COST-BENEFIT ANALYSIS OF COMPUTER-ASSISTED MINING THROUGH PRODUCTION AND COST MODELING

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Abstract - A mathematically simulated modeling technique is used in this U.S. Bureau of Mines paper to represent a hypothetical mining operation with existing mining technology and prevalent mining costs. Mining scenarios are prepared and evaluated for potential benefits and costs available through computer-assisted mining. Base criteria, parameters, and methodology are described.

Introduction

A mining operation can be represented by two models; production and cost. In order to evaluate the cost-benefits of mining scenarios for computer-assisted mining, it is necessary to develop a model representative of existing mining technology and cost of mining. This effort by the U.S. Bureau of Mines first identifies and selects major base parameters and criteria to be used in the development of base production and cost models to represent a hypothetical mine with existing technology. Improvements in production, cost, or both are applied to the base models to realize the potential benefits of computer-assisted continuous mining systems through various mining scenarios. The scenarios include different combinations of increased mining efficiency and shift uptime.

Mining costs and simulated mining operations are based on an actual 12-month period. Production model is prepared employing mathematical simulation techniques, keeping in view the following:

- Mine history - Production and Cost
- Production delay records
- Equipment maintenance records
- Industrial Engineering data
- Physical mine conditions
- Mining industry experience

While estimating cost of mining, prevalent United Mine Workers of America (UMWA) hourly rates and guidelines are used, where applicable; other cost items are representative of similar mining operations.

Anticipated improvements in productivity or cost are then applied for each scenario that can be obtained through computer-assisted mining, and compared with existing mine models. If a significant reduction in cost of mining results, the scenario is investigated in depth. All potential improvements are first modeled individually and then collectively to realize the overall impact on cost of mining. Two

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computer printouts are appended to this paper to show the model output and to assist people in the mining industry and elsewhere in gaining a general understanding of the modeling technique for their particular needs.

Base Criteria and Parameters for Mining Scenarios

General Mine Description

The hypothetical underground mine, located in the eastern U.S., operates in a relatively flat coal seam, approximately 1.52 m thick on average, employing continuous mining methods. The topography in the area is generally mountainous and relatively severe, average cover over the seam being about 152 m.

A slope belt delivers the mined coal out to surface. This slope also contains a track for transporting supplies. Mine ventilation is provided by the slope and two double-compartment shafts. One of these shafts serves as a portal for personnel.

The mine employs 35 salaried and 185 UMWA personnel for a total of 220. Mining is accomplished through the use of six continuous miners, five normally set for production and one for construction work. Four production crews are scheduled to operate continuous miner (miner) sections in each of the three shifts for a total of twelve scheduled shifts of production each day in the following areas:

- Mains development
- Submains development
- Longwall panel development
- Room and pillar section

The mine produces approximately 450 000 tonnes of clean coal annually in 240 workdays. The productivity per worker-day is about 9 tonnes. Cost of mining for this period is in the range of $29 to $32 per tonne.

The mine employs belt haulage for coal transportation and mine track with trolley wire for supplies and personnel transportation close to working sections. In the working face area, rubber tire supply cars moved by battery equipment are utilized.

Surface Facilities and Arrangements

Mine surface facilities include a building housing mine offices, bath and change-house, lamp-room, and warehouse. Other facilities include a mine maintenance and repair shop, hoist-house for slope, supply yard and a mine exhaust fan. A coal processing plant prepares the run-of-mine coal and supplies it to a mine-mouth power plant via a system of overland conveyors. A number of sedimentation ponds are situated in the general mine vicinity. Trucks are used to supply coal to the power plant as an alternate mode. Trucks are also used to transport refuse material from the plant to the dumping areas. Electric power to the mining complex is supplied from the nearby power station.

Mining Methods and Equipment

The systems include development of main headings, submains, longwall panels, and butt panel for room and pillaring. At present, no longwall or pillar mining is being conducted. Full roof bolting is practiced throughout the mine. A two-shuttle car system is used for face coal haulage. All section belts are 0.91 m wide and equipped with feeders. Single-split system ventilates the working sections. Mining section equipment models are standardized and typically include one Lee Norse[2] 265 HH continuous miner, and one Stamler BF-2 feeder.

Personnel

A section crew consists of a miner operator, miner helper, two shuttle car operators, one roof bolter, one roof bolter helper, one utility person, and a mechanic/electrician (total eight). Each section has a supervisor. Other UMWA personnel include general inside, general outside, maintenance, and preparation. Table 1 gives the UMWA personnel breakdown by work category for the example mine.

Base Production and Cost Models and Mining Scenarios

The existing mine is simulated through the two mathematical models, production and cost, utilizing a typical one-year period. Five continuous miners are set for production in the following areas:

- Two units in seven-heading mains,
- one unit in three-heading longwall development section,
- one unit in five-heading sub-mains,
- one unit in room & pillar development section, and
- a sixth unit is employed for mine construction work.

The following paragraphs relate to the appended models entitled "Mine Production Model by Continuous Miner Section," and "Cost of Mining Statement." Various mining scenarios which will be considered in potential cost-benefit analysis for computer-assisted mining are also described.

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[2]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

Mine Production Model

The model represents a six-section (including construction) mine producing 457 600 clean tonnes annually. Most of the items are self-explanatory; however, those needing explanations are appropriately defined and include the methodology for obtaining them.

Minutes per shift. Scheduled production shift is 8 h or 480 min.

Travel time. Includes mantrip-in and mantrip-out. Mantrip-in is total time to travel from mine portal to dinner hole in a working section, excluding any major delays but including traveling in mantrip cars and walking. Similarly, mantrip-out is the time from dinner hole in the section to the outside (mine portal) and includes waiting for mantrip and walking from the dinner hole to the mantrip car, but excludes major delays.

Lunch time. It is normally 30 min. If a crew is relieved for lunch, the time for lunch would be zero.

Service time. It is the scheduled maintenance time for major pieces of section equipment during a production shift. In this case, it is combined with another work element, Cleanup and Prepare to Mine (C/PTM), described later.

Remaining operating time. Total shift minutes (480) minus travel, lunch, and service time give this value. The next major category in the production model is "downtime" for various equipment items and mining conditions. Equipment delays and mine physical conditions that disrupt the production cycle are listed. These delays can be due to mechanical breakdowns or other conditions rendering equipment unavailable for production. These delays are normally referred to as the "section downtime." Items include continuous miner, shuttle car (SC), section belt conveyor, belt feeder, and section power supply. Additional roof control, if required in the section because of roof and rib conditions, comes under "timber and rail." Other natural conditions such as floor heaving, rock bursts, and water and mud in the roadways, are listed under "conditions." Any safety-related delays are listed separately if time is required solely for the section safety, e.g., increasing ventilation to dilute excessive gas and conducting safety checks on equipment and the section, in addition to the "safety meeting" before the crew proceeds to the working section. After reaching the dinner hole, the section supervisor holds a meeting discussing safety concerns with the workers, actual accident findings, unsafe work practices, or new regulations which may impact the section safety.

Cleanup and Prepare To Mine (C/PTM) is a major work activity towards the shift end. It includes servicing the equipment and cleaning up the face (shovel or scoop) so that the section is ready for the following shift. Servicing equipment includes necessary maintenance checks (oil levels) and taking care of such requirements, changing bits, lubrication, adjusting safety or monitoring devices, and the like, typically needed after a shift's operation.

Other preparatory work begins after the safety meeting, i.e., traveling from the dinner hole to the equipment and moving the equipment to the face (tramming and cable handling), and ends when the miner begins to load the first SC. Also, time is consumed in withdrawing equipment from the working face after loading the last SC, walking to the dinner hole, and any waiting (reasonable) prior to leaving the dinner hole.

All these items (previous paragraph) are lumped in a separate delay category; in this case, under "model adjustment," which also includes any improperly reported or unaccountable delays. The purpose of this category is to provide a means of adjusting the model to make it practical and consistent with achievable worker efficiency and equipment utilization.

"Unit shifts" are number of operating shifts for a particular mining machine unit during the year.

The next group of data in the model tabulation is called "place data" and relates to physical working face characteristics.

A "working place" is a three dimensional unit, in this case, a cut made by the miner (6 m deep by 5.50 m wide by 1.52 m high approximately). The volume of a cut when multiplied by the density of the mined material (seam, roof, floor) gives the raw tonnage applying an appropriate coal recovery factor.

The next group of data is identified as "place time" and represents the time necessary to complete mining activities in a cut. Based on time studies and general observations, typical unit rates for mining/loading, maneuvering, and SC change are developed. These rates when multiplied by number of cars per place provide total time for a particular event with one exception. SC change time is the time a SC is away from the miner, excluding major delays, that prevents the car from returning to the miner in the average time governed by the haul distance. The average SC change time in a place (cut) is equal to the total car change time divided by the number of car changes (equivalent to total SC loaded minus one).

There is no SC change after the last car is loaded nor before the first car is loaded. The normal practice, therefore, is to reduce the number of cars by one or eliminate the fractional part and multiplying it by average SC change time to obtain the total SC change per cut. Total loading and maneuvering times are obtained by simply multiplying total number of cars per place by unit (per car) values.

Other place work elements like "gas test" (mandatory, every 20 min while mining) "extending ventilation", and erecting "safety posts" right after mining (loading) a cut, before permanent supports (bolts) are installed, constitute additional necessary delays in a mining cycle. The miner then has to be trammed to the next place; this time, including handling cable, is listed under "tram time." These time values are added and the total time is called "total place time."

"Maneuver" (miner) time is the time for maneuvering the equipment when the SC is with the miner. As the name implies, "roof bolting place time" is the time to complete bolting operations in a cut so that the miner can move in for another cut. So long as the roof bolting place time is less than the mining place time, mining place time determines the number of places mined per shift. When roof bolting time is greater than mining time or roof bolting becomes a bottleneck, the number of cuts are reduced accordingly, since roof bolting time then prevails.

"Placetime," mining or bolting, the greater of the two is divided into "remaining uptime" to give the number of places per unit shift. Productivity in clean tonnes per unit shift is obtained by multiplying the number of places (cuts) to tonnage per place. The tonnage per minute or hour represent the value per remaining uptime. The value per unit shift multiplied by total unit shifts provide total annual tonnage by the mining section. Similarly, the values are tabulated for other mining sections. It is to be noted that the values (average) of line items in the last column of the model are weighted average according to the unit shifts in various section categories.

Mine Cost Model

This model or "cost of mining statement" provides detailed cost break-downs by line item. The annual cost is provided in total dollars and also in dollars per clean tonne. Individual cost items are termed either "fixed" or "variable." Fixed means fixed dollars for a particular period, in this case, one year. Examples are labor, overhead, and depreciation. Variable cost varies per shift, day, or month depending on tonnage produced. Examples are royalty, black lung fee, and supplies-operating. Any change in a mine production model will have an effect on its cost model. For example, new equipment used for increasing mine production will have two-fold effect:

- overall cost per tonne reduced,
- depreciation line item or leasing cost increased.

The example mine cost model shows a cost of $31.50 per tonne on clean coal basis for the base year 1988.

Mining Scenarios for Computer-assisted Mining

While considering potential mining scenarios, all equipment and mining systems are assumed to remain unchanged in the existing mine with the exception of continuous mining machine. The mining machine is envisioned to be operated by computer-assisted control, from a distance of 76 to 305 m (based on number of headings in a mining section). The operator compartment is situated near the section-belt tail piece in the fresh intake air. The operator is able to control all functions of the mining machine-cutting, tramming, etc., through visual, aural, and other displays in the compartment employing proven computer technology.

Normal mining cycle begins as the continuous miner advances the coal face on the ventilation side of a heading or crosscut. Extraction of coal in the immediate face is continued using SC to haul the coal to the belt tailpiece until the furthest depth of penetration (6 m) is reached. Upon completing both passes in the cut (5.5 m), the continuous miner is trammed to the next heading or crosscut, according to the cut-sequence plan. A roof bolting machine then enters the mined-out face to bolt the place in accordance with the approved roof control plan. The mine utilizes conventional shell-type (1.22 m) bolts. After completing the roof bolting, the face area is cleaned up and rock-dusted.

A computer-assisted miner will enhance the section productivity because of the following:

- reduced equipment downtime, thereby increasing available operating time (uptime),
- reduced mining cycle time, thereby providing additional number of cuts per shift

The productivity is increased simply by making the mining equipment available for more time and increasing its utilization (compared to the manually operated system). By effective planning of mining operations, standardization, maintenance, and spare parts inventory, improving the relations between management and labor, training, and coordination, it is possible to make more efficient utilization of labor. In addition, the quality of mined product can be controlled effectively to provide a consistent output to the beneficiation plant and the user.

The most important team player in the mining section is the continuous mining machine operator. In the computer-assisted section, this person is highly skilled to operate the machine and qualified enough to make necessary judgments in the mining operations. He or she has the authority of a section foreman and is able to work independently. A mining machine helper is not needed on a full-time basis. The role of a section supervisor involves non-miner operations, and can be called a "coordinator" or nominal section boss. Similarly, the mechanic/electrician is highly skilled to maintain the sophisticated mining machine. The role of utility personnel is also reduced as the mining machine performs the most face clean-up functions. Since the miner operator is to be involved in management and decision-making roles, it may be appropriate to make him/her a salaried employee. Necessary mine operations data have to flow to all employees involved salaried and UMWA, requiring an effective mode of distribution and coordination to properly organize, operate, and maintain the advanced mining equipment.

Computer technology will enable improved monitoring of equipment condition to help early detection of faulty problems and breakdowns allowing necessary preventative maintenance. Better maintenance planning not only improves equipment availability, efficiency, and productivity, but also reduces mining cost by maintaining a minimum inventory of spare parts.

Since the operator is located in a safer, cleaner, and relaxed environment and not doing monotonous work, he/she is subject to less physical and mental tension or fatigue and, therefore, able to work with greater efficiency, accuracy, and maintain high standards and housekeeping.

In the example mine, two scenarios are considered:

- continuous miner operating at existing efficiency reflected by existing loading rate, but for longer available time (uptime increased by 60 min, 75 min, and 90 min);
- continuous miner operating at improved efficiency reflected by new loading rate (existing rate increased by 25%, 50%, 75%, and 100%) and for longer available time as above.

Both the scenarios have improved maneuvering rate, but it is not a very significant amount. Other improvements which are common to all models include:

- elimination of gas test time (2 min) from the place mining cycle. By having a methane monitoring device on the miner and an operator's ability to read at control station, it is not necessary to interrupt mining operation to take manual gas tests every 20 min.
- improved tram time (including cable handling) in the place cycle. Improved efficiency increases the tram rate and reduces cable handling delays. An appropriate percentage for this improvement will be applied in the models.

Basis of increasing the "<u>remaining uptime</u>" follows:

Face cleanup is effectively done by the remote-controlled miner during the mining cycle. The need of utility personnel otherwise needed (with scoop or shovel), is significantly reduced. An effective equipment servicing and maintenance program and face cleanup by the miner can reduce the existing <u>C/PTM</u> time (60 min) to 30 min. Also, the miner downtime can be minimized or eliminated (saving 30 to 50 min). Since the miner operator is away from hazardous work face, it can be assumed that "<u>safety</u>" related down time is improved by 7 min. Prudent engineering and operating practices can further improve productivity of a mine. For example, maintain a miner when belt or SC's are down.

"<u>Model adjustment</u>" and "<u>other</u>" delays provide room for further improvement.

A review of section work force indicates that one person can be eliminated from the crew (now 7-person crew) with the new mining system.

Various improvement ideas discussed in this section will be modeled when conducting cost-benefit analysis for computer-assisted mining.

Cost-Benefit Analysis of Computer-Assisted Mining

In the example hypothetical mine, two scenarios are considered for computer-assisted mining:

- continuous miner operating at existing efficiency--reflected by existing loading rate (1.95 min/car), but for longer available time (uptime increased by 60 min, 75 min, and 90 min). This situation provides three production models,
- continuous miner operating at improved efficiency--reflected by new loading rates (existing rate increased by 25%, 50%, 75%, and 100%) and for longer time, i.e., increasing uptime by 60 min, 75 min, and 90 min, as above. The new rates are 1.56 min/car, 1.30 min/car, 1.11 min/car, and 0.97 min/car for the four efficiencies. One minute per car means a loading rate of 6.4 tonnes/min, which is a reasonably high number as an annual average rate. This condition provides a total of 12 production models.

Other improvements which are common to all models include:

- improved miner maneuver rate of 0.15 min/car,
- elimination of gas test time (2 min) from place mining cycle,
- improved tram time or 60% of normal time.

Each production model has a corresponding cost model. The new mining system has resulted in the following changes:

One person is eliminated from the crew, now 7-person crew; the total reduction is 12 personnel for 12 working shifts. It is assumed that miner-helper and utility personnel will be needed for one-half of their times or one person should replace two.

By effective planning of mine operations, standardization, maintenance, and spare-parts inventory, improving the relations between management and labor, it is possible to more efficiently utilize the work force.

The reduction of 12 personnel out of the total 185 UMWA personnel represents a 6% decrease in the labor-hourly and benefits costs and welfare-hourly costs. These line items on cost of mining statement are A2, A4, and A11. The new values for these items are $3,290,000, $846,000, and $282,000.

It is estimated that capital cost requirement for miner additions including computer and Mobile Control Structure is $250,000. Assuming interest at 10% and straight line depreciation over 7 years, (no salvage value), the increase in annual interest expense, line item B5, is $25,000, and the increase in line item C1 is $35,714. The new values for B5 and C1 are $525,000 and $585,714, respectively. Space limitation did not allow appending all 16 models (only one provided) in this paper. Contact the author for details.

The five changes shown above are applied to all cost models. The productivity figure (tonnes/worker-day) in each cost model is now calculated using new production and work force (new mine total 208).

Table 2 summarizes the results of 15 production and cost models along with the base case. Example of an improvement production and cost model is shown by tables 3 and 4 (increased uptime 75 min and efficiency 50%).

Comparing the highest production and corresponding cost figures, 944 900 tonnes and $18.25 to the base figures, 457 600 tonnes and $31.50, the resultant improvements are 106% and 42% for production and cost, respectively. Similarly, comparing the lowest improvement figures (674 100 tonnes and $23.05) to the base case, the resultant production and cost improvements are 47% and 27%, respectively. The mid-point of the range is 77% for production and 35% for cost improvement.

Because of possible variations in mining conditions, data limitations, inherent imprecision in any simulating system, necessity of using judgments, and the human factors involved where changes are projected, it is believed reasonable to expect 75% to 125% attainment of the results projected.

Conservatively, it can be assumed that the new mining system can improve mine production by 58%, resulting in a cost of mining improvement of 26%.

Although the mine scenario assumes a 6% reduction in face work force, it is not a true representation as it does not address potential increase in service personnel. It will vary with company size, organizational philosophy, system's success and penetration in the industry, and is not estimated at this time.

Figure 1 shows relationship of productivity, tonnes/worker-day, and cost of mining ($/tonne), as obtained from the base and improvement cost and production models.

CONCLUSIONS

Computer-assisted mining can significantly increase mine productivity and reduce the cost of mining. Also, it provides a safer and healthier work environment.

Estimates indicate a potential increase of 58% in mine productivity, reducing the cost of mining by 26%.

Table 1.--Example of mine UMWA personnel, by work category.

Work Category	No. of UMWA Personnel
Section.	96
General inside	32
Maintenance.	24
Preparation.	25
General outside.	8
Total	185

Table 2.--Summary of results of 15 production and cost models.

Mine Model	Uptime Increase, min	Annual Production, clean tonnes	Cost of Mining, $/tonne
Existing technology (base case).......	0	457 600	31.50
Computer-assisted Mining			
Normal efficiency..	60	674 100	23.05
	75	715 600	22.10
	90	756 500	21.20
Increase efficiency by 25%...........			
	60	732 200	21.70
	75	777 200	20.85
	90	821 700	20.05
Increase efficiency by 50%...........			
	60	776 900	20.85
	75	824 700	20.00
	90	871 800	19.30
Increase efficiency by 75%...........			
	60	813 100	20.20
	75	863 200	19.40
	90	912 400	18.70
Increase efficiency by 100%..........			
	60	842 100	19.70
	75	893 900	18.90
	90	944 900	18.25

Table 3.--Mine production model by continuous miner section improve uptime by 75 min for 50% efficiency.

Item identification	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Total/wtd ave.
Minutes per shift	480.0	480.0	480.0	480.0	480.0	480.0	480.0
Travel time	60.0	62.0	65.0	58.0	62.0	64.0	61.7
Lunch time	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Service time	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Remaining operating time	390.0	388.0	385.0	392.0	388.0	386.0	388.0
Downtime							
Miner	12.8	15.0	8.0	19.4	0.0	20.0	12.9
S.C.	15.0	10.2	12.0	15.5	12.0	18.2	13.7
Belt	21.0	22.2	28.0	18.5	21.0	19.5	21.9
Bolter	4.8	5.0	6.0	5.9	8.0	4.6	5.7
Feeder	3.0	3.8	4.2	3.6	5.0	6.8	4.3
C/PTM	30.5	31.0	22.0	28.8	35.0	38.0	30.2
Power	1.8	1.0	2.0	2.5	2.8	1.9	2.0
Timer and rail	2.0	2.9	3.0	5.0	5.3	3.0	3.5
Conditions	5.0	5.8	6.0	2.5	4.2	2.8	4.5
Safety	13.0	10.5	11.8	15.0	12.0	10.1	12.2
Model adjust delays	20.0	18.5	17.8	22.0	15.0	19.5	19.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total downtime	128.9	125.9	120.8	138.7	120.3	144.4	129.7
Remaining uptime	261.1	262.1	264.2	253.3	267.7	241.6	258.6
Unit shifts/year	502	480	536	528	354	380	2,780
Cubic feet/place	1,710.7	1,731.7	1,857.4	1,880.0	1,642.8	1,409.4	1,724.9
Density	94.50	94.50	94.50	94.50	94.50	94.50	94.50
Raw tons/place	80.8	81.8	87.8	88.8	77.6	66.6	81.5
Raw tons/S.C.	7.0	7.0	7.0	7.0	7.0	7.0	7.0
No. S.C./place	11.5	11.7	12.5	12.7	11.1	9.5	11.6
Reject %	22.8	22.8	22.8	22.8	22.8	22.8	22.8
Clean tons/S.C.	5.40	5.40	5.40	5.40	5.40	5.40	5.40
Place time							
Mining	15.01	15.20	16.30	16.50	14.42	12.37	15.14
Maneuvering	1.73	1.75	1.88	1.90	1.66	1.43	1.75
S.C. Change	20.68	20.90	25.20	19.44	16.50	18.00	20.46
Gas test and safety	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ventilation and posts	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Tram	3.48	3.72	3.83	4.68	3.18	4.11	3.86
Total place time	49.50	50.17	55.81	51.12	44.36	44.50	49.80
Roof bolting place time	38.80	40.20	39.50	38.75	36.80	37.00	38.67
Places/unit shift	5.274	5.224	4.734	4.955	6.035	5.429	5.26
Productivity - clean coal							
Tons/unit shift	329.1	330.0	320.8	339.8	361.6	279.1	327.0
Tons/hour	75.6	75.5	72.8	80.5	81.1	69.3	75.8
Tons/minute	1.261	1.259	1.214	1.341	1.351	1.155	1.264
Annual production, st	165,223	158,401	171,924	179,412	128,017	106,055	909,032
Tonnes	149 887	143 698	155 966	162 759	116 134	96 211	824 655

Table 4.--Cost of mining statement, base year 1988.

Basis of Estimates	Adj. Time St. Data		Uptime by 75 min for 50% efficiency	
Days of operation	240		240	
Total production (clean st) (000)	504.458		909.032	
Daily production (clean st)	2,102		3,788	
Approx. st/worker-day	9.550		18.210	
Cost basis	Dollars(000)	$/st	Dollars(000)	$/st
A. Direct operating costs				
* 1. Labor-Salaried	1,000.000	1.982	1,000.000	1.100
* 2. Labor-Hourly	3,500.000	6.938	3,290.000	3.169
* 3. Benefits-Salaried	46.000	0.091	46.000	0.051
* 4. Benefits-Hourly	900.000	1.784	846.000	0.931
5. Supplies-Operating	1,513.374	3.000	2,727.096	3.000
* 6. Supplies-Maintenance	1,800.000	3.568	1,800.000	1.980
* 7. Power	340.000	0.674	340.000	0.374
* 8. FICA and unemployment taxes	400.000	0.793	400.000	0.440
* 9. Workman's Compensation Insurance	175.000	0.347	175.000	0.193
* 10. Black Lung Compensation Insurance	340.000	0.674	340.000	0.374
* 11. Welfare-Hourly	340.000	0.595	282.000	0.310
* 12. Welfare-Tonnage	711.790	1.411	1,282.644	1.411
* 13. Safety expenses	150.000	0.297	150.000	0.165
* 14. Production and safety incentives	250.000	0.496	250.000	0.275
* 15. Accident costs	200.000	0.396	200.000	0.220
16. Reclamation fee	75.669	0.150	136.355	0.150
17. Federal Black Lung fee	252.229	0.500	454.516	0.500
* 18. Other costs	0.000	0.000	0.000	0.000
Total	11,954.062	23.697	13,719.611	15.093
B. Other cash costs				
* 1. Overhead	500.000	0.991	500.000	0.550
2. Royalties	302.675	0.600	545.420	0.600
3. Miscellaneous taxes	0.000	0.000	0.000	0.000
* 4. Equipment leasing costs	600.000	1.189	600.000	0.660
* 5. Interest expense	500.000	0.991	525.000	0.578
* 6. Miscellaneous income	0.000	0.000	0.000	0.000
Total	1,902.675	3.772	2,170.420	2.388
C. Other costs				
* 1. Depreciation	550.000	1.090	585.714	0.644
2. Amortization of development costs	0.000	0.000	0.000	0.000
3. Depletion	0.000	0.000	0.000	0.000
Total	550.000	1.090	585.714	0.644
Total cost of mining	14,406.737	28.559	16,475.745	18.124
$/tonne		31.481		19.978

* fixed dollars per year