Evaluation of selected pit configurations for surface mining a moderately pitching coal seam

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Abstract – *Physical mine modeling and computer simulation techniques were used to conduct technical feasibility and economic analyses of selected pit configurations for surface mining a single coal seam dipping at about 15% to a maximum depth of 46 m (150 ft). Pit orientations along the true dip (dipline), along the strike (strikeline), and along an apparent dip were studied. Physical models of each pit configuration were prepared first to delineate potential operational problem areas and also to furnish data for the computer simulation models. A dragline microsimulation, a shovel/truck simulation, and a surface mine cost analysis models were used to conduct the study. Sensitivity analyses were conducted on variables such as the pit width, block length, and seam pitch. The productivity (m^3/h) of the mining equipment (dragline or stripping shovel) under each set of conditions was used to optimize the pit configuration. Both block length and panel width were found to significantly affect the dragline productivity. Larger size trucks were preferable to smaller size trucks in the pit configuration along an apparent dip. The cost analysis results showed that the pit configuration along the seam dip was more economical than the pit along the strike or along an apparent dip for the mining condition studied.*

Introduction

In the US, a significant increase in surface mined coal production is expected in the western coalfields. It is estimated that coal production from the West (most of which is surface mined) will account for about 40% of the total US coal production.

Most coal seams in the western coalfields are characterized by thick and/or moderately (seam pitch less than 15% is considered moderate) to steeply pitching coal seams. Currently, most of the western coal production comes from thick rather than pitching seams because of lower stripping ratios. Mining systems for pitching seams need to be developed in the US for their effective and extensive exploitation in the future.

The seam pitch significantly affects both the mining cost and coal recovery because of operational problems associated with highwall and spoil instability, pit drainage, rehandle of overburden, nonconcurrent mining and reclamation operations, and highly variable stripping ratios over the life of the mine.

Skelly and Loy (1978) investigated mining techniques for moderately pitching coal seams in the US. They analyzed operational and reclamation problems associated with the mining operations and developed feasible mining techniques designed to alleviate these problems. This field investigation led to the development of six viable mining concepts that were also subjected to an economic evaluation. The concepts included dragline operating in pits along the true dip or an apparent dip and along the strike of the coal seam. Haulback mining with the pit advancing along the true dip and the strike of the seam was also evaluated.

The authors suggested that (1) overburden stripping with mobile equipment (dozer, scraper, trucks) and with pit oriented along an apparent dip (diagonal line), (2) the use of dragline for overburden stripping and pits oriented along the true dip (dipline), and (3) along the strike (strikeline) of the seam demonstrated enough merits to be researched further. It was further recommended that these economically viable concepts be evaluated for the effects of variables such as seam pitch, overburden depth, and stripping ratio on the system production potential. Therefore, the present study was specifically undertaken with the foregoing objectives in mind, and the methodology and results of this research form the content of this paper. Other studies of relevance in this area were conducted by Caterpillar (1980), Atkinson (1979), Ketron (1979), and Fluor (1981).

Study approach

The specific objective of this study was to conduct a technical and economic evaluation of selected pit orientations in mining a single seam dipping at 8.53° (15%) to a maximum depth of 46 m (150 ft). Such mining conditions are prevalent in the Hanna Coal Basin in Wyoming. The evaluation emphasized the effect of pit orientation on overburden stripping operations since it constitutes the major portion of the mining cost.

The study utilized physical models of the mining systems with different pit orientations, a dragline simulation model developed by Fluor Mining and Metals (1981), the Open-Pit Material Handling Simulation Model (OPMHS), and a surface mine cost model (COSTMOD) developed by Manula et al. (1976) to achieve the objectives of the study. Initially, visits were made to operational mines in Wyoming and to the Caterpillar Tractor Co. in Peoria, IL, where the preparation of physical mine models for different pit orientations was studied.

Three physical mine models were prepared, each representing the mining system in the dipline, strikeline, and diagonal line pit orientations. The physical mine models helped to visualize the operational problems in each mining system and to develop meaningful dimensions and numbers for system simulation using

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appropriate computer models. The overburden stripping performance of the dragline in dipline and strikeline orientations was optimized using the dragline simulation model. The effect of important variables such as overburden depth, seam pitch, pit width, digout length, and spoiling technique on the performance of the dragline was evaluated. The OPMHS model was used to optimize shovel-truck overburden stripping and haulback operations in the diagonal line pit orientation. The mining cost calculations for optimized mining systems in all three pit orientations were then conducted in 1983 dollars using the COSTMOD computer program. Only results of the analytical studies are presented here.

Mining techniques for moderately pitching coal seams

In pitching seams, pits may be oriented along the true dip, along the strike, or along an apparent dip. The mining equipment used for overburden stripping ranges from draglines and stripping shovels to mobile stripping equipment such as dozers, scrapers, wheel loaders, and trucks.

In the dipline pit orientation, the pit is oriented along the true dip, and each successive cut along the pit goes from shallow to deep overburden. Pit advance is along the strike of the seam. The mining operation can be started either at the shallow end or at the deep end, depending on the reclamation requirements and the feasibility of the mining plan. Coal production is uniform throughout the life of the mine for a given uniform coal thickness. However, the economic stripping ratio must be determined prior to the beginning of mining. For a dragline or a stripping shovel operation, the spoil is side cast along the strike. For in-pit mobile stripping equipment, the haul road usually runs along an apparent dip of the seam. Coal loading is achieved by either a loader/truck fleet or by belt conveyors, depending on the steepness of the haul road and production requirements. Advance bench stripping is generally necessary on the deeper side of the pit for the dipline technique to provide for an acceptable depth of stripping by a dragline consistent with its operating reach.

The advantages of this pit orientation are uniform stripping ratio throughout the life of the mine, concurrent mining and reclamation, and a better control of highwall and spoil stability problems. Disadvantages of the mining system include a relatively short pit length, reduced positive cash flows during the initial years of mine operation, and space required for spoiling the boxcut material downdip.

In the strikeline pit orientation, the pit is oriented along the strike, and the direction of mining can be either downdip or updip, depending on the economics and feasibility of the mining plan. Generally, mining is started at the shallow end, and it progresses downdip so that the initial capital outlay is recovered as soon as possible. This mining scheme permits future advancement and expansion because the economic stripping ratio does not have to be determined before mining is initiated. Mining updip permits concurrent mining and reclamation; pit drainage is facilitated; and spoil instability problems, if any, minimally affect mining operations. The drawbacks of the strikeline pit orientation include an inability to perform reclamation concurrently with the mining operations, spoil instability problems, and a considerable increase in rehandling the overburden with each successive cut downdip. Pit water accumulates along the highwall. Consequently, water seepage downdip through the spoils can accelerate spoil instability problems.

In the diagonal pit orientation, the pit is oriented along an apparent dip. This mining method is most useful where the true dip of the seam precludes either dipline or strikeline pit orientations for economic reasons. By orienting the pit along an apparent dip, the haulage grade is reduced to an acceptable level. The mine can advance either updip or downdip with the pit oriented along an apparent dip. Direct casting as well as mobile stripping equipment may be suitable in the diagonal pit orientation. However, mobile stripping equipment is used more commonly because of its flexibility and lower initial capital outlay. The mining and reclamation operations can proceed concurrently.

Analytical studies

The three mining orientations — dipline, strikeline, and diagonal line — were analyzed for a base case with the following assumptions: (1) average dip of the seam — 8.53° (15%); (2) maximum mining depth — 46 m (150 ft); (3) surface topography — relatively flat; (4) annual production — 1.8×10^6 t (2.0×10^6 st); (5) swell of material — 25%; and (6) seam thickness — 6 m (19.7 ft). The coal production was assumed to be obtained from two pits adjacent to each other. The base case assumptions are very similar to a mining operation located in the Hanna Coal Basin, where the seam pitch is 8° to 10° and annual coal production is 2.0×10^6 t (2.2×10^6 st). The overburden stripping equipment used in this mine included a dragline in each pit, coal loading shovels, overburden drills, bulldozers, front-end loaders, and haulage trucks. This mine in Wyoming was operated three shifts per day, and the remaining expected life of the mine was six years.

Simulation with diagonal pit orientation

The mining system utilizes a fleet of dozers and loading shovels in tandem for overburden stripping. Three cases, each using a different combination of truck types and capacities with a selected shovel, were considered. The objective was to match the truck capacities with those of the shovel such that the waiting time is minimized. The equipment used for overburden stripping, coal loading, and reclamation in the three cases is given in Table 1. The blasted overburden is dozed downdip to the shovel, which in turn loads it into trucks as shown in Fig. 1. The use of a dozer to push the material to the shovel reduces the shovel cycle time but significantly increases wear on the dozer. The trucks haul the overburden material along an apparent dip that is about 30% less than the seam true dip. The downtime of the trucks is also reduced due to the reduction in the haul-road grade.

The production summary for the shovel-truck operation, based on a 10-shift simulation of the mining system using the OPMHS, is presented in Table 2. The results indicate a coal production capability of 5840, 5449, and 5490 t (6437, 6006, and 6052 st) of coal per shift for the three cases evaluated. These figures are considerably more than the planned production, and case 3 simulated the designed production more closely than the other cases. Coal loading equipment always had to wait for coal to be uncovered. During this period, the coal haulage trucks could be used elsewhere, such as for reclamation work if needed.

Table 1 — Primary Stripping, Coal Loading, and Reclamation Equipment for the Three Diagonal Line Cases Studied

Diagonal Line Cases	Size of Stripping Equipment (m^3)		Number and Size of Trucks		Number of Reclamation Equipment	
	Dozer CAT DIO	Shovel	OVB loading	Coal loading	CAT 675B	CAT D9L
Case #1	19 (25 yd^3)	29 (38 yd^3)	8 (154 t) (170 st)	4 (109 t) (120 st)	4	4
Case #2	19 (25 yd^3)	29 (38 yd^3)	10 (109 t) (120 st)	4 (77 t) (85 st)	4	4
Case #3	19 (25 yd^3)	29 (38 yd^3)	8 (154 t) (170 st)	4 (77 t) (85 st)	4	4

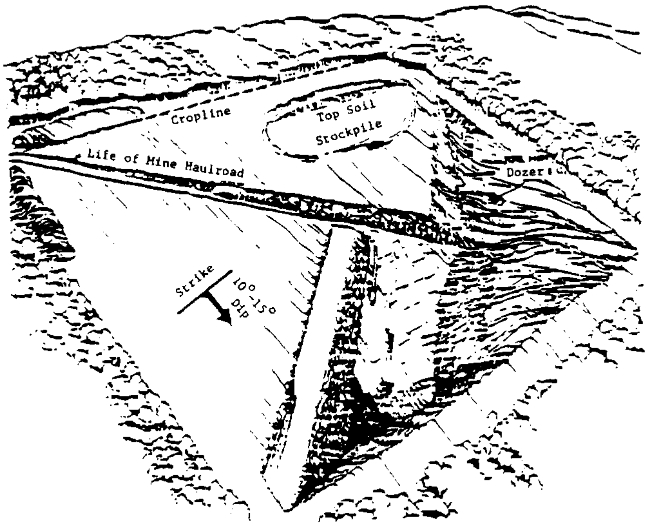

Fig. 1 — Diagonal mining using dozer/scraper combination (Skelly and Loy, 1978)

Table 3 presents results of truck performance for three cases. The shift time runs for 435 minutes on a five-second time increment in simulation. The remaining 45-minute period is taken as lunch break. Case 1 required the least number of trucks with eight rear dump rock haulers and four bottom dump coal trucks. The number of trips required to meet the desired production is also less in this case because of the larger capacity of the trucks used. The average travel times for empty and loaded trucks were not much different in all cases due to the short haul distances selected for simulation.

The stripping and loading equipment performance summary showed that a major portion of the equipment time (360 to 390 min) in a shift was spent productively in overburden stripping. Based on the optimization studies, it was decided to consider case 3 for economic evaluation for comparison with the dipline and strikeline pit orientations.

Simulation with strikeline and dipline pit orientations

The Fluor model was validated by conducting a case study of a surface mine located in southern Indiana prior to its utilization in this study (White and Ehie, 1983). The mine utilized a BE 3270 dragline with a bucket size of 134 m^3 (176 cu yd). At the Indiana mine, advance benching was practiced with the dragline developing a two-pit width advance bench. The cycle times and productivity (m^3/h) calculated from the simulated model were within 10% of the actual data observed in the field. Also, the final pit profile of the model after mining was reasonably close to that observed at the actual mine.

Most surface mines in the western coalfields mining moderately pitching seams use 19- to 38-m^3 (25- to 50-cu yd) bucket size draglines. A 27-m^3 (35-cu yd) bucket size dragline was selected in this study based on production requirements. A similar size dragline is currently being used at the surface mine from which the basic assumptions for this study were drawn. The selected dragline characteristics are presented in Table 4 and are estimated from the dragline performance curves supplied by the manufacturer. The dragline operating parameters are shown in Table 5, and the range diagrams of the dipline and strikeline pit orientations are shown in Figs. 2 and 3.

Table 2 — Production Summary for the Three Diagonal Line Cases Studied

Diagonal Line Cases	Availability		Average OVB Depth	Average Coal Thickness	Average Coal Prod. per Shift	Average OVB Prod.** per Shift		Average Stripping Ratio	OVB Prod. Rates	
	OVB	Coal Loading	(m)	(m)	(t)*	(t)	(m^3)	(m^3/t)	(t/h)	(m^3/h)
Planned Production (Average Condition)	0.85	0.95	46 (150 ft)	6 (20 ft)	4114	20400	11430	5.83***	—	—
Case #1	0.85	0.95	46 (150 ft)	6 (20 ft)	5840	20850	11680	4.20	278	996
Case #2	0.85	0.95	46 (150 ft)	6 (20 ft)	5449	20980	13980	5.39	260	1003
Case #3	0.85	0.95	46 (150 ft)	6 (20 ft)	5490	20730	13820	5.29	263	989

* *Two coal loading shifts per day*

** *Three overburden stripping shifts per day*

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$$\frac{11430\ m^3/\text{shift} \times 3\ \text{shifts/day} \times 7\ \text{days/week} \times 52\ \text{weeks/year}}{4114\ m^3/\text{shift} \times 2\ \text{shifts/day} \times 5\ \text{days/week} \times 52\ \text{weeks/year}} = 5.83$$

Table 3 — Truck Performance Summary for the Three Diagonal Line Cases

Diagonal Line Cases		Total No. and Size of Trucks	Total No. of Trips/ Shift*	Average Wait Time (Min)	Average Load Time** (Min)	Averate Down Time** (Min)	Average Travel Time*** Loaded (Min)	Average Travel Time*** Empty (Min)
Case #1	1st Loading Point	4 (154-t)	66	421.55	504.05	82.49	8.08	5.83
	2nd Loading Point	4 (154-t)	71	501.45	388.42	54.34	8.33	5.67
	Coal Loading Point	4 (109-t)	51	341.45	582.72	36.38	7.08	5.75
Case #2	1st Loading Point	5 (109-t)	92	541.18	463.19	74.61	8.08	5.92
	2nd Loading Point	5 (109-t)	102	412.92	284.55	23.71	8.25	5.67
	Coal Loading Point	4 (77-t)	76	221.65	417.64	79.80	6.33	5.75
Case #3	1st Loading Point	4 (154-t)	69	509.58	469.24	38.37	8.08	5.83
	2nd Loading Point	4 (154-t)	73	502.84	412.69	98.31	8.33	5.67
	Coal Loading Point	4 (77-t)	72	229.18	470.56	111.42	6.33	5.75

* *Average shift time is 435 minutes (45-minute lunch break).*

** *Average wait, load, and down times are average times spent by all trucks per shift either waiting in line or in actual loading.*

*** *Average travel loaded and travel empty times for a truck per trip from the loading point to dump and back.*

Table 4 — *Dragline Specifications*

Boom length	94.5 m (310 ft)
Boom angle	32°
Boom foot to ground distance	4.1 m (13.5 ft)
Boom foot to center distance	6.2 m (20.3 ft)
Dumping height	39.6 m (130 ft)
Dump bucket clearance	9.1 m (30 ft)
Dumping radius	86.9 m (285 ft)
Digging depth	48.8 m (160 ft)
Length of steps	2.1 m (7 ft)
Walking speed	0.07 m/s (0.15 mph)
Dragline to center	10.7 m (35 ft)
Fair leed to ground	4.6 m (15 ft)
Bucket capacity	26.0 m^3 (34 cu yd)
Base diameter	15.2 m (50 ft)
Owning and operating cost	*$300.00/hr*

Table 5 — Operating Specifications for the Dragline

Time increment	0.50 sec
Hoist rate	3.20 m/s (630 fpm)
Payout rate	4.06 m/s (800 fpm)
Swing rate	0.007 m/s (1.46 fpm)
Lower rate	5.76 m/s (1134 fpm)
Retrieve rate	4.06 m/s (800 fpm)
Drag time	10 sec
Dump time	2 sec
Spot time	2 sec
Average cycle time	45 sec

Dragline stripping operations in both the dipline and strikeline pit orientations were optimized using the dragline simulation model. The modeling of the strikeline and dipline pit orientations was similar except for the advance of the pit and of the entire mining operation. Only the downdip advance was simulated for the strikeline pit orientation. Dragline stripping performance was optimized by considering an area 610 × 610 m^3 (2000 × 2000 cu ft). A computer program developed by Chugh and Barras (1983) was used to compute the width of the extended bench for varying overburden depth, pit width, and dip of the seam, and these were utilized as input in the dragline simulation model.

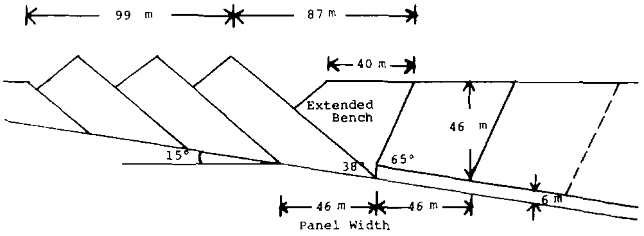

Fig. 2 — Range diagram for strikeline pit orientation at a maximum depth of 46 m (150 ft)

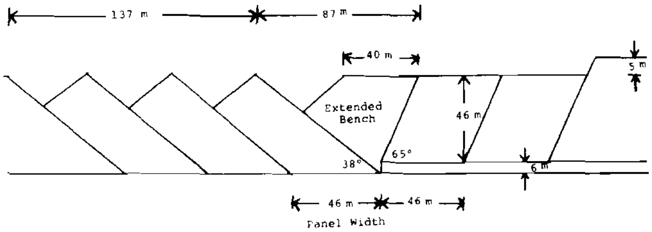

Fig. 3 — Range diagram for dipline pit orientation at a maximum depth of 46 m (150 ft)

Panel width affects the coal loadout, spoil stability, and operating cycle times of the dragline (Atkinson, 1979; Fluor, 1981). Therefore, sensitivity analyses were conducted on the pit width, digout length, depth of overburden, and dip of the seam to evaluate their effects on dragline performance. A coal seam dipping at 15% grade, a pit width and digout length of 46 m (150 ft) and 30 m (100 ft), respectively, and an overburden depth of 46 m (150 ft) were selected for the base case in conducting the sensitivity analyses. The effects of pit width and overburden depth on parameters such as width of the extended bench and volume of material rehandled were also considered.

In all analyses, operation of the dragline was found to be swing critical, which means that the swing action is the last motion occurring upon arriving in place at the dump or dig position. Thus, the swing cycle time governed the dragline production and productivity.

The effects of varying the digout length from 15 to 60 m (50 to 200 ft) on the dragline performance for a level seam and for dipline and strikeline pit orientations for a 15% pitching seam are shown in Fig. 4. In general, dragline productivity decreased with increasing digout length for a pitching seam. The dipline pit orientation is, however, most affected; a 20% decrease in productivity may be expected in increasing the digout length from 30 to 60 m (100 to 200 ft). The digout length affects the total amount of time that a dragline spends walking within a single digout and along the total length of the pit. The digout length is a function of the distance between the dragline fair lead and a point just below the top of the boom. The optimum digout length depends on maximum drag distance of the bucket and the operating efficiency of the dragline.

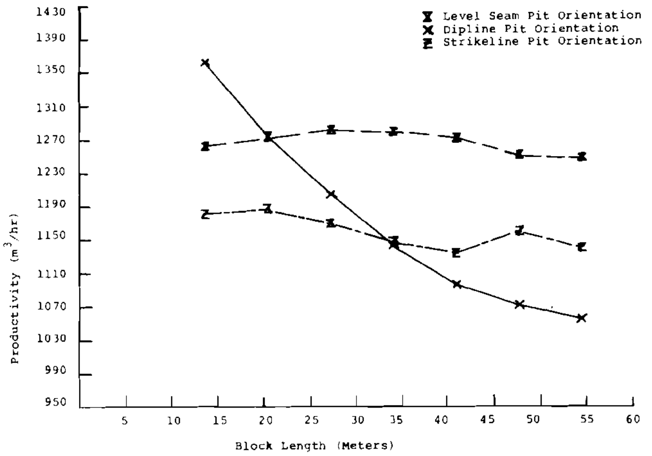

Fig. 4 — Dragline productivity vs. block length (38-m, or 125-ft, panel width)

The effects of varying the pit width from 15 to 60 m (50 to 200 ft) on dragline performance is shown in Fig. 5. The productivity of the dragline generally decreased with increasing pit width, while it is most drastically reduced for the strikeline pit orientation. It is clear that dipline pit orientation is far superior for pitching seams with seam pitch of 15%, and an optimum pit width of 30 to 35 m (100 to 115 ft) is recommended.

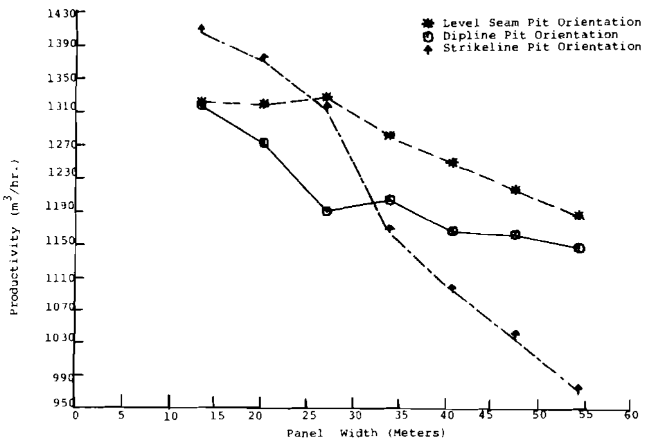

Fig. 5 — Dragline productivity vs. panel width (30-m, or 98-ft, block length)

The cycle time increases rapidly with increasing pit width for the dipline pit orientation. On the other hand, both the stripping ratio and the rehandled volume increased rapidly with wider pits for the strikeline pit orientation. This is partly shown in Fig. 6. The stripping ratio was almost a constant with the increasing pit width for the dipline orientation. This is one of the advantages of the pit orientation along the dip.

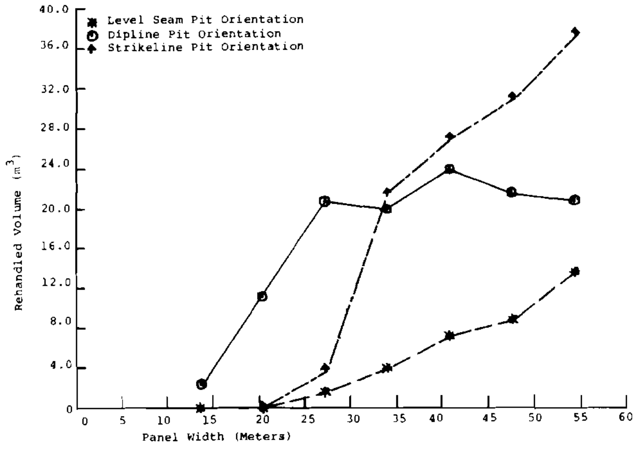

Fig. 6 — Rehandled volume vs. panel width (30-m, or 98-ft, block length)

The spoil piles seem to encroach on the top of the coal seam for seam pitch over 10% with strikeline pit orientation. This is caused by what has been referred to as the "spoil crowding effect." Digout length must be reduced with increasing depth to minimize this effect. In the case of the dipline pit orientation, the height of the spoil piles increases as the mining depth increases. Rehandle volumes are significantly increased as the dragline moves toward the dipside. The height of the advance bench must be increased toward the deeper side in the dipline pit orientation to minimize rehandle volumes.

Based on overburden stripping optimization studies, the optimum values of the pit width, digout length, and dragline productivity are shown in Table 6. These optimum cases were subjected to an economic evaluation along with the optimized diagonal line pit orientation case (see *Simulation with diagonal pit orientation*).

Table 6 — Optimized Pit Parameters and Dragline Productivity for Dipline and Strikeline Pit Orientations

Pit Orientation	Pit Width (m)	Digout Length (m)	Productivity (m³/h)
Dipline	23-30 (75-100 ft)	23-30 (75-100 ft)	1203.3 (1575 cu yd/hr)
Strikeline	26-30 (85-100 ft)	23-30 (75-100 ft)	1241.5 (1625 cu yd/hr)

Economic evaluation of dipline, strikeline, and diagonal line pit orientations

The surface mine cost model (COSTMOD) was used for economic evaluations of the optimized mining systems. The equipment cost data were obtained from the equipment manufacturers, and some of the operating cost information was updated to reflect current values. The equipment and operating costs were based

Table 7 — Cost Comparison of Mining Systems in Different Pit Orientations*

Pit Orientation	Operating Cost ($/t)	Total Manpower Requirements (salaried & labor)	Selling Price of Coal ($/t)	Selling price of coal / Selling price of coal in Diplina Orientation
Diagonal Line	12.17	129	14.81	1.04
Strikeline	12.14	167	16.86	1.18
Dipline	10.08	141	14.23	1.00

* *Annual coal production — 1.80 × 10^6 t (2.00 × 10^6 st); rate of return 20%*

on 1983 dollars. Information pertaining to labor cost in 1983 was obtained from the UMWA labor contract of 1981 to 1982. The capital cost included both primary and support equipment costs. The supplies cost was calculated as a fixed percentage of the capital cost in the model. Cost of land and exploration was included in the analysis as a royalty cost of $1.50 per ton of clean coal. The numbers of salaried and hourly personnel were obtained from default values built into the COSTMOD program.

The rate of return (ROR) was varied from 15% to 20% to determine its effect on the selling price of coal for selected mining techniques. The prices were compared for the pit orientations under study. The selling price obtained for the strikeline pit orientation was within 25% of those experienced by the coal company in the Hanna Coal Basin.

The results of comparative economic evaluations for 20% ROR are summarized in Table 7. These are presented as a percentage of the mining system with dipline pit orientation since it was the most economical. Under present-day economics, all three mining systems are feasible for mining a moderately pitching coal seam.

The dipline technique resulted in the lowest selling price per ton of coal. The operating and supply costs were the least for the dipline pit orientation. The diagonal line pit orientation provided the least capital outlay, and it ranked second to the dipline pit orientation in the selling price of coal (4% to 6% higher). The strikeline technique was the most expensive (18% to 20% higher than dipline). This is primarily due to a large volume of rehandled overburden material.

The selling price of coal per ton as calculated by Skelly and Loy (1978) for a rate of return of 15% and 1977 dollar costs was $10.62 per ton for the diagonal pit orientation and $13.26 and $13.28 per ton, respectively, for dipline and strikeline pit orientations. At an inflation rate of 10% compounded annually, these prices would be expected to increase about 77% in 1983. This study projected significantly lower mining costs than did Skelly and Loy, and these costs were within 25% of those experienced by the mining company in the Hanna Coal Basin. The large disparity in mining costs is due to the inflation adjusted equipment costs.

Concluding remarks

This paper has discussed and evaluated selected pit configurations for surface mining a coal seam pitching less than 15%. The available dragline and open-pit material handling simulation models and surface mine cost models were used to optimize the mining systems and estimate the mining cost for each pit configuration. The study has shown that for mining conditions typical of the Hanna Coal Basin in Wyoming, dipline pit orientation with a dragline for overburden stripping is most economical. The diagonal line pit orientation at an apparent dip of 11% with shovel-truck mobile equipment for overburden stripping is the second most economical mining technique. Pit orientation along the seam strike with a dragline for overburden stripping is most expensive. It is interesting to note that most mines utilize pit orientation along the seam strike. The authors strongly recommend that coal companies surface mining moderately pitching seams consider dipline pit orientation during the mine planning and feasibility studies. The dipline pit orientation has the added advantages of improved mine reclamation, uniform stripping ratios, and uniform coal production over the life of the mine. ■

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