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An evaluation of mining methods using continuous miners in thin coal seams

by R. TRUEMAN*

SYNOPSIS

The imbalance between the coal resources contained in thin seams (1,5 m or less) and the production from them is outlined. It is suggested that an increase in the exploitation of thin coal seams is necessary, and that drum-type continuous miners can produce a substantial amount of any increase.

Continuous miners are employed in a number of mining methods including bord-and-pillar, pillar extraction (stooping), rib-pillar extraction, and shortwalling. These techniques of mining are evaluated with respect to production rates and the cost of extraction for South African conditions. Included in these evaluations are the types of equipment used to transport coal from the mining machine to the section conveyor belt. Computer simulation techniques are used to generate the required production levels, and interpretations are made of other results from the computer modelling.

For thin coal seams, bord-and-pillar mining utilizing continuous haulage is apparently the most productive and cost-effective of all the methods using the continuous miner. The relative efficiencies of the other techniques of mining and of coal-transportation vehicles are also outlined.

SAMEVATTING

Die wanbalans tussen reserwes en ontginning van steenkoolerts in dun lae van 1,5 m dikte of minder word hier toegelig. Daar word voorgestel dat 'n vermeerdering in the ontginning van dun steenkoollae noodsaaklik is en dat die drom tipe aaneendelwers 'n groot bydrae tot hierdie toename kan maak.

Aaneendelwers word tans in 'n verskeidenheid ontginningsmetodes toegepas insluitende kamer en pilaarafbou, pilaarafbouing, strookpilaarwinning en kort strookfronte. Hierdie mynboumetodes word vergelyk met betrekking tot produksie tempo's en ontginningskoste in Suid-Afrikaanse omstandighede. Hierdie vergelykings sluit die toerusting in, wat gebruik word om the steenkool van die front af tot by die afdelings-vervoerband te vervoer. Produksietempo's is bereken deur middel van rekenaarsimulasie terwyl ander resultate wat deur simulasie verkry is, ook vertolk word.

Dit wil voorkom asof vir dun steenkoolerts, die kamer en pilaar mynboumetode met volgbande die mees produktiewe en doeltreffende van al die metodes is wat die aaneendelwer gebruik. Die relatiewe doeltreffendheid van ander mynboumetodes en vervoer toerusting word ook in die referaat bespreek.

Introduction

The number of drum-type continuous miners working in narrow seams in South Africa increased from 5 in 1977 to 11 at the present time. Approximately one-third of the Republic's production of thin-seam coal is now being obtained by this type of continuous miner. A thin coal seam is defined here as any seam that is 1,5 m thick or less, 0,75 m being the minimum thickness at which drum-type continuous miners can operate if continuous-haulage transport is used.

In South Africa, continuous miners are at present used only in thin seams for stooping, bord-and-pillar workings, and longwall development. These techniques are, in general, characterized by low production rates compared with the use of continuous miners in thicker seams. The average monthly production using the machines in narrow seams between 1977 and 1980 was 12,1 kt. The monthly output in the same period in medium and thick seams was 21,6 kt and 28,7 kt respectively[1].

In other parts of the world, shortwall mining is practised in thin seams, but has not been used under similar conditions in South Africa. Interest in the shortwall method has significantly waned since the late 1970s, before which the technique was relatively successful in countries such as the U.S.A.[2]. Shortwall mining could, nevertheless, prove to be a successful method at the present time in South Africa owing to the differences in mining conditions and labour economics between the Republic and overseas countries. Rib-pillar extraction has never been utilized in thin seams but is proving to be successful in moderately thick seams in the Republic, and is being considered for narrow seams. With low production rates from present operating methods, the evaluation of shortwall and rib-pillar extraction for South African narrow-seam conditions appears to be warranted.

For the reserves of thin-seam coal in South Africa, reference must be made to the results of the Petrick Commission[3], which is the only recent work that separates coal resources on the basis of seam thickness and coal quality. However, a more recent estimate by the Geological Survey[4] concluded that the Republic's total *in situ* coal resources are 35 per cent greater than those estimated by the Petrick Commission. Also, the definition of thin seams given by the Petrick Commission is a range of 0,7 to 2,0 m for metallurgical and anthracite coals, and 1,2 to 2,0 m for steam coals, which does not correspond exactly to the definition given in this paper. The reserve estimates from the Petrick Commission, outlined in Table I, nevertheless give a reasonable guideline to the resources of thin-seam coal in the Republic. It can be noted from Table I that a substantial proportion of the coal resources occurs in the thinner seams. Also, a high percentage of the better-grade coals, which are in relatively short supply in South Africa, are contained in seams that can be classified as thin.

Less than 5 per cent of the coal produced in the

* Research Fellow, Department of Mining Engineering, University of the Witwatersrand, 1 Jan Smuts Avenue, Johannesburg 2001.

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TABLE I

ESTIMATED *in situ* COAL RESERVES*

	Thin-seam reserves Mt	Total reserves Mt	Thin-seam reserves as a percentage of total %
Raw bituminous (includes washed bituminous and metallurgical)	17 400	81 300	22
Washed bituminous	10 910	34 150	32
Metallurgical	1 470	2 300	64
Anthracite	1 070	1 220	88

Source: Petrick Commission[3]

Republic is extracted from thin seams. If the current imbalance between coal resources and production is to be rectified, the amount of thin-seam mining must be increased. If recent trends concerning the greater use of continuous miners in narrow seams continue, a substantial portion of any such increase will be mined by continuous miners.

There is a need for an evaluation of the mining methods that incorporate the use of continuous miners in narrow coal seams, and computer modelling offers a technique by which this can be done cheaply and quickly. Simulation is used in this paper in the comparison of four methods of mining that use continuous miners in thin seams.

The Necessity for Computer Simulation

Comparative production rates and costs could be measured in operating sections if there were a sufficient number of different mining methods working under similar conditions. This is not the case for the use of continuous miners in thin seams within South Africa. In 1981, there were only 7 production sections, excluding longwall development, utilizing continuous miners within this range of extraction heights. Mining conditions were very different in most of the sections, making a comparative evaluation difficult. Also, continuous miners have been used only in bord-and-pillar and stooping methods within thin seams in the Republic. Shortwall mining has been utilized in narrow seams abroad, but a comparison of techniques operating overseas with those within this country would be very difficult since there are marked differences in labour availability and cost, industrial relations, shift times, and geological conditions. Rib-pillar extraction, the other mining method to be evaluated, has never been used within thin seams, either in this country or abroad; therefore, an analysis using actual operating production units is not possible.

It was considered that comparative production results could best be obtained by the use of computer modelling techniques. In this way, mining methods, even those that have never operated within narrow seams, could be evaluated on the same basis. The other important criterion for the evaluation of mining methods, economics, will be discussed later.

The FACESIM Computer Program

FACESIM is a computer program, written in Fortran, that was developed at Virginia Polytechnic Institute, U.S.A., in the early 1960s and modified for use in the Republic in the late 1960s by the Chamber of Mines of South Africa. Many of the larger mining houses and at least one manufacturer of mining machines within the Republic have copies of this program. The major components of the simulator were designed for the bord-and-pillar method of mining using conventional equipment. Built-in flexibility, however, allows for the modelling of other mining methods and equipment, including the continuous miner[5].

By the use of computer simulation, variables not relating to the techniques of mining, such as travelling time and outbye stoppages, were kept constant in the work described here. However, it was found unpractical to include the effects of varying geological conditions, which can influence mining methods differently. Only 'good mining conditions' were considered in each case. As similar mining equipment is used in all the mining techniques, it was considered that, for comparative purposes, this simplification does not detract from the results obtained.

The Mining Methods Simulated

A mining height of 1,2 m and a depth below surface of 200 m was considered for all the techniques evaluated. As such, the results given in this paper are valid only for this particular seam thickness and depth. However, work has been completed on the evaluation of the mining methods both for a range of depths and for narrow-seam extraction heights[6], and the general conclusions arrived at in the paper were found to remain valid.

Bord-and-pillar Mining

A safety factor for pillars of 1,6 was adhered to. At the depth and seam thickness outlined, pillars 11 m wide and bord widths of 6 m were considered. The four types of primary coal transporters were simulated: shuttlecars, ramcars, tractor-and-trailers, and continuous haulages. Because of the similarities between ramcars and tractor-and-trailers, notably in carrying capacity, these machines were considered to be identical for evaluation purposes. A seven-roadway production section was modelled for wheeled coal transport and, because of the limited reach of the system, a five-roadway section for continuous haulages. It was assumed that cross slits were driven at 60 degrees in the case of continuous-haulage coal transport.

Pillar Extraction

A safety factor of 2,0 was used for pillars. Pillar widths of 13 m and bords 6 m wide were therefore utilized in the development phase. In the pillar-extraction stage, extraction lines of 45 degrees were worked. When pillars are extracted by continuous miners, operations are concentrated on a single pillar, which is extracted completely before moving to the next pillar. Support operations, in the form of timber finger lines, resulted in the halting of production. Ancillary operations, such as changes of cutter picks, were considered to be taking place when

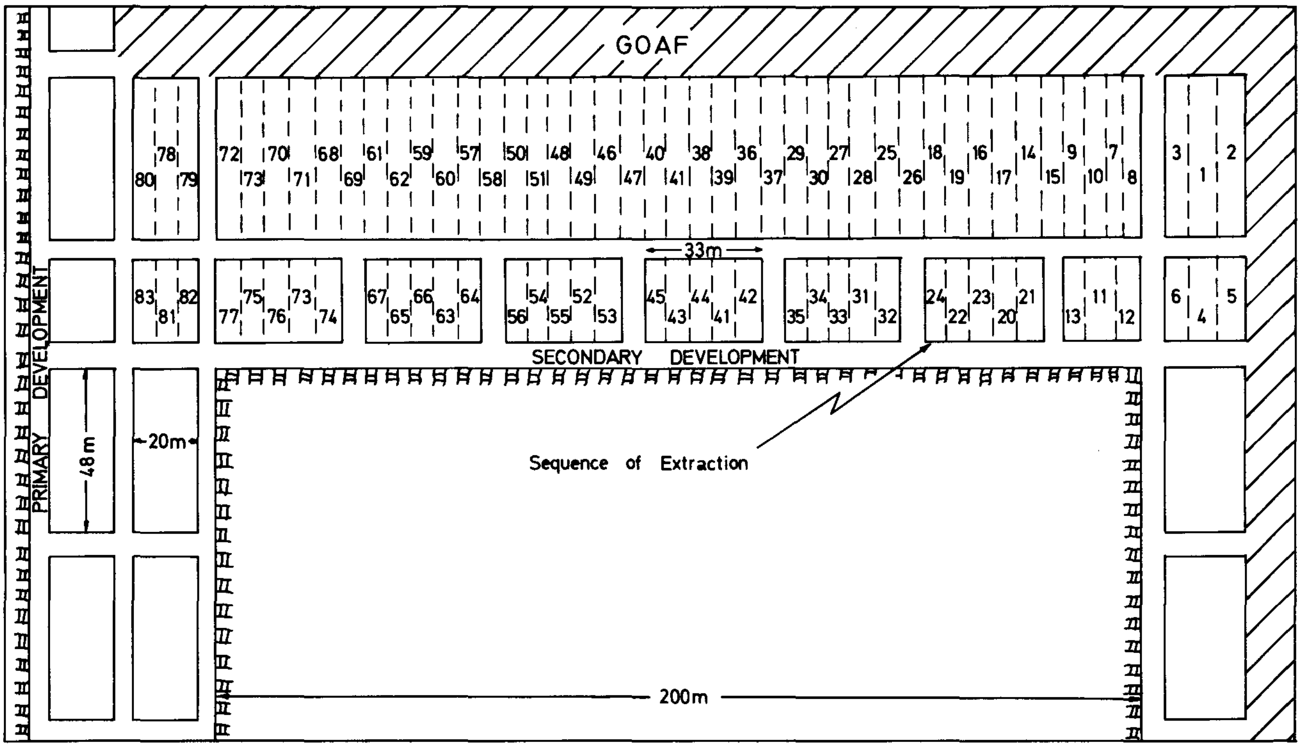

Fig. 1—Layout for rib-pillar extraction (Sigma method)

coal winning stopped for the placement of support. Only wheeled coal transporters are used in stooping operations at the present time. Both types of wheeled coal transporters, i.e. shuttlecars and ramcars/tractor-and-trailers, were simulated.

Rib-pillar Extraction

The standard rib-pillar extraction section as developed at Sigma Colliery was simulated. In this method, primary development consists of three roadways at one side of a panel of coal, which is 200 m wide, as shown in Fig. 1. Bord widths are kept at 6 m. A secondary development is driven at right angles to the primary development to intersect a bleeder roadway left from a previous panel. A solid rib of coal 48 m wide is left between the secondary development and the goaf, and is extracted by the driving of a tertiary roadway to the goaf, leaving a rib of coal 7 m wide, which is extracted in retreat. Both the primary and secondary pillars are stooped in a similar manner for the full panel width before another secondary development is started. Production must be halted in tertiary drivages to allow roofbolting every 12 m. Ancillary operations on the continuous miner can be carried out during this stop in production. When the 7 m wide rib of coal is extracted, breaker lines must be set before each drum-width lift is commenced, resulting in a series of short delays to production. Both types of wheeled coal transporters were utilized.

Shortwalling

The shortwall panel simulated is shown in Fig. 2.

In this method of mining, developments consisting of three roadways are driven at either side of a panel of coal 50 m wide. These developments are intersected at 90 degrees to form the shortwall face, which is supported by self-advancing powered supports. The continuous miner

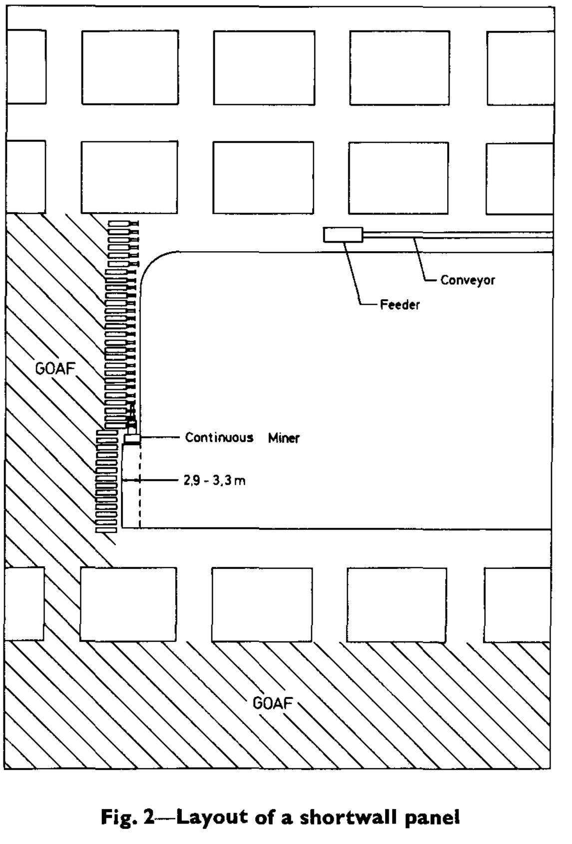

Fig. 2—Layout of a shortwall panel

takes a lift of coal that is the same width as the drum off the shortwall face from the intake airway side towards the return. A waiting time is required between lifts for coal spillages to be cleaned up before the final advance of the supports. This clean-up is usually carried out as a separate operation with a scoop tram. Ancillary operations, such as pick changes and continuous-miner maintenance, can be carried out in this unproductive time.

Input to FACESIM

Table II outlines the input data to the FACESIM program as regards mining machinery.

These are typical values being achieved at the present time in South African collieries, and do not take into account the human element in operating the machines. This simplification should not, however, detract from the results obtained since similar machinery is used in all the mining methods. In addition, the following parameters must be stated for each cut in the sequence of extraction for all the mining methods:

(i) cut width and depth,
(ii) the tramming distance for each wheeled coal transporter from the change-out point to the conveyor tip,
(iii) the change-out distance,
(iv) the tramming distance for the continuous miner between cuts.

Each simulation is carried out until the need for a conveyor-belt extension or retraction.

TABLE II

MACHINERY INPUT DATA TO THE FACESIM COMPUTER PROGRAM

Payloads	
Low-profile shuttlecar	3,75 t
Low-profile ramcar/tractor-and-trailer	5,40 t
Continuous haulage (conveyor-belt type)	7,28 t/min
Average Tramming Rates	
Continuous miner	5,00 m/min
Shuttlecar/ramcar/tractor-and-trailer	84,70 m/min
Roofbolter	33,30 m/min
Continuous-miner cutting/loading rate	4,00 t/min
Time to erect breaker lines or finger lines	10 min
Time to clean-up and advance powered supports (shortwall)	30 min

Results Obtained from FACESIM

The output obtained from the computer program for the production stages of the four mining methods can be seen in Table III, and the results of simulations of the development phases, where this is applicable, are outlined in Table IV. It must be noted that the productivity results represent the potential for the techniques of mining that were simulated.

Interpretation of FACESIM Results

The results from the FACESIM computer program not only give productivity figures, measured in tons per available minute, but also provide a breakdown of the various mining activities. This enables a partial evaluation of the methods. Each technique of mining is discussed separately.

TABLE III

PRODUCTIVITY SIMULATION FOR PRODUCTION STAGES

Mining method	Bord-and-pillar			Pillar extraction		Rib-pillar extraction		Shortwalling	
Primary coal transportation	Shuttlecar	Ramcar/ t & t*	Continuous haulage	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*
Tons per available face minute	2,24	2,47	2,63	1,68	1,92	1,30	1,50	1,69	1,92
Cutting/loading time as a percentage of total	55,89	61,81	65,85	42,12	48,00	32,54	37,57	42,32	47,94
Tramming time as a percentage of total	21,98	24,49	34,15	21,18	24,14	6,17	7,13	5,70	6,46
Wait-no-shuttlecar as a percentage of total	5,10	0,0	—	6,32	0,79	4,47	0,95	0,85	0,0
Waiting time roofbolting as percentage of total	0,0	0,0	0,0	0,0	0,0	8,68	10,02	—	—
Waiting time erecting breaker or finger lines as a percentage of total	—	—	—	10,70	12,20	17,99	20,78	—	—
Wait—clean up and advance powered supports for next lift time as a percentage of total	—	—	—	—	—	—	—	18,36	20,79
Change-out time as a percentage of total	17,03	13,05	—	19,68	14,87	30,15	23,55	32,79	24,81

* t & t = tractor-and-trailers

TABLE IV

SIMULATION FOR DEVELOPMENT STAGES

Mining method	Pillar extraction		Rib-pillar extraction: Primary development		Rib-pillar extraction: Secondary development		Shortwalling	
Primary coal transportation	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*
Tons per available face minute	2,11	2,36	1,21	1,44	1,60	1,86	1,53	1,78
Cutting/loading time as a percentage of total	52,69	58,99	30,22	36,00	40,04	46,47	38,24	44,61
Tramming time as a percentage of total	22,76	25,78	30,60	36,45	26,28	30,50	30,45	35,52
Wait-no-shuttlecar as a percentage of total	6,69	1,30	13,67	6,50	9,67	3,79	5,45	0,82
Waiting time roofbolting as a percentage of total	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Change-out as a percentage of total	17,86	13,93	25,52	21,05	24,07	19,32	25,87	19,05

* t & t = tractor-and-trailers

Bord-and-Pillar Mining

It can be seen in Table III that the unproductive tramming time of the continuous miner is substantial. This is due to the very slow tramming speed of the mining machine, and the fact that the amount of coal produced per unit of advance of the production equipment is less than for thicker seams, requiring more heading changes. Where wheeled coal transporters are employed, delays associated with this equipment, particularly change-outs, are high at this seam height. This is due to the low carrying capacity of these units in thin seams. The higher capacity of ramcars/tractor-and-trailers result in an increase in productivity over shuttlecar haulage due to a reduction in the wait-no-shuttlecar and change-out times. Higher-capacity vehicles take a longer time to fill; thus transporters have more time to return to the change-out point. With a greater carrying load per vehicle, the number of loads are reduced, which results in a reduction in the number of change-outs. The use of continuous haulages negates the effect upon coal output of wait-no-shuttlecar and change-outs, thus leading to higher productivity.

Pillar Extraction

The development stage of stooping is bord-and-pillar mining. However, because of the higher safety factor required, larger pillars are formed than if pillars were not to be extracted. This results in longer tramming and change-out distances, with a corresponding negative influence upon productivity. In the stooping stage, delays associated with the wheeled coal transportation are even higher. The higher capacity of ramcars/tractor-and-trailers is again an improvement upon shuttlecars. The time spent erecting timber finger lines also has an adverse influence upon coal output. This unproductive time, however, can be partly offset in that pick changes can be carried out during this period.

Rib-pillar Extraction

Large pillars are formed in the development stages of rib-pillar extraction, which has a negative influence on productivity, as previously discussed. In the production phase, a considerable amount of time available for production is lost owing to support operations and change-outs of wheeled coal transporters. Less coal is produced in thinner seams before the erection of breaker lines or roofbolting is needed than in thicker seams, thus increasing the influence of these activities. Pick changes can, however, be completed during the setting of breaker lines, and some continuous-miner maintenance can be done while awaiting roofbolting of the tertiary drivage. Change-out distances are very long compared with those for bord-and-pillar mining in thin seams. When low-capacity vehicles are used, the number of change-outs for a given output is increased. The use of ramcars/tractor-and-trailers is an improvement upon shuttlecars in this respect. The unproductive tramming time of the continuous miner is relatively small in the production stage.

Shortwalling

The relatively large pillars associated with shortwall development result in delays to production associated with continuous-miner tramming and wheeled coal transporters, as previously discussed. During the working of the shortwall face, the time spent by the production machine in tramming is low. However, the change-out times of the wheeled coal transporters are high because of the low carrying capacity of the vehicles and the long change-out distances. Ramcars/tractor-and-trailers are again an improvement on shuttlecars in this respect because of their higher payload. The clean-up operation that is required before the powered supports are advanced takes up a considerable amount of the time available for production, but some of this time can be usefully employed in that cutter-pick changes and some con-

TABLE V

MONTHLY PRODUCTION STATISTICS

Mining method	Bord-and-pillar			Pillar extraction		Rib-pillar extraction		Shortwalling	
Primary coal haulage	Shuttlecar	Ramcar/ t & t*	Continuous haulage	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*
Monthly production, t	29000	31900	32700	26300	29600	17900	21700	23100	26500

* t & t = tractor-and-trailers

tinuous-miner maintenance can be carried out.

Monthly Production

Monthly production statistics were calculated from the computer-simulated productivity results, the following parameters being used for all the mining methods:

(i) an average shift time of 540 min,
(ii) a travelling time of 60 min per shift,
(iii) an inspection time of 10 min per shift,
(iv) two production shifts per day,
(v) 22,4 production shifts per month.

There are slight differences in the time available for production in the mining methods. From studies carried out by the Chamber of Mines of South Africa[7], an average engineering availability of 61,4 per cent was deduced for bord-and-pillar mining with continuous miners and wheeled coal transporters. This includes the ancillary operation of changing picks. As the same equipment is utilized for pillar extraction and shortwalling, a similar engineering availability is expected. The support operations for these methods can take place concurrently with pick changes and/or a part of continuous-miner maintenance, as previously discussed. This has the apparent effect of decreasing the engineering down-time, although obviously this is not the case. An engineering availability of 57,8 per cent can be expected for continuous haulages with continuous miners. The extra down-time can be attributed to the unavailability of back-up coal transporters and to complete stops in production should there be any downtime for the continuous haulage.

The expected monthly production statistics for all the techniques of mining that were investigated are shown in Table V. The development stages were taken into consideration, where applicable, in that the proportion of coal extracted in each stage was taken into account. These are arrived at by multiplication of the tons per available minute by the time available at the face (shift time minus travelling time minus inspection time), by the engineering availability, and by the number of shifts per month. Because 'good mining conditions' were simulated, the results outlined represent the potential at present availabilities.

Economic Analyses

The mining costs were taken directly or, in the case of methods that have not operated within the Republic, were derived from information gathered from coal mines operating in the Republic at January 1981 levels. These costs were obtained from mines that were representative of the 'good mining conditions' used to generate production levels. An evaluation of in-panel costs only was made. This was considered applicable since outbye costs such as management, surface workshops, and shaft conveyors are linked to the mines' output and should therefore be similar on a cost-per-ton basis. The in-section capital and running costs for the mining methods evaluated are outlined in Table VI. A typical breakdown of other costs, using bord-and-pillar mining with wheeled coal transporters as an example, can be seen in Table VII. These are proportioned costs between the production and development stages where appropriate. The extra labour costs involved in moving, repairing, and setting up the powered supports are included for shortwall mining.

In the economic analyses, all the mining methods were compared over a fixed life of 10 years. The estimated escalation of working costs, labour, and capital equipment, together with the rates of inflation in the period

TABLE VI

IN-SECTION CAPITAL AND RUNNING COSTS

Mining method	Bord-and-pillar		Pillar extraction	Rib-pillar extraction	Shortwalling
	Wheeled coal transport	Continuous haulage			
Capital cost, R	1 975 000	1 744 000	1 975 000	1 841 000	2 775 000
Annual cost of skilled labour, R	120 100	120 100	145 300	139 200	136 300
Annual cost of unskilled labour, R	100 300	90 100	111 600	109 300	96 000
Other working costs, c/t	186	179	181	174	171

TABLE VII

OTHER WORKING COSTS: BORD-AND-PILLAR MINING WITH WHEELED COAL TRANSPORTERS

Cost Centre	Cost, c/t
Underground mining	
Mining overheads	1,35
Coal extraction	27,68
Conveyor-belt maintenance	3,49
Ventilation	6,19
Pumping	0,77
Stonedust	5,08
Roof support	16,94
Transport	4,93
SUB-TOTAL MINING	66,43
Engineering	
Spares, lubrication, and sub-assemblies	86,46
Conveyor-belt maintenance	5,40
Power reticulation	16,00
Fan maintenance	0,04
Transport maintenance	9,96
Pump maintenance	0,63
Compressor maintenance	1,34
SUB-TOTAL ENGINEERING	119,83
TOTAL 'IN-SECTION'	186,26

1981 to 1990 inclusive, are detailed in Table VIII. The estimated life of equipment was either taken in years of life or tons produced, as applicable, and is outlined in Table IX. It is assumed that, at the end of useful life of the capital equipment, it has no resale value. After a period of 20 years, all the machinery is considered to be obsolete, also without resale value. In the last year of the fixed 10-year period, sums were paid back to the projects, which are proportional to both the remaining life of the equipment and the original purchase prices.

The in-panel cost per extracted ton of coal was calculated for each year of the projects at 1981 levels, and then regularized, a cost of capital of 3 per cent over the rate of inflation being assumed in all cases. A cash-cost flow example for shortwall mining can be seen in Table X. Evaluations were also carried out at a 7 per cent effective cost of capital but, as no differences were noted, these evaluations are not given here.

The regularized in-section costs per ton, at 1981 prices, for all the techniques evaluated are outlined in Table XI.

TABLE VIII

PROJECTED ESCALATION RATES: 1981 TO 1990* (INCLUSIVE)

Year	Inflation rate %	Working costs, %			Capital costs %
		Unskilled labour	Skilled labour	Other	
1981	—	—	—	—	—
1982	15	14	10	15	16,5
1983	13	17	13	13	13,5
1984	12	19	12	12	15
1985	12	19	12	12	17
1986	13	20	13	13	20
1987	14	21	14	14	20
1988	13	20	13	13	19
1989	12	19	12	12	18
1990	11	18	11	11	17

* Source: Anglo Transvaal Consolidated Co. Ltd

TABLE IX

LIFE EXPECTANCY FOR INDIVIDUAL ITEMS OF EQUIPMENT*

Item	Life expectancy per unit
Continuous miner	3 Mt
Shuttlecar/ramcar/t & t†	1,5 Mt
Roofbolter	6 Mt
Coal scoop	2 Mt
Feeder, C/V tail-end drive, chute	2,5 Mt
Gate-end boxes, signals, communications, pumps and mobile stores, powered supports	10 years
Transformer (750 kVA FLP)	20 years
Transformer (lighting)	20 years
Other	Included in working costs

* Source: Estimates obtained from several manufacturers of mining machinery

† t & t = tractor-and-trailers

TABLE X

CASH-COST FLOW EXAMPLE: SHORT WALLS WITH RAMCAR/T & T* COAL HAULAGE

Conditions
Annual production 317,9 kt
Regularized cost per ton R3,50

Year	Inflation rate %	Unskilled wages R	Skilled wages/ salaries R	Other underground working costs R	Capital cost R	Total cost R	Current terms R/t	1981 terms R/t
1981	—	95 900	136 300	543 500	2 775 000	3 550 700	11,17	11,17
1982	15	109 300	149 900	625 000	—	884 200	2,78	2,42
1983	13	127 900	169 400	706 200	—	1 003 500	3,16	2,43
1984	12	152 200	189 700	791 000	—	1 132 900	3,56	2,45
1985	12	181 200	212 500	885 900	—	1 279 500	4,03	2,46
1986	13	217 400	240 100	1 001 000	—	1 458 500	4,59	2,48
1987	14	263 100	273 700	1 141 200	—	1 677 900	5,28	2,50
1988	13	315 700	309 300	1 289 600	—	1 914 500	6,02	2,53
1989	12	375 600	346 400	1 444 300	368 600	2 534 900	7,97	2,99
1990	11	443 300	384 500	1 603 200	–134 700	2 296 200	7,22	2,44

* T & T = Tractor-and-trailer

TABLE XI

IN-SECTION COST PER TON

Mining method	Bord-and-pillar			Pillar extraction		Rib-pillar extraction		Shortwalling	
Primary coal transportation	Shuttlecar	Ramcar/ t & t*	Continuous haulage	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*	Shuttlecar	Ramcar/ t & t*
Regularized cost per ton, R	3,26	3,12	2,93	3,31	3,16	3,87	3,53	3,71	3,50

* t & t = tractor-and-trailers

In the economic analyses, no account was taken of the different percentage extractions for the various mining methods, which range between 58 and 90 per cent in-panel.

Conclusions

Of the present methods of thin-seam mining employing continuous miners, a bord-and-pillar layout produces the highest output of coal at the lowest cost. In the 'good mining conditions' simulated, continuous haulages give better results than the use of wheeled coal transporters. If wheeled vehicles are used, ramcars/tractor-and-trailers are preferable to shuttlecars.

Of the methods of mining using continuous miners that result in the caving of roof strata, pillar extraction is the most efficient from the viewpoints of both production and cost of extraction. The use of ramcars/tractor-and-trailers as the primary coal-haulage vehicles is preferable, which is also the case with rib-pillar extraction and shortwalling. It was found that shortwall mining has a greater output potential and lower extraction cost than rib-pillar extraction in thin seams at the present time.

The use of computer-modelling techniques permits the evaluation of a range of mining methods without resort to costly practical testing. The breakdown of the production activities may also provide information that can be used in the improvement of existing techniques and equipment for the mining of narrow coal seams. As the technique described here investigates only 'good mining conditions', allowance must be made for local conditions.

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