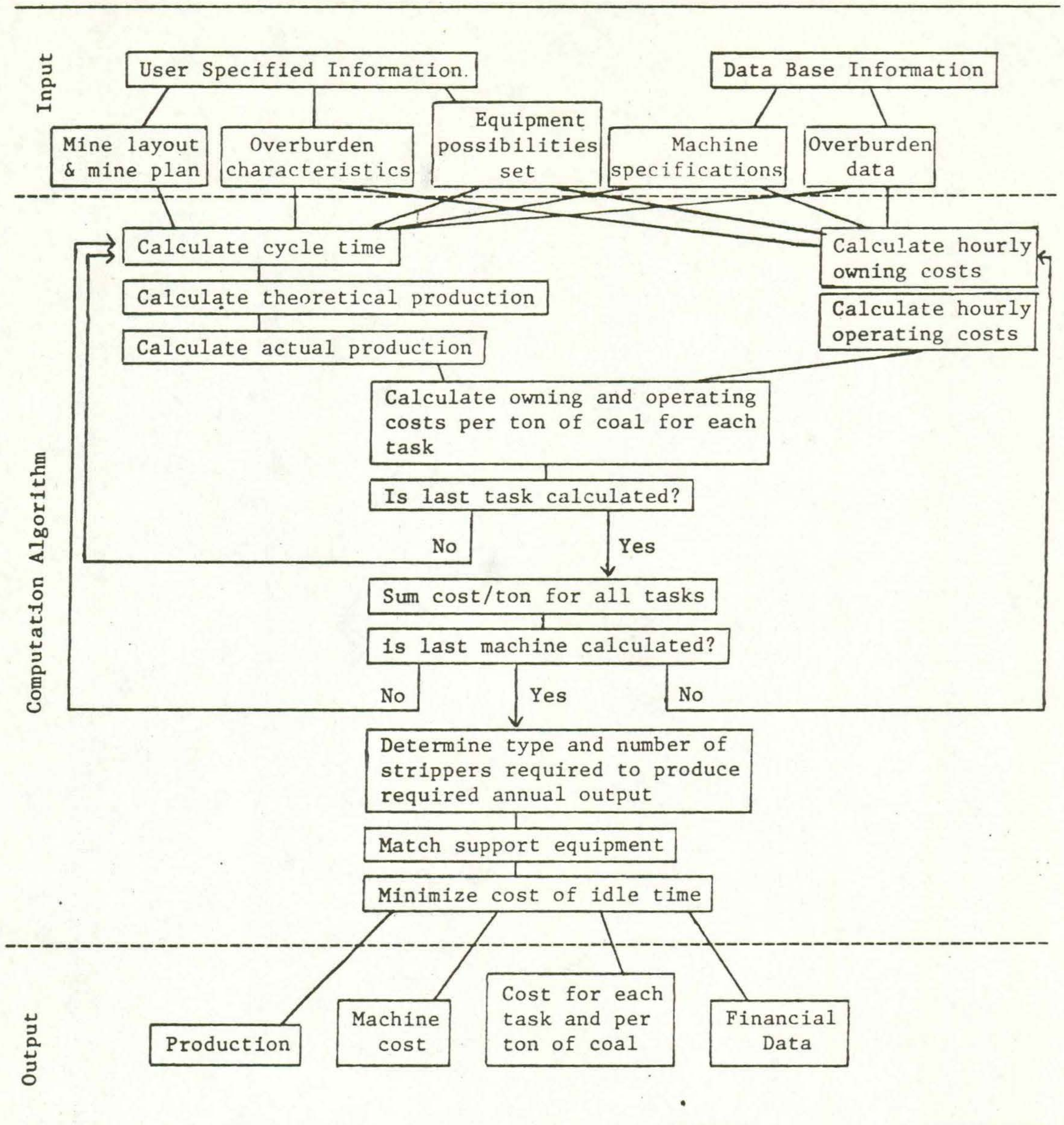

Table 1. User Specified and Data Base Information

User Specified Information	Data Base Information
1) Mine layout 2) Road grades segment lengths rolling resistances speed limits 3) Overburden number of strata type thickness hardness location of acid shale 4) Mining plan placement of soil stockpiles required placement order of strata location of drainage ditches characteristics of haul roads to be built blasting powder cost and requirements hole spacing 5) Equipment to be considered blade types self load, push load, or push-pull job efficiency mechanical availability other vehicle interference 6) Fuel and lubricant prices 7) Labor wage rate 8) Land lease or purchase charges 9) Coal seam thickness 10) Desired annual production	1) Density & swell factors 2) Machine model and description 3) Investment 4) Salvage value 5) Expected life in three working zones 6) Tires number needed replacement costs tire life in three working zones 7) Number of operators/shift 8) Fuel consumption in three working zones 9) Lubricant consumption 10) Specific items for specific machines Dragline bucket size cycle time casting distance bucket fill factors Drill penetrating speed bit life bit cost Bulldozers blade type and cost ripper, shank & tip life & cost maximum seismic velocity rippable dozing distance and production curve for each blade Mobile units (scrapers, trucks, loaders) shifting velocities rotating mass factor rimpull curve empty weight shifting time load capacity life and cost of bucket teeth bowl fill factors

Computation Algorithm

Once all data have been inputted, the computation algorithm begins data manipulations. The computation algorithm determines production and cost on a per ton of coal produced basis for each strata. This cost for each strata is then summed for all strata to determine the total cost per ton of coal.

Annual Production

The first computation involves the determination of production. First, the strip ratio of bank cubic yards (BCY) of overburden per ton of coal is calculated. This indicates how many total yards of material must be moved per unit of coal output. The second step is to determine the volume of each strata to be removed. This volume is calculated for each successive strata using equation 1.

$$(1)\quad B_s = S \cdot \frac{T_s}{T_t}$$

where:

B_s = bank cubic yards (BCY) of individual strata, s, per ton of coal

S = strip ratio in BCY of overburden per ton of coal produced

T_s = thickness in feet of the individual strata s

T_t = total overburden thickness in feet

Next expected theoretical production per hour for a given machine in a given strata of overburden is calculated by equation 2.

$$(2)\quad P^t_{si} = C_i \cdot \frac{60}{M_i} \cdot F_i \cdot \frac{1}{W_s}$$

where:

P^t_{si} = expected theoretical production in BCY/hour for machine i in strata s

C_i = machine bucket or bowl capacity in loose cubic yards for machine i

M_i = machine cycle time in minutes for machine i

F_i = fractional bucket fill factor for machine i in strata s

W_s = one plus fractional swell for strata s

Cycle time must be inputted directly for draglines and shovels. Cycle time for mobile units (scrapers, trucks or front end loaders) is calculated within the model using a program developed by Caterpillar Tractor Co. [5]. In the Caterpillar program, cycle time is calculated as a function of vehicle weight, grade and rolling resistance of haul road segments, length of each segment, rimpull, rimpull velocity, rotating mass factors, shifting time, load time, maneuver and dump time, and maximum speed limits on individual course segments. The bucket fill percentage from user input or the data base reflects the operator's own experience or manufacturer's recommendations. The BCY's of material to be moved must be adjusted by the swell factors for each strata to obtain an accurate measure of production.

Theoretical production is calculated for each individual strata using different bucket fill and swell factors and different cycle times for mobile units to reflect changes in haul distances and grades as the pit gets deeper.

Theoretical production represents the amount of material a machine could move in constant operation under ideal conditions. Several factors prevent the machine from achieving this production, thus requiring the derating of theoretical production to determine expected actual production. Actual production is calculated as:

$$(3)\quad P_s^a = P_s^t \cdot A_i \cdot J_i \cdot Q_i$$

where:

P_s^a = expected actual production in BCY/hour in strata s

P_s^t = expected theoretical production in BCY/hour in strata s

A_i = fractional machine mechanical availability for machine i

J_i = fractional job efficiency for machine i in strata s

Q_i = other machine specific efficiency factors (i.e., slot vs. straight dozing or load from stock pile vs. seam)

Mechanical availability measures the proportion of total operating hours when the machine is available to work. It represents the time when the machine is not "down" for repairs or periodic maintenance. Job efficiency derates the machine for such factors as operator efficiency, other vehicle interference and activities such as advancing a dragline on the face or a drill to a new hole. A common method to express job efficiency is to reduce the effective amount of time the machine works. Forty-five or fifty working minutes per hour would result in job efficiencies of 75 and 83 percent respectively.

Production from a given machine will also vary with its method of operation. A front end loader will be able to load more coal from a stock pile than directly from the seam. However, time must be allocated for the stock piling operations. Scrapers can load faster in well ripped material than in poorly ripped material. The machine specific efficiency factor allows the miner and the computation algorithm to adjust for these differences in machine use.

Machine Cost per Hour

Machine costs are composed of owning and operating costs. Owning costs basically encompass the fixed costs related to investment in the machine. Operating costs vary as the machine is used.

Ownership costs remain about the same regardless of amount of use. They include depreciation, interest on investment, property taxes, and insurance for liability, fire and theft and are computed as:

$$(4)\quad O_i^w = \frac{D_i + X_i + I_i + N_i}{H_i}$$

where:

O_i^w = owning costs/hour for machine i

D_i = annual depreciation (depreciable investment ÷ hours of life) for machine i

X_i = annual taxes for machine i

I_i = annual interest charge for machine i

N_i = annual insurance charge for machine i

H_i = annual hours of operation for machine i

Depreciation is an accepted accounting method to allocate the capital expenditure for a machine over the useful life of that machine. The straight line method is used in this analysis. Interest, taxes and insurance can be determined as a percent of initial or average investment [(original investment + salvage value)/2]. Initial investment includes the capital outlay for the base machine, extra or specialized equipment, shipping charges, unloading, and any set up costs at the job site. Shipping, unloading, and set up costs may be estimated as a percent of investment in the base machine. However, care must be exercised in selecting the appropriate percentage charges for these costs.

Interest is treated in this analysis as an opportunity cost, or what rate of return the funds invested in machinery could earn in their next best alternative. A market rate of return on one half of the average annual investment is commonly used to determine interest cost. However, this procedure does not reflect the true interest opportunity cost during the early years on large investments in new mining equipment. An alternative method is to calculate interest cost at the market rate on the non-depreciated investment. Both methods are used in this cost generator.

The economic life of the machine is needed to calculate hourly depreciation, repairs, maintenance, and supply cost. Useful life has a significant impact on hourly fixed costs. Severity of operation, use and wear, preventive maintenance, quality and timeliness of major repairs, weather, obsolescence, and quality and reliability of the machine as it comes from the manufacturer all have a direct influence on the economic life. Salvage or scrap value is necessary to calculate average investment used in the determination of interest, taxes and insurance costs.

Operating costs are variable costs which cease if production ceases. These costs are influenced by the severity of operating service, number of shifts the machine is working, repair part costs and mechanics wages, and quality of operating labor, supplies, fuel and lubricants. More specifically, operating costs per hour are calculated as:

$$(5)\quad O_i^p = E_i + L_i + K_i + G_i + R_i + Z_i$$

where:

O_i^p = operating cost per hour for machine i

E_i = fuel or power consumption per hour for machine i times price

L_i = filter cost and lubricant consumption for engine, transmission, final drives, hydraulics and grease for machine i times price per unit for each type of lubricant

K_i = labor wage per hour times number of operators per machine plus benefits for machine i

$G_i = \frac{\text{tire investment per set}}{\text{hours of use per set}}$ for machine i

R_i = repairs, maintenance, and supplies for machine i

Z_i = hourly costs specific for individual machines such as ripper shanks and teeth, drill bits and rods, bucket teeth and wire rope

Fuel or power and lubricant costs are determined by taking actual hourly fuel and lubricant consumption and multiplying by the current or estimated future price per gallon. Fuel consumption will vary with type of service for machines with several applications. For example, a dozer ripping constantly will consume more fuel than the base machine operating under normal dozing conditions.

The direct operating labor for each shift for each machine includes the operator, and oiler and ground men if necessary for different machines. Hourly wages are based on United Mine Workers labor contracts for each labor classification. The hourly rate includes overtime pay and all fringe benefits such as employer's contributions to benefit and trust funds.

Tires are a significant repair item on mobile units. Tire life depends on type of machine, material being handled, amount of slippage, and heat build up which is a function of load weight and speed. Tire life may range from 2,000 to 5,000 hours.

Items such as filters, bucket teeth, and wire ropes have more definite lives and service intervals, depending on operating conditions. Once life is estimated, the replacement cost is divided by the hours of life to determine an hourly operating charge.

Repairs, maintenance and supplies cover normal labor, parts and supplies for ordinary operation of the machine as well as provision for periodic overhaul. Again, costs vary widely depending on preventive maintenance, operator skill, quality of supervision, severity of service, manufacturing quality, and mechanical reliability. Repair history and operating cost experience is the most reliable guide to estimate annual repair costs, but this information is often not well documented by the operator. Consequently, a percentage of average investment is used to determine repairs, maintenance and supplies. Certainly, care must be exercised to select the appropriate percentage repair estimate to reflect increased repair and down-time losses as the machine becomes older.

Coal Cost Per Ton

Once hourly machine production and hourly owning and operating costs are determined for each strata, the cost per ton of coal to remove that strata is readily determined as:

$$(6)\quad \overline{O}_i^s = \frac{O_i^w + O_i^p}{P_s^a} \cdot B_s$$

where:

$\overline{O}_i^s$ = cost per ton of coal to remove an individual layer for machine i

O_i^w = owning costs per hour for machine i

O_i^p = operating cost per hour for machine i

P_s^a = expected actual production in BCY per hour in strata s

B_s = bank cubic yards (BCY) of individual strata, s, per ton of coal

After cost per ton of coal in each strata is determined, these costs are summed for all strata to determine the total cost of uncovering a ton of coal (equation 7):

$$(7)\quad \overline{O}_i = \sum_{s=i}^{n} \overline{O}_i^s$$

where:

$\overline{O}_i$ = total cost per ton to uncover coal for machine i

$\overline{O}_i^s$ = cost per ton of coal to remove an individual layer for machine i

By determining production and costs for each strata individually, the miner can adjust input data to most accurately reflect conditions in each overburden layer. Since production and costs will vary with overburden conditions, the model provides more accurate results by evaluating each strata separately and then determining a total cost per ton of coal removed.

In a well designed haulback method of strip mining, the amount of material rehandled will be minimized. Some material may have to be rehandled in the land reclamation phase. If rehandle production and operating conditions can be determined, the cost for rehandling can be readily determined and allocated to each ton of coal produced.

The cost to remove topsoil ahead of a dragline with scrapers and replace it on leveled dragline spoil can also be determined and added to the per ton cost. Total dragline production cost would then involve five tasks, remove and spread topsoil, prepare drill bench, drill and shoot, cast with the dragline, and level dragline spoil in preparation for topsoil spreading.

The basic three step methodology of determining hourly production, determining hourly owning and operating costs, then calculating production cost on the basis of a ton of coal is used for all machines. The procedure is easily understood and executed when a single unit such as a self-loading scraper is being used. When scrapers are push loaded, or trucks are filled with loaders, two types of vehicles must be matched for each production strata. Similarly in a dragline operation, dozer production for bench preparation and drilling and blasting must be matched to the dragline capacity.

Equipment Matching

Support equipment production must be matched to the production level of the primary stripper to minimize total mining cost. For example, a miner may want to load in one shift all the coal uncovered in three stripping shifts. The necessary loader and hauler production is determined by the output of the primary stripper.

Cycle times for machines working in various combinations are often longer than for the same machines working individually because machines are imperfectly matched. Mismatched machines often have a waiting time added to their cycle time. Therefore, total productivity is lower than would be possible under independent operation. To match stripper, loader and hauler equipment, the program calculates a match ratio for each combination of machines. The match ratio is calculated as (Number of haulers X loader cycle time)/(Number of loaders X hauler cycle time). Based on the match ratio, a waiting time efficiency is calculated for each machine using a program developed by the Caterpillar Tractor Company [4].

The waiting efficiency is a function of cycle time of each machine, availability, number of units, hourly cost for each machine, and production for one of the machines. Expected production for each combination of machines can then be calculated.

The optimally matched combination of machines should have the production capacity to exceed the minimum required production as well as high utilization efficiencies for all machines. The optimal combination is selected on the basis of minimizing the total cost of idle time for all types of machines in the combination. The cost of idle time for all machines is calculated as:

$$(8) \quad Y = \sum_{i=1}^{m} [A_i \cdot H_i \cdot U_i \cdot (1-V_i)][O_i^w + O_i^p]$$

where:

Y = annual cost of idle time

A_i = fractional machine mechanical availability for machine i

H_i = annual hours of operation for machine i

U_i = number of units of machine in in the combination

V_i = the waiting time efficiency of machine i ($1-V_i$ measures the amount of idle time)

O_i^w = owning cost per hour for machine i

O_i^p = operating cost per hour for machine i

The first term in equation (8) measures the annual amount of idle time for a given machine. Multiplying annual idle time by the owning and operation costs measures the direct cost for having that machine sit idle rather than being used to generate revenue through production. Minimizing the summation of the cost of idle time over the equipment set reflects the relative differences in idle time costs of more compared to less expensive machines. This provides a better measure of economic loss associated with idle time compared to physical measures of the same phenomenon.

Output Analysis

The model provides a wide range of information useful to the miner and mining engineer who are comparing and selecting equipment for a potential mine site. Theoretical and actual expected production allows the miner to compare output of machines working in a given pit design. Production information enables the mining engineer to evaluate production increases if he adds more equipment. Owning and operating costs per hour indicate relative costs to operate different machines as well as expected cash outflow while operating the mine. Itemized costs enable the miner to identify areas where costs may be reduced. Most interesting is the cost for individual tasks and total costs per ton of coal produced. The weighted cost per ton of coal directly indicates a break-even price the miner must receive for coal. The output tables also provide financial information useful to the mine operator including investment requirements and annual cash flow. Table 2 outlines the specific types of information printed in the output.

Table 2. Ouput Information.

Production	Machine Cost	Task Costs	Financial Data
Cycle time for each machine in each task	Owning cost for each machine in each task	Cost per unit of output for each machine in each task	Investment for each machine
Theoretical production for each machine in each task	Operating cost for each machine in each task	Cost per ton of coal for matched sets of machines	Total mine investment
Actual production for each machine in each task			Annual cash flow

IV. ILLUSTRATIVE RESULTS

To illustrate the type of information generated by the model, it was applied to mining a typical set of overburden conditions with mobile equipment. Table 3 summarizes the user input information on overburden thickness. It also shows the calculated bank cubic yards and tons of material in each strata. The strip ratio measures the bank cubic yards of all overburden per ton of coal. The following tables and output analysis are based on the overburden information in Table 3.

Table 3. Overburden Type, Thickness and Volume.

Type	Thickness	BCY per acre	Tons per acre
	(ft.)	(BCY)	(tons)
Earth	2.0	3,227	3,743
Clay and Gravel	10.0	16,133	25,813
Shale	58.0	93,573	202,118
Coal	3.0	4,840	5,227
Total	70.0	117,773	231,675

The strip ratio is 23.3/1.

Table 4. Haul Road Description and Cycle Time Calculations for Earth Removal Using a 38 Yard Scraper.

Road Segment	Distance	Rolling resistance	Grade	Accumulated time
	(Ft.)	(Percent)	(Percent)	(Minutes)
Haul Road				
1	50	2	-1	0.28
2	250	2	-8	0.46
3	830	2	0	0.80
4	260	2	0	0.97
Return Road				
1	260	2	0	0.21
2	830	2	0	0.56
3	250	2	8	0.71
4	50	2	1	0.99

Total haul time 0.97 minutes

Total return time 0.99

Total load time 0.60

Total dump time 0.70

Total cycle time 3.26

Haul and return distance 2780 feet

Table 4 summarizes the haulroad characteristics provided as input and the calculated travel time for each haul segment and total cycle time using a 38 yard caterpillar 641B as the primary stripping machine. Cycle times for each strata or change in haulroad within a given strata are calculated and printed separately. Printing each haulroad description input by the user allows him to verify his input for the total mining plan at a later date. Table 5 shows the theoretical and actual production of the scrapper in the earth strata. Since swell factors, efficiency factors and haul road will vary among strata, production will also change among strata.

The owning and operating costs incurred to remove the earth strata with the 38 yard scraper are indicated in Table 6. The net depreciable value is the initial investment in the machine less resale or salvage value and tire cost. Tire costs are itemized as an operating expense and are calculated by dividing tire replacement costs by expected tire life in the individual strata. The maximum annual use of 4080 hours represents a two shift operation. Operating costs are calculated on a per hour basis for individual items.

Table 5. Production Calculations for Earth Removal Using a 38 Yard Scraper.

Item	Value	Production/hour
Rated load	38 cubic yards	
Distance traveled	2780 feet	
Total cycle time	3.26 minutes	
Theoretical production		698.4 BCY/hour
Earth swell factor	1.25	
Bucket fill factor	90%	
Mechanical availability	85%	
Job efficiency	50 minutes/hour	
Actual production		356.2 BCY/hour

Calculating owning and operating costs independently for each strata allows the operator to reflect different machine and tire life, fuel consumption, repairs etc., in each strata, resulting in more accurate cost analysis. As indicated in Table 7, costs per BCY for each strata are weighted by the volume of each strata to determine the cost to uncover a ton of coal.

Table 7 also shows a comparison of two different scrapers operating in the same overburden characteristics and haul road course summarized in Table 4. Using the program an operator can evaluate cost data on various machines to assist in his machine selection decision. In this overburden and pit configuration the 38 yard Caterpillar 641B and the 20 yard 627 had the lowest and highest costs respectively to remove overburden of the scrapers compared.

Table 8 shows the cost per ton to uncover, load, and haul coal from the pit. Owning and operating costs per hour remain constant for the scraper throughout all strata because machine life, tire life, and all other machine cost items are assumed constant in this example. However, different swell factors and haul road conditions in each strata cause differences in production and thus differences in the cost per ton to remove each strata. Hourly production of loaders and haulers are determined by the matching routine discussed earlier. Cost per ton of coal to mine and reclaim is the sum of the costs incurred in each task.

To determine total cost to extract a ton of coal, costs for ripping or drilling and blasting, plus loading with a dozer, other dozer work, material rehandle for reclamation, and other tasks must be added. Cost analysis for these tasks are still being developed, and the matching process is being refined to match the equipment for these additional tasks to the primary stripper output.

Determining mining costs based on actual production is more useful than costs based on theoretical production. However, operators may be interested in costs based on theoretical production, particularly when theoretical data are already available on a given machine, or when the operator does not have appropriate efficiencies to derate theoretical production. Table 9 provides costs based on a theoretical basis comparable to the actual production cost data in Table 8. Note the significant difference in cost per ton for the two analysis methods.

Table 6. Cost Calculation for Earth Removal, 38 Yard Scraper.

Item	Value	
Owning costs		
Investment (38 yard scraper)	$256,882	
Resale value	0	
Tire costs	$ 25,644	
Net value for depreciation	$231,238	
Machine life	8,000 hrs.	
Hours used per year	4,080 hrs.	
Depreciation per hour	$28.90/hr.	
Interest, Insurance, taxes 10.5% of average annual investment	5.95/hr.	
Total Owning Cost Per Hour		$34.85
Operating Costs		
Labor	$8.77/hr.	
Fuel $0.35/gal. X 23.8 gal/hr.	8.33/hr.	
Lubricants-price x consumption		
Engine $3.00/ gal x $0.19 gal/hr = $0.57/hr.		
Transmission 3.00/ gal x 0.03 gal/hr = 0.09		
Final drive 2.00/ gal x 0.05 gal/hr = 0.10		
Hydraulic 3.00/ gal x 0.14 gal/hr = 0.42		
Grease 0.30/ lb x 0.10 gal/hr = 0.03		
Filter cost = 0.17		
Total lubricant costs	$1.38/hr.	
Tire costs		
Replacement cost of tires $25,644		
Tire life 2,500 hrs.		
Tire cost per hour	$10.26/hr.	
Repairs, maintenance and supplies	$17.00/hr.	
Total Operating Cost per hour		$45.74/hr.
Total Owning and Operating Costs per hour		$80.59/hr.
Cost per BCY of earth moved		$ 0.23/BCY
Cost per ton of coal produced to remove earth strata		$ 0.15/T.

Table 7. Cost Comparison to Remove Overburden Using 38 Yard and 20 Yard Scrapers.

Strata	Owning & operating costs/hr. (38 yard scraper)	Owning & operating costs/hr. (20 yard scraper)	Cost/ BCY (38 yard scraper)	Cost/ BCY (20 yard scraper)	Cost/ ton of coal (38 yard scraper)	Cost/ ton of coal (20 yard scrapper)
	($/hr.)	($/hr.)	($/BCY)	($/BCY)	($/T.)	($/T.)
Earth	$80.60	$59.61	$0.23	$0.30	$0.15	$0.19
Clay & Gravel	80.60	59.61	0.19	0.26	0.63	0.84
Shale	80.60	59.61	0.26	0.35	5.03	6.77
Total cost to uncover a ton of coal					$5.81/T.	$7.80/T.

Once particular types and sizes of equipment have been chosen based on the cost calculations, the final step is to determine the total number of machines needed to mine a specific site. The first step in matching equipment to a potential mine site is determining level of annual coal production. Time required by the primary stripper to uncover the desired amount of coal is calculated next. Hours of annual use per stripper and total stripping hours required determine the number of strippers needed. A double shift operation used for scrapers in this example reduces the number of machines, and therefore decreases initial investment for primary strippers. To minimize cost and idle time the production of the stripper must be matched to the production of the coal loader, which must then in turn be matched to the production of the trucks. As more tasks such as drilling and blasting, ripping, or push-loading are added, the matching process becomes increasingly complex.

Table 10 summarizes the equipment sets required to uncover and load coal from a 300,000 ton per year mine assuming two different strip ratios. The first mine in Table 10 shows a matched set of equipment to uncover and load 300,000 tons per year from a three foot seam of coal. Total machine investment, total owning costs, and total owning and operating costs are summarized. Total investment plus total operating costs indicate total cash outflow for the first year of operation. Owning and operating costs per ton of coal summed for all tasks indicates the cost per ton to uncover and load coal. Note that the coal loading operation has about ten times as much production per hour as the uncovering operation. Therefore, the scrapers must be operated about ten times as long. The smallest loader and smallest truck available to the solution were selected. If smaller trucks had been available, they may have been selected.

Many factors influence mine production. Among these are change in haul road distance, overburden thickness, type of overburden, conditions such as weather changing material handling characteristics, and changes in coal seam thickness. The second example in Table 10 illustrates the impact on the cost per ton of doubling coal seam thickness while maintaining overburden depth and characteristics used in previous examples. Only half as much overburden must be moved to uncover 300,000 tons of coal per year. Therefore, owning and operating costs to uncover the coal are only half of the three feet seam example. Since the same volume of coal must be loaded in both examples, coal loading costs are not reduced. Consequently, total production cost per ton is more than half of the cost to produce coal from the thinner seam. Note that only 2.5 stripping machines would be required to operate 10,000 hours per year at 4,000 hours per machine. Therefore, three machines must be purchased. The third unit provides some reserve capacity. If depreciation were calculated on a yearly, rather than hourly basis, not fully utilizing the

Table 8. Total Cost to Uncover, Load and Haul Coal Using a 38 Yard Scraper, 1 3 BCY Loader, and 2 36 BCY Trucks Based on Actual Production.

Task	Owning & operating costs	Actual production	Total Cost/ BCY moved based on actual production	BCY moved per ton of coal actual production	Cost/ton of coal based on actual production
Uncover Coal	($/hr.)	(BCY/hr.)	($ /BCY)	(BCY/T.)	($/T.)
Earth	80.60	356.2	0.23	0.66	0.15
Clay and gravel	80.60	414.7	0.19	3.33	0.63
Shale	80.60	307.4	0.26	19.33	5.03
Load Coal		(T./hr.)			
1 3 BCY loader	39.64	147.4	--	--	0.27
2 415 HP trucks[a/]	96.88	147.4	--	--	0.65
Total cost to uncover, load and haul one ton of coal					$6.73/T.

[a/] Owning and operating costs per hour for both trucks.

Table 9. Total Cost to Uncover, Load and Haul Coal Using a 38 Yard Scraper, 1 3 BCY Loader, and 2 36 BCY Trucks Based on Theoretical Production.

Task	Owning & operating costs	Theoretical production	Total Cost/ BCY moved based on theoretical production	BCY moved per ton of coal based on theoretical production	Cost/ton of coal based on theoretical production
Uncover Coal	($/hr.)	(BCY/hr.)	($ /BCY)	(BCY/T.)	($/T.)
Earth	80.60	698.4	0.12	0.66	0.08
Clay and gravel	80.60	767.6	0.11	3.33	0.36
Shale	80.60	733.5	0.11	19.33	2.13
Load Coal		(T./hr.)			
1 3 BCY loader	39.64	173.4	--	--	0.23
2 415 HP trucks[a/]	96.88	173.4	--	--	0.56
Total cost to uncover, load and haul one ton of coal					$3.36/T.

[a/] Owning and operating costs per hour for both trucks.

Table 10. Equipment, Investment, Operating, and Owning and Operating Costs for Two Different Mines Producing 300,000 Tons of Coal Per Year.

Item		Thin seam mine		Thick seam mine
Coal seam thickness		3 ft.		6 ft.
Desired level of production		300,000 T/yr.		300,000 T/yr.
Production for 1 38 yard scraper		1,322,455 BCY of overburden/yr.		1,322,455 BCY of overburden/yr.
Coal uncovered/scraper/hr.		14.4 T		28.8 T.
Coal loaded/hr.		147.4 T.		147.4 T.
Total overburden to remove		6,750,000 BCY		3,375,000 BCY
No. of 38 yard scrapers required		5		3
No. of 3 BCY loaders		1		1
No. of 36 BCY trucks		1		1
Investment				
scrapers		$1,284,410		$770,646
loaders		106,865		106,865
trucks		293,186		293,186
Total investment		$1,684,461		$1,170,697
Annual operating costs				
scrapers	20,826 hrs x $45.74/hr. =	952,581/yr.	10,413 hrs x $45.74/hr =	$476,291/yr.
loader	2,038 hrs x 27.07/hr. =	55,169	2,038 hrs x 27.07/hr =	55.169
trucks	2,038 hrs x 56.08/hr. =	114,291	2,038 hrs x 56.08/hr =	114,291
Total annual operating costs		$1,122,041/yr.		$645,751/yr.
Annual owning and operating costs				
scrapers	20,826 hrs x $80.60/hr. =	$1,678,576/yr.	10,413 hrs x $80.60/hr =	$839,288/yr.
loaders	2,038 hrs x 39.64/hr. =	80,786	2,038 hrs x 39.64/hr =	80,786
truck	2,038 hrs x 96.88/hr. =	197,441	2.038 hrs x 96.88/hr =	197,441
Total annual owning and operating costs		$1,956,803/yr.		$1,117,515/yr.
Investment/ton of production capacity		$5.61/T.		$3.90/T.
Operating cost/ton		$3.74/T.		$2.15/T.
Owning and operating cost/ton		$6.52/T.		$3.73/T.

third scraper would increase owning cost.

V. SUMMARY AND CONCLUSIONS

Recent developments in mining techniques, materials handling methods and reclamation procedures have increased the alternatives available to the strip mine operator. A user oriented computer program has been developed to assist the miner in the cost analysis of the different equipment and equipment combinations in alternative overburden and pit configurations. The model calculates production and costs for each individual task performed to uncover and remove coal and reclaim the surface for productive use. Total costs per ton of coal removed and the capital outlay required to obtain a specified level of annual production are also determined. Several sizes and types of equipment can be analyzed to select the optimal equipment set before the mine operator commits his capital. Illustrative results indicate the detail of the information generated by the model and the impact of overburden characteristics and depth, machine size and theoretical versus actual production on mining and reclamation costs.

Costs other than those incurred in the materials handling processes are also important in developing a new mine. Overhead items such as bookkeeping, payroll determination, new operator training, supervisory personnel, licenses and permits and bond fees must be allocated to mine production. One time costs incurred in coal exploration and subsurface right acquisition must be allocated to production over the life of the mine. The loss of income that results from decreased productivity of the land during and after the mining and reclamation processes must also be included in the analysis. Further work is underway to incorporate these additional cost items in the model.

Certainly minimum cost is not the only consideration in choosing a particular machine or mining plan. A mine operator may choose a larger machine or fleet to have built in reserve capacity, if he should encounter more adverse conditions or anticipates he can capture a larger market for his coal. Non-economic considerations such as proximity to parts suppliers and manufacturers, type of equipment already in service, and previous operator experience with some machines may influence the miner's equipment selection decision. Environmental and ecological considerations will also influence the pit design and materials handling procedures.

Numerous additional issues can be evaluated with a model in addition to the cost analyses discussed herein. The sensitivity of costs to changes in input prices for fuel, labor, and equipment can be evaluated. New technological developments that improve the productivity of various machines can be analyzed. The benefits of acquiring trained operators or of various training programs for current operators to reduce the difference between actual and theoretical production can be determined. Finally, the cost of impact of alternative reclamation regulations for different mine sites can be evaluated as in input into public policy.

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