Dragline Digging Methods in Australian Strip Mines - A Survey

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ABSTRACT

Open cut mining in Australia is facing the greatest challenge in its history in attempting to compete not only with other operations internationally, but also with underground operations domestically. Most flat dip and shallow depth surface-mineable coal reserves have been depleted during the last two decades and new open cut operations must extract deeper coal deposits. As open cut coal mines move into deeper areas and the stripping ratios increase, the relative cost of overburden removal also increases. It therefore becomes even more important to design the mine around the optimum overburden removal scheme. The deeper mines are usually multi-seam operations with a more complex geology and with more geotechnical and hydrological problems. Deeper mines are subjected to greater problems requiring more detailed mine planning and design, such as selection of the optimum mining method and pit layout. In planning and design of such operations, the number of alternative methods which need to be considered is consequently greater.

Dragline productivity and its stripping capabilities are directly affected by the selection of digging method, strip layout and pit geometry. Every mine has a unique combination of geological conditions. The operating methods that work well at one mine may not necessarily work at another site. Selection of an optimal stripping method, strip layout and pit geometry for a given dragline must be considered with respect to the geological conditions of the mine. With increasing geological complexity of Australian strip mines, it is becoming more important to use sophisticated techniques such as computerised mine planning methods to assist in optimising dragline operations.

THE PROBLEM

In the past twenty years the walking dragline has emerged as the dominant overburden removal machine in surface coal mining operations in Australia. There are now over 60 large walking draglines operating in Australian open cut coal mines (Aspinal, 1992). Four new units were expected to be ordered in 1996 and possibly another four units in the next five years. The book value of these new draglines is about A$800 million (Hamilton, 1996). In NSW, there has been a significant growth in using dragline operations compared with other mining methods since 1980 (Fig 1). Unlike underground mining, the productivity of Australian open cut coal mining has been disappointingly static during the last two decades with the annual raw coal output per man employed remaining the same as it was in 1970/71 (Wentworth, 1988). Although there are several reasons for this steady status, the major factor is due to insufficient technical improvement in mining methods as the geological conditions become more complex.

Overburden depths at many mines have already reached depths which draglines alone cannot handle without additional pre-stripping equipment. Many Australian mining companies are currently faced with the decision either to continue stripping to increasing depths or to commence underground mining operations. These specific conditions require an extensive analysis of each dragline's working method to establish:

- the operating limits for the machine;
- the productivity during chop cut and rehandling operations; and
- the efficient sequences of different mining activities.

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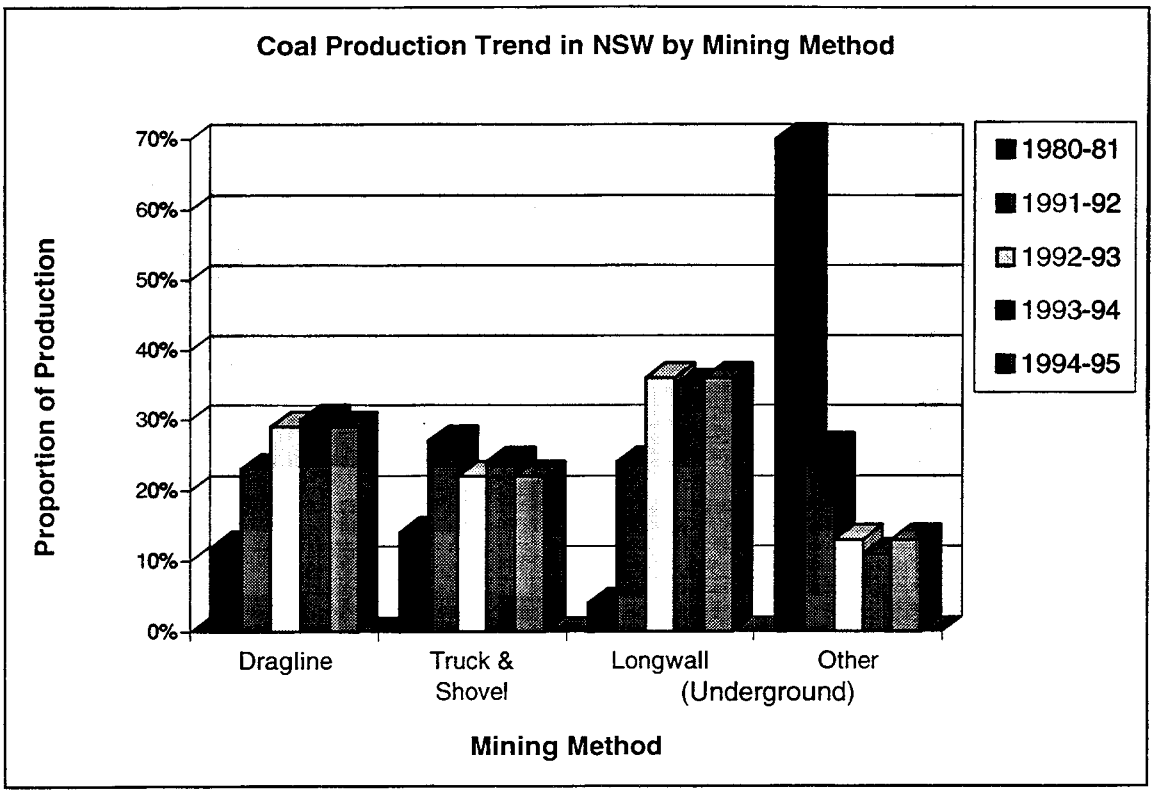

Fig. 1- Comparison of coal production by principal mining method in NSW[2]

A review of several case studies of stripping operations by Atkinson et al (1985) clearly indicated that the stripping capabilities of the draglines used in Australian open cut coal mines were not fully utilised, resulting in low operating efficiency. There are several ways to increase the efficiency of overburden removal operations, such as improved design of dragline components. However, dragline productivity improvement through the modification of the digging method is the most cost effective and usually the most efficient means (Pippenger, 1995). The feasibility of significant improvement in dragline performance (up to 20%) through modifications to the digging method has been reported by several mines. The idea of modifying the digging method becomes increasingly more attractive as stripping ratio increases during mine life, particularly in multi-seam operations.

In order to improve the efficiency of a dragline operation it is necessary to have a thorough understanding of the characteristics of the digging method and the sequencing of the excavation operations. There is no comprehensive study evaluating the various digging methods currently in use by Australian open cut coal mines. Very limited information can be found describing innovative digging methods and most of them are internal and confidential mine reports. Most of the available literature describe basic dragline digging methods applied to the US coal fields. Australian dragline mines generally have greater overburden and to some degree have more complex geological conditions than US and European strip mines. Small draglines are rarely used and no tandem dragline operation currently exists in Australia. Many Australian dragline operations are using innovative digging methods to cope with these more difficult geological conditions and to increase dragline capabilities such as maximum reach and dump height. Because of the deeper overburden, most Australian strip mines have wider pits, typically 60-80m versus 40-50m pit width overseas, to reduce overall rehandle, dragline walking time and avoid both spoil and highwall failures.

A study was conducted to highlight the current status of the use of dragline in Australian coal mining. As the first step a questionnaire was prepared and sent to twenty eight open cut coal mines with a total of about sixty large walking draglines as the major overburden removal units. The questionnaire sought information about general geology of the coal deposit, the mine's dragline(s) and other major equipment specifications and details of the pit geometry with a particular reference to the dragline digging methods. A number of site visits was also undertaken to directly observe and evaluate current dragline operations.

Of the twenty eight mines, twenty one mines (75%), covering fifty one dragline operations responded to the questionnaire. One mine has stopped using its dragline. The remaining 25% did not respond because of either lack of

[2] NSW Coal Industry Profile, 1996

operational data or the company did not have personnel available to gather the requested data. The information provided by the mines was classified according to the mine geology. The details included number of dragline passes, number of lifts per pass, dragline positions, whether or not a throw blasting technique is used, and cut and spoil procedures. The results of the questionnaire have been summarised in Table 1.

RESULTS

Various sizes of draglines are in use in Australian mines. The bucket size of the current draglines varies over a wide range of 12 to 103 m^3. Normally smaller draglines are used to remove the shallow depth interburdens (less than 30 m). Most of the recently ordered draglines or those under contract have larger stripping capacities when compared with the old generation of draglines (Seib and Carr, 1990). The dominant form of dragline ten years ago was a medium size dragline such as BE 1370W or Marion 8050 with bucket capacity around 47 m^3 (Atkinson et al, 1985). The new generation of draglines in Australian mines have an average bucket capacity around 75 m^3. Contributing factors toward the very large draglines are the increasing overburden depths, the need to increase stripping capacity of the mine to reduce unit stripping cost, and advances in dragline manufacturing technology. Fig 2 shows the changes in dragline size and its stripping capability during the last two decades.

Ideally the digging method which results in the highest coal exposure rate should be adopted for a particular operation. The choice of strip geometry is mainly governed by the selected stripping method and the size of dragline. Seven digging methods were identified to be representative of most of the Australian dragline operations. The common stripping methods were:

- simple side cast;
- standard extended bench with an advance bench;
- split bench (deep stripping);
- chop cut in-pit bench;
- extended key cut;
- single highwall and double lowwall multi-pass; and
- double highwall and single lowwall multi-pass.

In the last ten years as shown in Fig 3 there has been a significant tendency towards digging techniques with higher productivity such as extended key cut and in-pit bench methods. There are a variety of reasons for modifications to the conventional techniques, including:

- changes in geology such as significant increases in overburden depths;
- introduction of more efficient cast blasting techniques;
- development of multi-seam operations; and
- requirement for closer control on production costs.

Table 1- Summarised results of the digging method survey

No	Geology Condition				Dragline Specification					Digging Method	Prod-uctivity (Mbcm/y)	Digging Method Description
	Number of Seams	*Coal Thick-ness (m)*	*Waste Thick-ness (m)*	*Strip Width (m)*	*Model*	*Bucket Size (m^3)*	*Operat-ing Radius (m)*	*Dump Height (m)*	*Dig Depth (m)*			
1	1	8	55 (then to 35)	80	Marion 8200	55	87.2	45	47	Modified Low wall Technique	12 (Total) 9 (Prime)	After a cast blast, a small fleet of shovel and truck reduces the overburden depth from 35m to 55m. Then the dragline with a modified lowwall pass removes the rest of the overburden. Using this method, rehandle is reduced from 30% to 7%.
2	1	0.5 - 6	25	60	BE 1370-W	47	87.2	57	47	Cast Blasting & Extended Bench	9.8 (Total) 6.2 (Prime)	In some areas the dragline removes two seams in one pass, chopping the first interburden. The main overburden is initially cast blasted with 30% thrown, then the dragline removes remaining material using an Extended Bench method.
3	[3] Seam 1 Seam 2 Seam 3	0.5 - 1 0.5 - 1 5 - 7	26 - 30 1.5 -5 2 - 6	60 - 70	BE 1570-W	52	92	47.8	45.7	Three Pass Method	6.5 (Prime)	The first pass method is a standard underhand technique with a highwall keycut. The spoil is directly cast into the previous void with no bridging involved. In the second and third pass dragline technique is a lowwall pass involving the digging of the mid-burden from lowwall pad.
4	1 (up to 4 splits)	18 - 22	65	70	BE 1350-W	41	85	30	45	Two Highwall Passes	10 (Total) 3.9 (Prime)	Two highwall pass standard method. The first pass is a Simple Side Casting with some rehandle for the key cut. The second pass is a standard key with the Extended Bench.
5	1 (up to 6 splits)	20	70	80	Marion 8750	103	87	57	63	Standard Extended Bench & Advance Bench	22 (Total) 16 (Prime)	A single pass Extended Bench method where overburden thickness is less than 45m. A single pass Extended Bench with overhand chopping and cast blasting for more than 45m overburden. A two pass Extended Bench where overburden thickness exceeds 60m. The first pass is more productive.

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6	1	13-17	35 to 45	90	BE 1370-W	47	87.5	52.2	48.8	Extended Bench & Extended Key Cut	N.A.*	Two of the three pits are mined using standard Extended Bench method with a 10 metres advanced bench, and the third pit uses Extended Key Cut associated with cast blasting.
7	1	6 - 8	33 - 40	80	2 BE 1370-W	46	88	41	50	Extended Key Cut	12.5 (Total) 10.5 (Prime)	The overburden is removed in a two-stage operation. The first stage involves the use of shovel/loader and truck pre stripping operation to provide a dragline working level of 33 m. An 11% improvement in performance was obtained in 1993 changing digging method from Extended Key Cut to Extended Bench.
8	1	10	40	60	Marion 8050	54	73.6	38.1	51.8	Lowwall In-Pit Bench	10.2 (Total) 8.8 (Prime)	The overburden is removed in a two-stage operation. In the first stage dragline sits on a pad prepared on spoil pile and chops a narrow main cut. The material is spoiled in previous pit to make a new pad (bench) for next dragline position. In the second stage dragline removes the old pad and spoils material into final position.
9	[3] Seam 1 Seam 2 Seam 3	1 - 5 2 - 6 2 - 4	15 - 20 25 15	50	BE 1570-W	60	87.5	45	55	Single Highwall & Double Lowwall	7.5 (Prime)	The first pass method is a standard underhand technique with a highwall keycut. The spoil is directly cast into the previous strip void with no bridging involved. In the second and third pass the digging method is a lowwall pass involving the digging of the mid-burden from lowwall pad.

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10	[2]				Marion 8050	47	87.2	45.7	53.3	Standard Extended Bench & Extended Key Cut	N.A.*	The Extended Bench method is used in the single seam. The maximum overburden depth is generally 45m. The second method (Extended Key Cut) is employed in multi-seam. The critical factor in this method is spoil room. When designing a multi-seam area, a maximum spoil height of 80m is used.
	Seam 1	2 - 10	30 -50	70	BE 1370-W	47	84.5	39.6	51.8			
	Seam 2	7.5	3 - 30		BE 1260-W	25	74.7	39.6	51.8			
11	1	4 - 6	15 - 200	70	3 BE 1370-W	48	86	43.5	45.7	Extended Bench, Extended Key Cut & In-Pit Bench	70 (Total for all draglines)	A trial was implemented at the mine to establish an Extended Key Cut method. Although higher swing angles are required in this technique, the overall coal exposure rate is increased due to lower rehandling of the material. Rehandle decreased from 63.4% to 47.1% and a 17% time saving was provided through the implementation of the new method.
					2 Marion 8050	48	83.8	44.7	51.8			
12	[2]				Marion 7700	19	68	32	45	In-Pit Bench Chopping	2.9 (Total) 2.3 (Prime)	The first interburden is cast blasted and the material is pushed with dozer or a small fleet of truck and shovel to make an in-pit bench for dragline. The dragline pulls back material of the second interburden.
	Seam 1	2-3	0-25	40								
	Seam 2	4-6	11									
13	[2]				2 BE1370-W	48	84.5	39.6	52.8	Extended Bench, Extended Key Cut & In-Pit Bench	N.A.	Coal is removed by open-cut mining methods, using five draglines for overburden removal. A BWE and associated conveyors used to assist in pre-stripping operations. Two truck and shovel stripping fleets also operate at the mine.
	Seam 1	6 - 10	15 - 45	55-75	2 BE1350-W	36	87.0	30.5	45.0			
	Seam 2	8 - 10.5	10 - 30		4 Marion 8050	48	87.2	45.7	53.3			

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14	[2]	4 - 5	30-55	60	3 BE 1370-w 3 Marion 8050 Marion 195M-2	48 48 12	86 83.8 N.A.	43.5 44.7 N.A.	45.7 51.8 N.A.	Chop Cut In_Pit Bench & Stacked Multi-Seam Method	N.A.*	The first method involves a three-pass operation in conjunction with cast blasting. Using the chopped material an in-pit bench is constructed progressively along the pit to complete the first pass. The final pass involves removing the remaining materials in spoil pile. This method showed a 20% increase in the uncovering rate compared with standard Extended Bench method as a result of a decrease in rehandle about 25%.
15	1 (up to 3 Splits)	4 - 6	20 - 60	45 - 70	4 Marion 8050 BE 1370-W	46 46	87 87.5	45 43	50 48	Extended Bench, Extended Key Cut & In-Pit Bench	25.2 (Total) 15.0 (Prime)	A two-pass sequence with the alluvial unit being stripped down to expose the top of the sandstone forming an in-pit bench on which the dragline would operate to strip out the sandstone unit. Drilling and blasting operations would follow the stripping of the first pass.
16	[5]	3.5 - 4	15 - 50	60 - 70	Marion 8200 Marion 8200 Marion 7900 Marion 7901 BE 1370-W	72 57 27 30 47	87.5 92 72 72 87.2	50.9 48 38 38 43	60 60 40 40 45	Extended Bench, Extended Key Cut & In-Pit Bench	39.4 (Total) 29.0 (Prime)	A combination of three common methods is used. The current methods are standard Extended Bench with chop, in pit bench method and Extended Key Cut. A 72 m^3 replacement dragline was erected on site in December 1993.
17	[3] Seam 1 Seam 2 Seam 3	0.5 - 1 0.5 - 1 0.4 - 4	26 - 30 1.5 -5 2 - 6	40-50	BE 1370-W	46	92	47.8	45.7	Single Highwall & Double Lowwall passes	9.0 (Prime)	The first pass method is a standard underhand technique, with a highwall keycut. The spoil is directly cast into the previous void with no bridging. In the second and third passes digging technique is a lowwall pass involving the digging of the midburden from lowwall pad.

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18	[3] Seam 1 Seam 2 Seam 3	2 - 4 0.5 - 3 0 - 2.5	12 - 50 6 - 30 2 - 22	50-70	4 Marion 8200	57	87	48	60	Multi-Pass Operation	N.A.	The operation utilises four draglines for overburden and interburden removal, generally in two passes. The first pass is a highwall keycut and the second pass is a chop pass from a lowwall bench. Where parting exceeds 7 m in thickness, a lowwall pass is utilised.
19	2 Seam 1 Seam 2	2 - 19 2 - 10	13 - 32 6 - 22	55-60	Marion 7820	28	80	45	40	Extended Key Cut & In-Pit Bench	N.A.	The operation starts with digging an extended key cut along the highwall, side casting overburden into the adjacent diversion channel beyond the designed lowwall batter. The key cut spoil is then used as an elevated working level for the dragline whilst pulling back the remaining prime overburden.
20	1	5-7	25-58	55	P&H 9020	93	87	57	65	Extended Key Cut	22 (Total) 17 (Prime)	The thick interburden is cast blasted after pre-stripping the top seam overburden. The overburden is then blasted using a cast blasting technique with 25% thrown. The dragline first makes an extended key cut along the 500m strip in the first pass and then walks to the levelled spoil side bench to pull back the remainder of material.

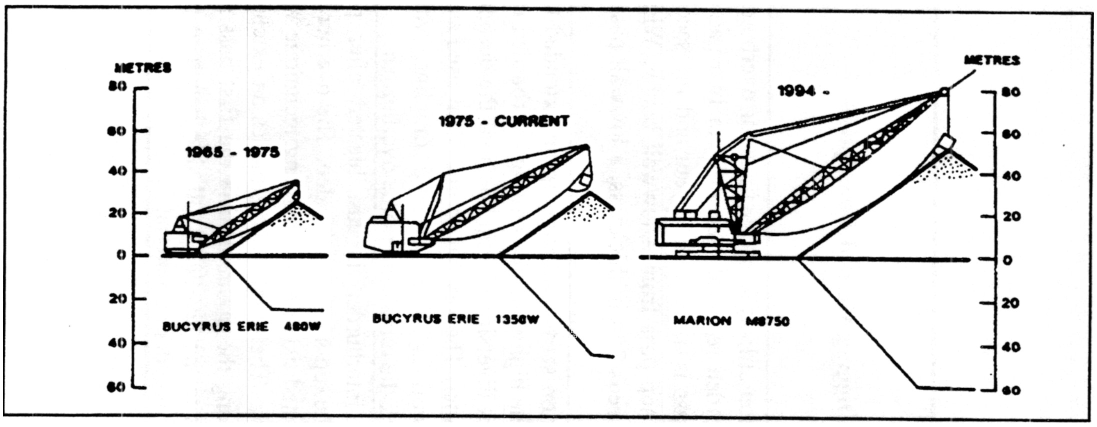

Fig 2- Increases in dragline size over the last two decades (After Seib and Carr, 1990)

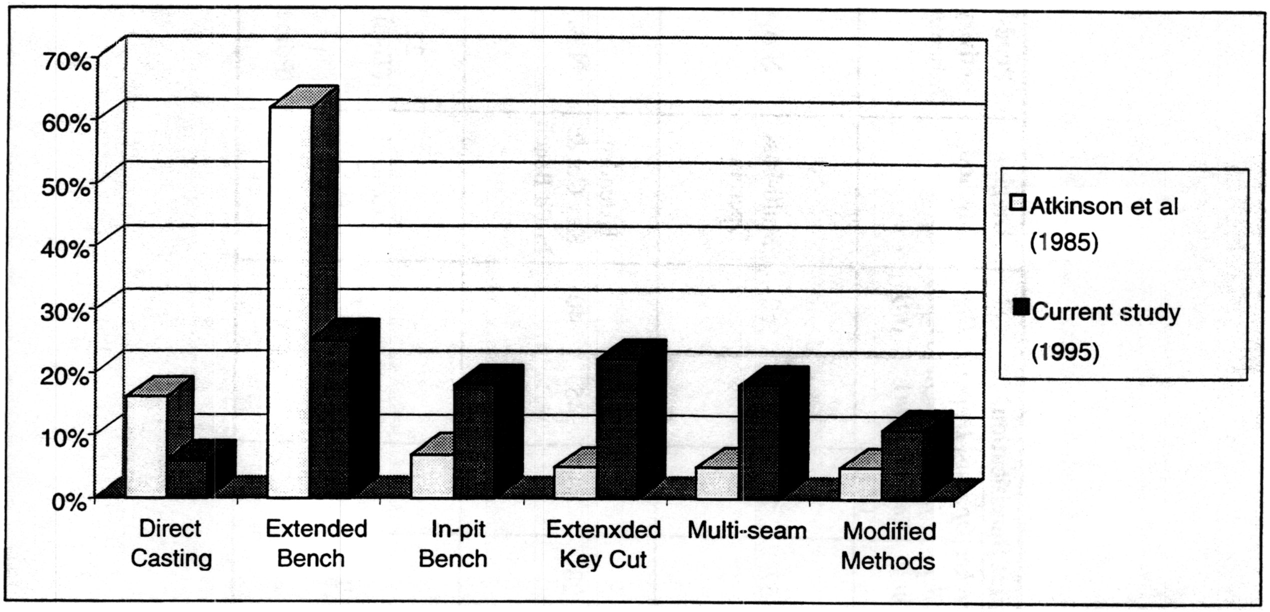

Fig. 3- Changes in dragline digging methods used by Australian open cut coal mines over the last decade

The selection of the best digging method depends on a combination of geological conditions, dragline size and characteristics, and management planning targets. The nature of the coal deposit and geological conditions such as the number of seams, overburden/interburden thickness and coal thickness are among the most important factors governing the choice of a digging method. Other factors such as geotechnical conditions, spoil stability, blasting techniques, material strengths and engineering and operator's experience are also important in the selection of a digging method. The combination of various factors results in a wide variety of methods at strip mines. Shared experience among different sites of a company owning various draglines is an important factor in the selection of a digging method. For example, BHP-Utah Coal Limited (BUCL) operates 35 draglines of varying sizes across the Bowen Basin of Central Queensland (Hill, 1989). The four common methods used by the BUCL group are:

1. standard extended bridge;

2. deep prestrip (split bench);

3. extended key cut; and

4. in-pit bench.

The stripping operations commenced with box-cuts on the shallow area at depths of 15 to 25m. The depths have increased over the years and average overburden depths now are around 50 to 55m in single seam operations. In many cases additional waste stripping is occurring ahead of dragline operation. In some instances, draglines are being used to dig depths as much as 70 metres.

Unlike overburden depth which is mainly governed by the geology, strip width is an operating factor which can be varied within a practical range. Variations in strip width affects dragline productivity. Pit geometry, especially the strip width, must be evaluated in conjunction with the digging method adopted by the mine. Wide strips (greater than 60m) are more preferable for methods such as the standard extended bench method due to the reductions in rehandle, while narrower pits are more productive for methods using a cast blasting technique, such as extended key cut or in-pit bench method. The strip widths currently employed ranged from 40 to 90 metres with an average of 60 to 70 metres.

Computer simulation and digging method selection

Draglines move waste at the lowest cost per unit volume only when they work within their normal range. Both efficiency and productivity of a given dragline drop off dramatically with changes in its effective operational factors. To improve the performance of a dragline, its mode of operation and influencing parameters must be fully understood and analysed. Finding the normal working ranges for a given dragline and optimising its operation requires repetitive arithmetic and analytic solutions. This problem is ideally suited to the application of computer aided simulation methods. Better mine planning and mining method selection through computer simulation has been successful in many cases and this has been strongly recommended for Australian operations (Atkinson et al, 1985; Hill, 1989; Wentworth, 1988; Aspinal, 1992; Sengstock, 1992). A computer simulation model which can simulate different mining methods (particularly the innovative ones) is a useful means for selection of the optimum dragline digging method for a given geology.

Computer simulation of dragline operation has the potential for rapid, low cost analysis of different mining scenarios. Simulation of the dragline operation enables an operator to test the logic of how the machine should be used, and the design of optimum operating methods for the varying mining conditions. Such an application may also be used as a training simulator or to evaluate dragline performance with a given set of geological and operational conditions. Computer simulation can also be used for evaluating proposals for modifications to existing operations and is also useful in comparing the performance of different types of new draglines which are being considered for purchase (Hill, 1989).

Due to the variety of digging methods currently used by open cut mines, a more general approach was necessary for simulation rather than using standard digging methods such as extended bridge. As a result of this study, a dragline simulation model has been developed which can be used in evaluation and optimising different dragline operations. A highly flexible simulation language "DSLX" was used to program different dragline digging scenarios in the model. Such an approach provided a library of various dragline digging techniques. The results from the simulation stage are then aggregated with time study data to estimate productivity and costs of the operation. The final decision then can be made based on either the highest production rate or the lowest unit cost from various digging techniques. An example of such a comparison for a single seam dragline operation is shown in Fig 4. The process of the modelling and results of different case studies have been discussed in detail in previous papers (Baafi, Mirabediny and Whitchurch, 1995; 1997).

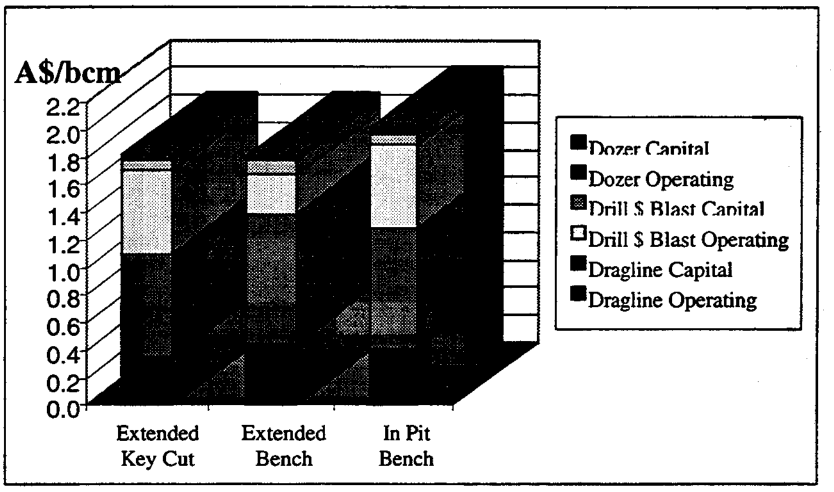

Fig. 4 - Unit cost for various digging methods with their components

CONCLUDING REMARKS

Productivity and efficiency of walking draglines can be improved by modifications in dragline digging methods. To select the most suitable digging method and working parameters for dragline operations, the first step is to analyse characteristics of various digging methods. A survey was conducted with the objective of evaluating the effects of various digging methods currently used by Australian dragline operations. The survey was conducted through sending a questionnaire to twenty eight mines covering more than sixty dragline operations. The questionnaire sought information about the general geology, major equipment specifications, digging methods and pit geometry. The surveyed showed that with the natural increase in overburden depths and complex geology, most strip mines have introduced various innovative dragline digging methods and larger draglines.

All the possible options can then be tested on a specific set of geological and mining conditions via a computer simulation model. Such an approach has been developed and applied to several Australian open cut coal mines both in NSW and QLD.

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