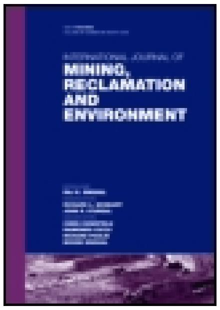

International Journal of Surface Mining, Reclamation and Environment
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/nsme19

Computer simulation of complex dragline operations

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Published online: 02 Apr 2007.

To cite this article: E.Y. Baafi , H. Mirabediny & K. Whitchurch (1997) Computer simulation of complex dragline operations, International Journal of Surface Mining, Reclamation and Environment, 11:1, 7-13

To link to this article: http://dx.doi.org/10.1080/09208119708944049

Computer simulation of complex dragline operations

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ABSTRACT: Large walking draglines are capital intensive pieces of equipment. To maximise the return on investment and to improve the performance of a dragline, its operation and influencing parameters must be understood and fully analysed with the view of optimising the process. Finding the normal working ranges for a given dragline and optimising its operation usually requires that various possible mining scenarios and pit configurations be assessed. This task is normally both difficult and time consuming and requires an analytical solution. This is ideally suited to the application of computer simulation methods.

An integrated computer simulation model was developed to assist the mine engineer in planning dragline operations. The model uses a 3D geological modelling system to access the geological database. The model can simulate complex multi seam operations and different digging methods using a developed database. A generalised computer package, *DSLX*, is used to simulate various dragline digging methods. The software is based on a highly flexible simulation language which uses predefined functions to build strip geometry, working benches, blast profiles and spoil piles. The basic features of the simulation model, the algorithms used in developing dragline pit designs and the results of two case studies are discussed.

1 INTRODUCTION

During recent years, the Australian coal industry has increasingly used large walking draglines as the dominant waste removal equipment in open cut coal mines. Because of the nature of the coal formations, dragline operations in Australian coal mining situations are quite complex and draglines are frequently used in applications beyond their normal capabilities. This is especially true in the Hunter Valley area of New South Wales, where almost all the large open cut mines have complex multi-pit and multi-seam operations. In the Hunter Valley several mines have been designed to extract up to 50 different seams during the mine life (Runge 1983). Because of the complex nature of dragline operations, a large number of alternative digging methods are used in practice.

There is a growing recognition by mining companies of the importance of productivity improvements and innovation in digging methods. Computer based simulation models have proved effective in designing complex mining systems and in optimising processes. Numerous computer packages have been developed to simulate dragline coal mining operations (Huddart and Runge 1979; Sadri and Lee 1982; Ramani and Bandopadhyay 1985; Lee 1988; Stuart and Cobb 1988). However, most of the currently available packages are limited to the standard digging methods or specific mining conditions and a "black box" approach is used to determine the "best" mining parameters. This means that the user cannot follow the logic of the package and has no means to change or extend the software limitations (Michaud and Calder 1988).

Conventional computer dragline operation simulators use a trigonometric approach to carry out the required calculations such as volumetric calculations. To evaluate various mining scenarios for a complex geology the dragline simulation must be performed on a full set of closely spaced sections that are not necessarily similar in geological characteristics. With the conventional approach, the process for a complex geology becomes tedious. This is specially true in optimisation processes where iterative runs are necessary. Recent developments in 3D CAD softwares have provided the opportunity to automate the process and overcome the limitations of the conventional approach.

Recently, Engineering Computer Services Pty Ltd (ECS) has developed a CAD based computerised dragline simulator (*DSLX*) which can be adapted to all mining environments and is suitable for both short-term and long-term planning stages (ECS 1993). In this software all dragline operations and decision makings such as dragline positioning, cut and fill processes and mining sequences are left to the user, thus avoiding a "black box" approach.

2 MODELLING PROCEDURE

Figure 1 is a generalised flow chart of the modelling process. The sequence of the associated tasks of the dragline simulation depicted by Figure 1 is listed below.

1. A geological model is created using borehole data (or digitised data from contour maps). The geological data are then converted to gridded surfaces of topography and top and bottom of coal seams.
2. Coordinates of mining strips and vertical cross sections which intersect with the gridded surfaces are generated and stored in ASCII format to be read later by the dragline simulator. Different layers from the gridded surface are also generated in the form of strings for each section and stored in text files.
3. A data file of operating parameters of the dragline is created.
4. The design of the initial cuts, the post-blasting profiles, the original surfaces, the existing spoil piles and pre-strip operations are coded using a series of developed macros.
5. Simulation of a digging method is performed to define sequencing of different dragline operations, removal and placement of overburden materials and dragline walking patterns. These procedures are all coded in the specific language of *DSLX* to calculate prime and rehandle volumes, swing angles and hoist distances. Common digging methods used in Australian strip mines include simple side-casting, extended bench, split bench, bench on spoil and multi-pass methods.
6. The simulation results are analysed to define the dragline's prime and total productivity using a spreadsheet. By analysing the simulation results, it is possible to evaluate the effect of various operating parameters.
7. The pit geometry is finally changed, especially the strip width and dragline working level within their normal range. The simulation is re-run to achieve optimum pit configuration for a defined digging method, given geological condition and known dragline specifications.

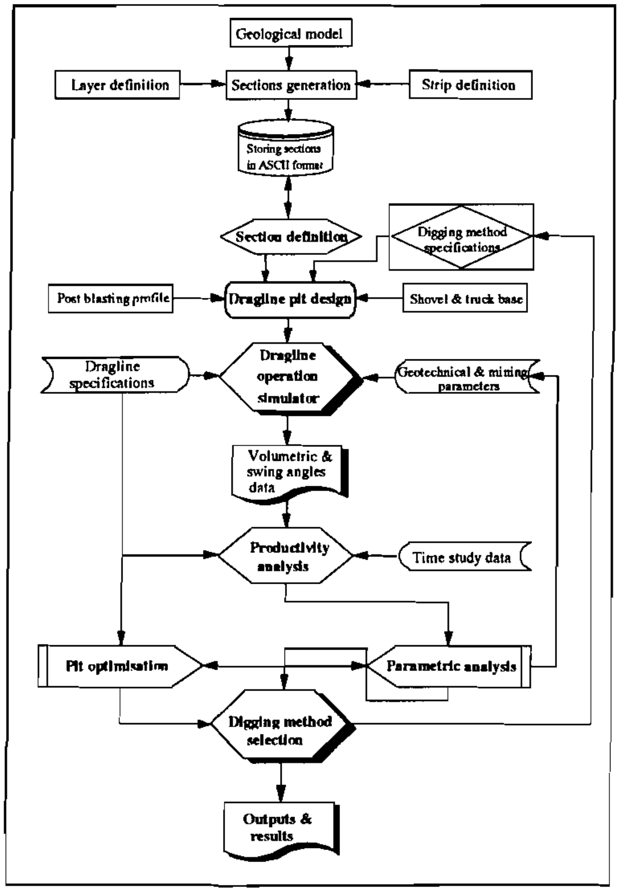


Figure 1. The modelling procedure

DSLX is a relatively complex but extremely flexible software in practical applications. The software is based on a language concept which uses predefined functions to build spoil piles, working benches, blast profiles and strip geometry. With this approach the user can control the planning procedure, dragline movements and positions, the cut dimension and spoil placements.

3 PROCESS OF THE SIMULATION

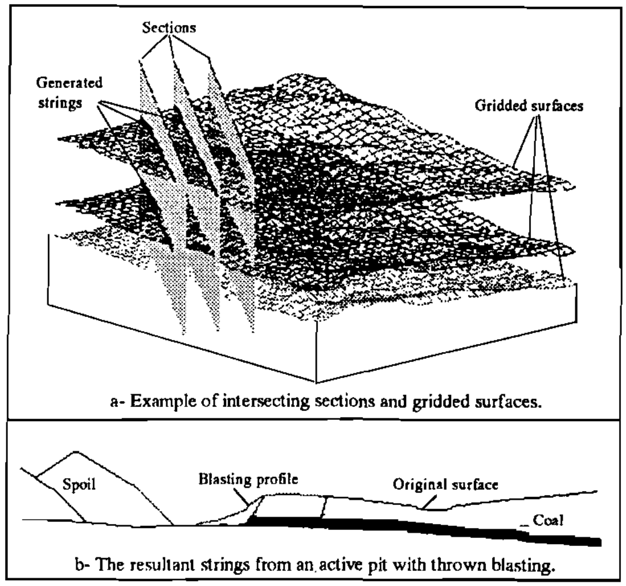
3.1 Generation of the cross sections

The software constructs sections from the geological models by intersecting vertical sections with a series of 3D grids of topography and roof and floor structures of the coal seams. The interval distance along a section line from which data is extracted is user defined. The idea is illustrated in a simplified manner in Figure 2.

3.2 Establishment of planning and design criteria

Mine design details can be input in DSLX from existing mine planning software. Alternatively, a starting toe can be generated and developed by intersecting a single line such as a box cut toe line with the sections. This line is then used as a starting point for the pit design. Mine design features are frequently generated in the program based on the user's constraints, rather than being input (eg. spoil room available). In such a case, the DSLX's macros will construct the pit design using a number of available functions. These functions allow exotic designs to be created as well as typical ones.

The *DSLX*'s simulation language contains all the basics of any simulation language, such as loops, nested loops, line labelling, GOTO statements, conditional logic and basic arithmetic operations. Like any CAD based software, the package contains a number of functions to allow strings, points and scalars to be manipulated. Basic functions are provided to intersect strings, to create points by coordinates or by moving existing points by bearings and distances and to join and convert points into strings or existing strings into new strings. More powerful functions exist to handle procedures such as cast blast profiles, volumetric calculations and cut-and-fill procedures. The most frequent design procedures such as spoiling a given volume at the defined repose angle are coded in the program. For handling more special dragline cut-and-fill designs the routines are developed by the user. Figure 3 is a simple example of the coding in *DSLX* to construct a key cut.



a- Example of intersecting sections and gridded surfaces.

b- The resultant strings from an active pit with thrown blasting.

Figure 2. Definition of sections.

```
global  bw,pcut,xa,za; global_point P1,P2,P3,toe,posdl; global_string
topo,roof,floor,key,temp
sectloadn(sect,S<1>); topo=sect[1];Drawstr(topo,1,0); roof=sect[2]
floor=sect[3]; Drawstr(roof,2,0)
!First find the Key cut position of the Dragline.
Drawstr(floor,3,0); P1 = toe +{180}*bw; ang = 180 - pcut
pntints(topo,P1,ang,P2)
pntints(topo,toe,pcut,P3); strextr(topo,P2,P3,temp)
Key = P2//temp//P3//toe//P1//P2
strvol(Key,vol); drawstr(Key,4,0); vol = vol * swell
!Position dragline half a bucket width from the toe.
xa = bw/2; posdl =P3+{180}*xa; pntattr(posdl,1,xa); strattr(topo,xa,2,za)
posdl = xa,za  DRAWDR(1,posdl,1,180)
```

Figure 3. Coding used to construct a key cut.

The procedures involved in this example are

1. declaration of the scalars, points and strings,
2. retrieving and drawing the main strings (spoil, topo, roof and floor) of the geology,
3. positioning of the left-hand and right-hand toe points,
4. projecting the toe points up at the nominal angles to calculate the crest points, and
5. creating and drawing a closed string (key) for volumetric calculation.

After constructing a pit geometry, different mining options and dragline operating sequences are simulated using the simulation language. A mining operation is carried out using a series of linked geological cross-sections that are spaced along a particular strip design at a user defined interval. Like a normal dragline operation, the simulation can be run in incremental section mode, where the program moves the dragline from one geological section to the next along a strip until it reaches the endwall and then returns it to the first geological section of the next strip.

Outputs from *DSLX* consist of 2D cross sections, 3D view of the pit at any stage and a series of user-definable reports. Figure 4 shows a 3D image of the dragline pit after simulation. For a subsequent analysis such as productivity, sensitivity or cost analysis, output data are formatted in a manner suitable for input into a standard spreadsheet such as EXCEL® or LOTUS 123®.

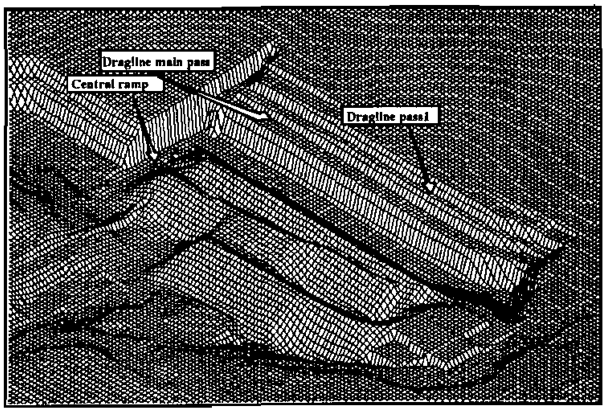


Figure 4. A 3D view of the dragline pit after simulation.

4 MINE DESIGN

The objective of a mine design is to maximise coal uncovering rate subject to the constraints of pit stability, machine size and scheduling. One application of a dragline simulator is to evaluate different operating methods and minor changes to pit geometry, particularly pit width. Changing these factors alters productivity of the machine through changes in rehandle percent, cycle time and walk time components. Using *DSLX's* language several specific routines have been developed to carry out complex dragline pit design procedures. Four examples of these procedures are given below.

4.1 Design of post blasting profiles

Blasting for draglines is basically not different from other blasting operations. However in recent years cast blasting (also called throw blasting) has been aggressively and successfully applied in Australian open cut mines wherever geometric factors permit (Elliott 1989). Cast blasting can increase overburden removal rate, hence improving dragline productivity. The following benefits make the technique more attractive;

a) eliminating benching dug in the chop down mode,
b) reducing dragline working level,
c) improving fragmentation, and
d) removing partings that are presently being excavated with shovel and truck system.

The improved dragline productivity can result in significantly increased rate of coal uncovering. However, throw blasting may not necessarily result in reduced operating costs, due to the large increase in drilling and explosive costs. Narrow pits result in improved percentage throw, but total excavation economics are adversely affected by increased dragline rehandle volumes and the influence of pre-splitting costs (Sengstock 1992).

A dragline simulator must be capable of handling blast parameters and predicting thrown percentage in final spoil position, rehandle percentage, and dragline productivity. Simulation of throw blasting results can be carried out by *DSLX* in two ways. First an existing blast profile can be measured by survey techniques (conventional or laser methods) and converted to a triangulated surface. This surface on each section is then used as a string in the simulation. Alternatively, when blasting profile has not been recorded, specific routines predict the blasting results. These routines fit post blasting profile to the geometry of the pit. In either case, the program measures blast performance relative to the dragline operation. Relevant data calculated from pre-blast and post-blast profiling include;

a) percentage throw (moved to final spoil),
b) vertical/horizontal heave,
c) changes in dragline dig depth,
d) rehandle volumes, and
e) pad preparation requirements by dozer.

Figure 5 shows an example of various cut shapes and areas used for post-blasting calculation in a standard key cut method.

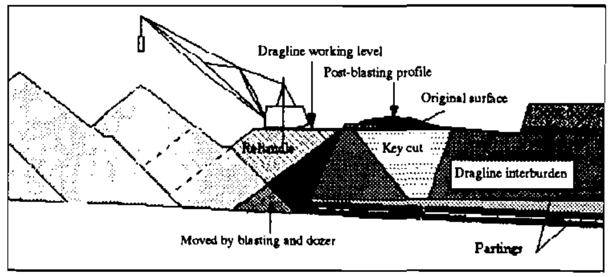


Figure 5- Details of post blasting calculations.

4.2 Design of coal haulage ramps

A common case of rehandle, is around haulage ramps where spoil must be carried along the pit to clear the ramp. In the vicinity of a ramp a different procedure is used to place "extra" material on the spoil pile due to the ramp. In the current program a reference surface is used to determine whether a limitation exists for spoil placement. This reference surface indicates the available spoil room between the cut surface and the maximum spoil surface in each region. For example, if a section is at the centre line of the ramp, the reference surface is almost the same as original cut string and this means that no spoil can be placed in the void of the old pit. The reference surface can be created either by digitising or by accessing the current ramps' surveyed data.

In Figure 6, when sections progress further from a ramp, the reference surface changes until it reaches a steady state in regions unaffected by the ramp. The reference surface for each section is also stored with other characteristics of the section. The cumulative extra volume from sections affected by the ramp is carried along the strip until it can be dumped in the sections with more available spoil room.

4.3 Design of curvature strips

When mining is started along the coal outcrop and with a rolling topography, the pit may be designed so that it follows a uniform contour. As a result, this type of design may develop pits in a curved shape. Where the curved pits are designed, a series of inside and outside curves are usually encountered. One criticism of traditional range diagrams is that they do not work well with curved strips. The major problem with volumetric calculation of a curved strip is the difference in available area for spoiling between an inside and outside curve. Further, the width between two adjacent sections along the pit is variable and therefore a constant value cannot be used to convert calculated areas to volumes. An example of curved strips and generated section lines is shown in Figure 7.

To solve the problems caused by curves, a variable width along the length of a section is used in *DSLX*. The program uses the start and end coordinates of the section lines to create a table of

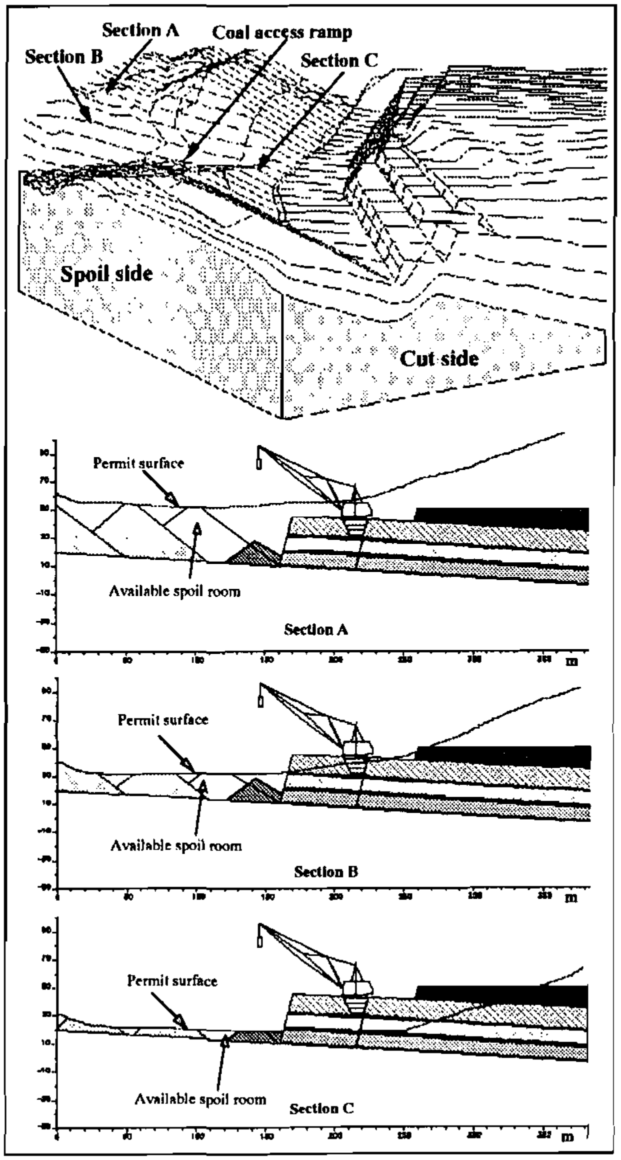


Figure 6. Effect of permit surface on the available spoil room in vicinity of a ramp.

width information. By subtracting the related values of the coordinates and computing the length, a ratio can be calculated for each section. By considering the X value of the centroid point and the width ratio for the section, the width of influence is determined for the calculated area. The width of influence is then used to convert the 2D areas into the 3D volumes.

4.4 Grade control between mining blocks

Walking draglines are limited to a maximum walking grade. This grade, dragline gradeability, has a specific influence on the minimum ramp length required for any dragline level changes and thus on the amount of pre-strip material for dragline access. A dragline with higher gradeability can be used in rugged topography for pit access with a minimum of earthworks (Seib and Carr 1990). When simulating the dragline operation for an entire deposit the model must be able to measure and control the grade for the dragline movements.

By running simulation along a strip, section by section, the information gained on a section can be passed to the next section and used in designing the strip for that section. Typically the information passed from section to section consists of volumetric information and working levels in each section.

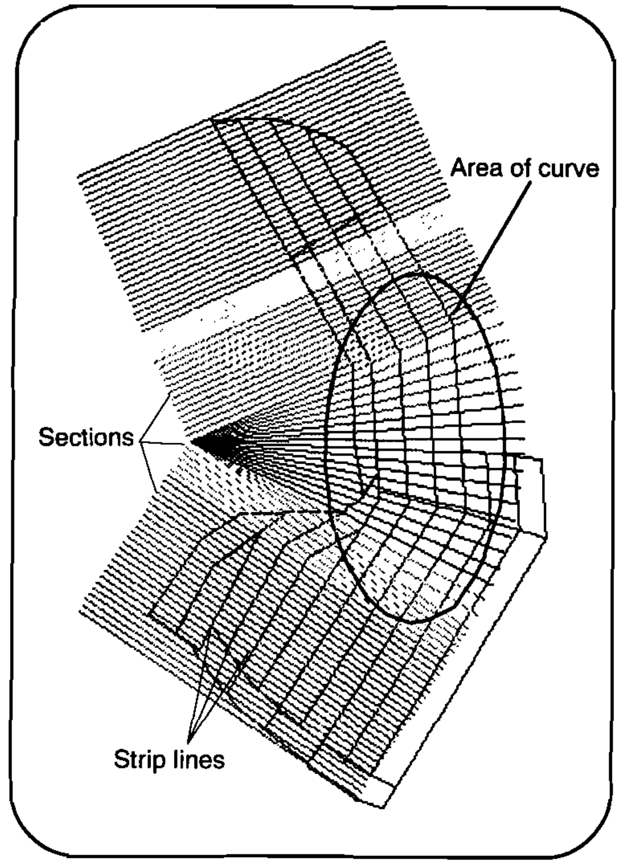


Figure 7. Plan view of curved strips and sections.

The maximum grade is controlled by comparing the average dragline level for adjacent sections and the maximum grade which a dragline can operate on. In certain situations, particularly in rugged topography, the grade between sections may exceed the maximum allowed grade of the dragline. In these cases chopping/filling of the dragline bridge achieves the necessary elevation changes between moves. Extra rehandle results and is reported with other rehandled volumes.

5 CASE STUDY 1

5.1 Geology and mining method

The model's capabilities were tested by simulating a multi-pass dragline operation. The dragline operation at the mine involved three dragline passes with three seams dipping at approximately 5°as shown in Figure 8.

1. First pass: This is a standard underhand technique, with a highwall key cut and a main dig component. The overburden thickness varies between 11 and 23m and coal thickness varies between 1.9 and 2.2m. The spoil is directly dumped into the previous strip void so there is no bridge rehandle. However, this pass involves almost ten percent rehandle mostly due to the coal haulage ramps.

2. Second pass: This is a low wall pass involving chop operations from an in-pit bench. The interburden thickness varies between 7 and 17m, and coal seam thickness ranges from 0.5 to 1.5m. The dragline is subject to tight spoiling and dumping to maximum height. The requirement to dump behind the machine greatly increases cycle time due to the longer swing angle.

3. Third pass: The third pass is essentially the same as the second pass. However, due to shorter swing angles, the cycle times are decreased compared with those of the second pass. Interburden

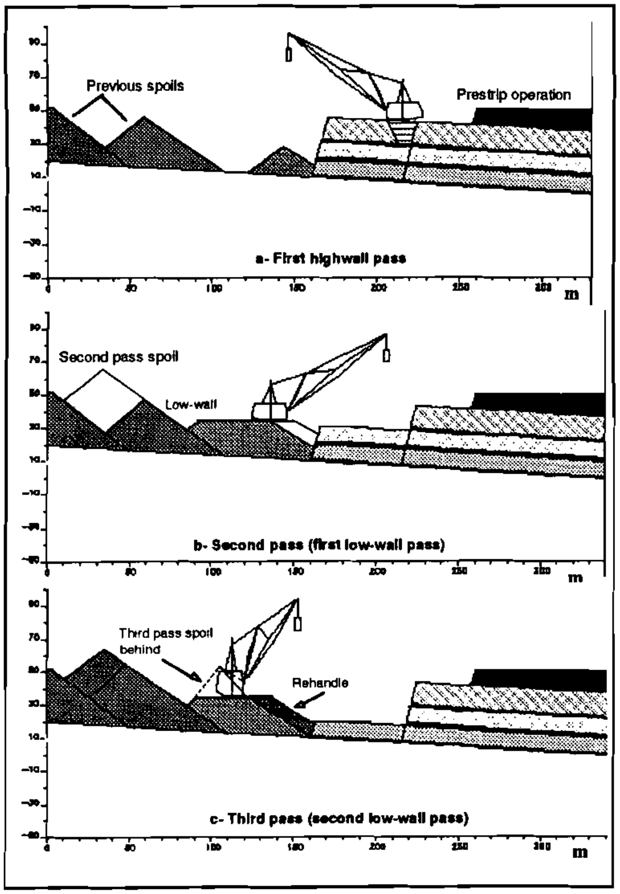


Figure 8. Three seams operation, single highwall and double low-wall method.

thickness varies from 5 to 10m, and overlies a 1.1 to 1.8m thick coal seam.

5.2 Results

A comparison of the simulation results and data from the field monitoring system (at the same pit with the same configurations) is given in Table 1. The results show that the simulation model is able to recognise the mode of operation and to predict most of the operational parameters in a reasonable range.

Having modified and calibrated the model using the monitoring data, the next stage was an optimisation process to determine the optimum configuration of the pit geometry such as strip width and dragline working levels. The working level was kept at the minimum to reduce rehandle. The main criterion to determine the working level was providing available spoil room for all three passes. The dragline pad was also designed to satisfy the dragline reach in the second and third pass. The amount of rehandle material was increased in the low wall passes as the strip width increased. However, the rehandle percent was decreased from a certain strip width for the low-wall passes as the rate of increase in prime volume was higher than that of rehandle material in the wider strips. Figures 9 and 10 show the effect of strip width on rehandle percent and total productivity of each pass. The first pass rehandle was mainly due to the effect of the coal haulage ramp.

Table 1. Comparison of the field monitoring data and the simulation results.

Performance Parameter	Highwall			Low-wall		
	Field monitor	Simulation	Variation*	Field monitor	Simulation	Variation*
Fill time (sec)	14.4	18.0	25%	18.9	18.0	-5%
Swing time (sec)	18.6	15.1	-19%	22.9	23.9	4%
Swing angle (°)	67.4	55.6	-18%	109.0	146.1	34%
Dump time (sec)	7.7	6.0	-28%	6.6	6.0	-10%
Return time (sec)	17.6	15.85	-10%	23.0	24.8	8%
Cycle time (sec)	54.4	54.9	1%	70.1	73.6	5%
Hoist distance (m)	14.9	17.0	14%	35.8	36.5	2%
Cycle/dig. hrs	61	65	7%	51	49	-4%
Cycle/sch. hrs	44	42.5	-3%	38	37	-3%
Cycle/day	1066	1020	-4%	901	880	-2%
Dig Hours	17.6	17.3	-2%	17.5	17.3	-1%
Efficiency (%)	73.5	72.6	-1%	72.8	72.6	0%

$$* : Variation = \frac{(Simulation - Field)}{Simulation} \times 100$$

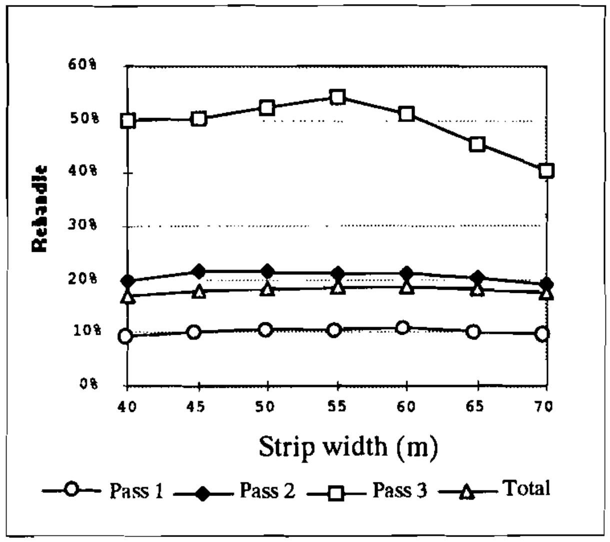


Figure 9. Effect of strip width on the rehandle.

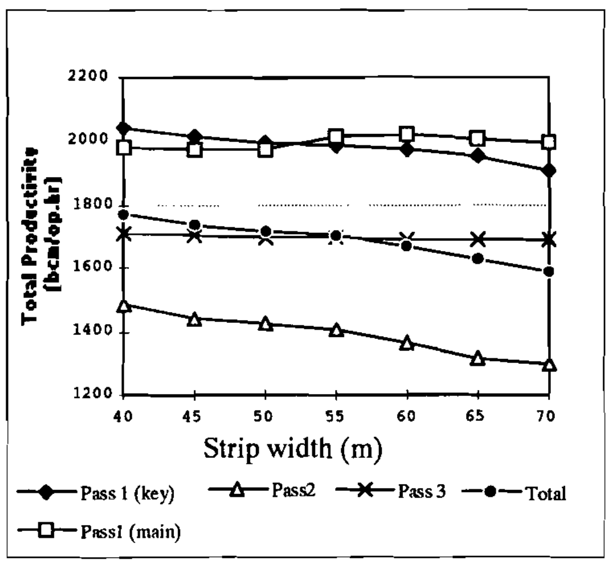


Figure 10. Effect of strip width on the productivity.

The results show that although rehandle is decreased for wider strips, the total productivity is decreased due to the longer cycle times for those strips. However, due to the coal mining constraints, a strip width of 50 metres was determined as an optimum.

6 CASE STUDY 2

6.1 Geology and mining methods

The productivity terms for three dragline digging methods were evaluated on a single seam operation with a thickness as 2-6m of coal and 25-50m of overburden. The three digging methods considered in this case study were the standard extended bench, the low wall chop cut in pit bench and the extended key cut.

Standard Extended Bench method

This method employs an extended bench of sufficient length to allow the low wall coal edge to be cleaned with a trench width equal to a dragline's bucket width. A general view of the method is illustrated in Figure 11.

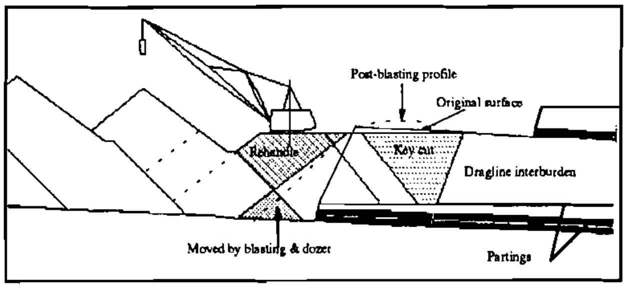


Figure 11. The Extended bench method.

Low-wall In-Pit Bench method

This is a single pass, two lifts low wall operation employing a highwall chop cut in the first lift and a pullback operation in the second lift. The method is associated with a throw blasting technique and the greatest benefit of the method is derived from this. As mining progresses along a strip a dragline return road is also built at a width of 45 metres to allow the dragline to walk back to the opposite digging area after completing the strip. A general view of the method is illustrated in Figure 12.

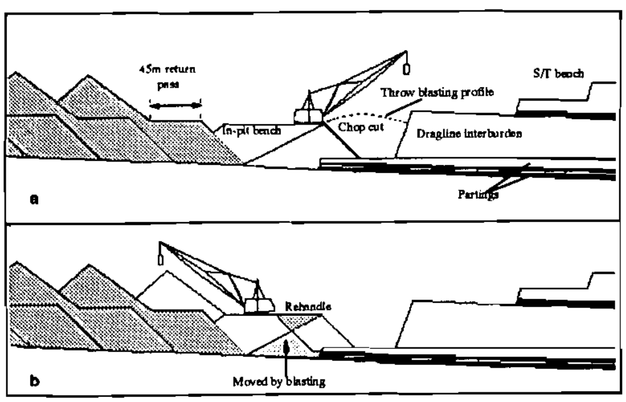


Figure 12. The Chop cut in pit bench method.

The Extended Key Cut method

This is a two-pass operation employing a highwall extended key cut in the first pass and a low wall pullback operation in the second pass; the method is also associated with a throw blasting technique. The dragline bench in the first pass is on the highwall side and in the second pass the dragline works from a bench in low wall side about 10-15 metres below the pre-blasted surface. A general view of the method is illustrated in Figure 13.

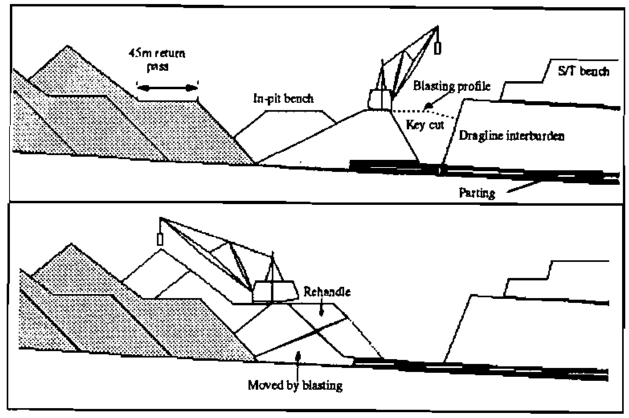


Figure 13. The Extended key cut method

6.2 Results

The results of the case study 2 are summarised in Figures 14 and 15.

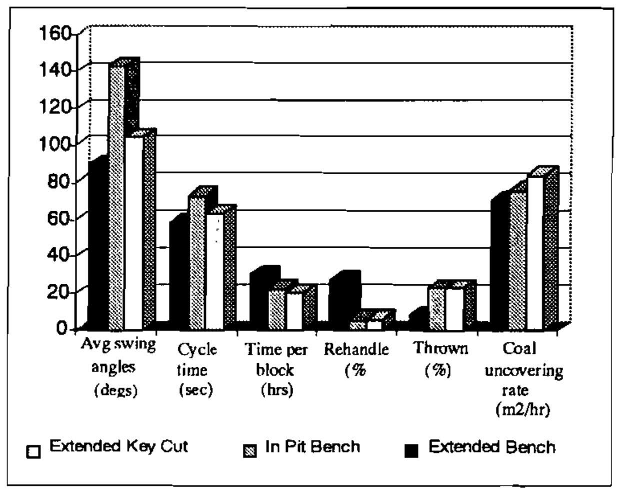


Figure 14- Comparison of the different operating parameters for the three methods

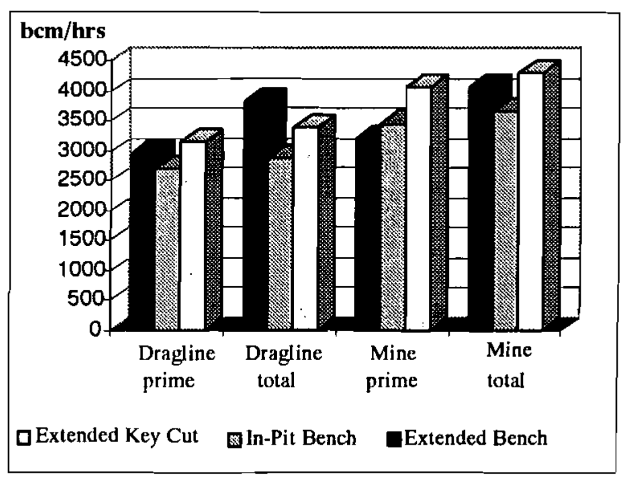


Figure 15- Comparison of the different productivity terms for the three methods

Figures 14 and 15 show that of the three stripping methods, the extended key cut method removes the highest amount of overburden due to the reduced rehandle and increased blasting factor. The dragline total productivity is highest for the standard Extended Bench method due to the shorter swing angles and similarly cycle times. In summary regardless of needs for stronger blasting, the third method is the most productive and results in the highest rate of coal uncovering. However, the selection of a digging method must include consideration of several factors including the cost of operation.

Table 2 summarises a preliminary cost estimation for the three digging methods. The results show that the cost of dragline is greater for the extended bench method due to a lower prime productivity, but this can be offset by cost of drilling and blasting. In addition, if the coal losses due to the throw blasting are included, the extended bench method is again the cheapest method and results in the least cost per tonne of the recovered coal.

Table 2-Estimation of costs, A$ per prime bank cubic metre.

	Dragline	Drilling	Blasting	Levelling	Total
Standard ext. bench	0.64	0.12	0.18	0.03	**0.97**
In-pit bench	0.54	0.19	0.35	0.02	**1.10**
Extended key cut	0.49	0.19	0.35	0.03	**1.06**

7 CONCLUDING REMARKS

A language-based dragline simulation model has been developed to automate procedures of the simulation. This approach has provided the flexibility of simulating different mining methods even in complex multi-seam operations as well as optimising operational parameters. Testing the model on two case studies has shown that model features can be successfully used to simulate a complex geology.

ACKNOWLEDGEMENT

The authors are grateful to Engineering Computer Services Pty Ltd, for assistance and support provided to this study. The strip mines in the Hunter Valley (NSW) and the Bowen Basin (QLD) are acknowledged with thanks for permission to visit their operation and for providing data for model testing.

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