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The economics of extended pre-strip stripping

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THE ECONOMICS OF EXTENDED PRE-STRIP STRIPPING

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ABSTRACT: Waste stripping involves the most costly processes for any given open cut coal mining operation, As such, it is fundamentally important to optimise material scheduling and the sequences involved in excavating and hauling waste material. In situations constrained by fleet capacity and productivity. The only viable option to potentially yield further cost gains is to modify current mining methods. In the case of many Australian coal mines, truck-shovel systems excavate the initial overlying waste, known as pre-strip, down to a predetermined level known as the pre-strip horizon. This paper provides and analyses a simulation model to derive the optimal strip width for pre-strip activities. Case study data obtained from an established leading coal producer in the Bowen Basin was implemented into a pit simulation model to assess the effect of pre-strip width on the overall pit economics. Pre-strip widths of 60 to 120 m in 10 m increments were assessed whilst keeping dragline and coal stripping widths constant at 60 m. The simulation revealed the potential for cost reductions to be significant when a 90 m pre-strip case is adopted as opposed to the base case of 60 m. The paper presents the simulation findings for each case and discusses the key drivers behind the cost variations for each case.

INTRODUCTION

A major operation in the recovery of any coal seam by surface mining methods is the removal of the overburden (Fidler, 1979). Of the available surface mining methods, strip mining is arguably the most common method used to mine coal in Australia. Pre-strip by definition is the removal of any waste material not considered to be valuable. In surface coal mines, pre-strip often refers to the initial material that is removed to facilitate another digging process and is distinctly different from subsequent overburden removal as a continuous process in the recovery of coal (Commissioner of Taxation, 1994). Current practice involves a pre-strip pass by a truck-shovel fleet, which exposes a 60 m wide interburden bench suited for dragline excavation (Figure 1).

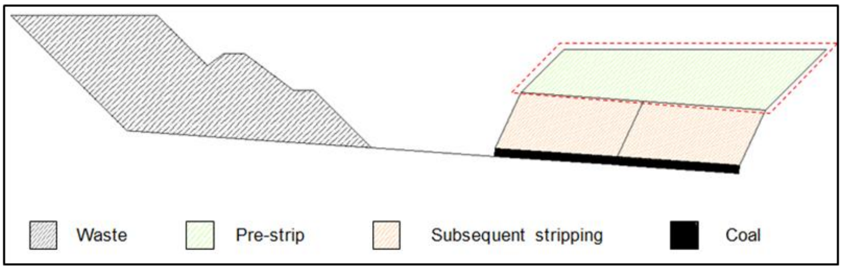

Figure 1 - Pre-strip compared to subsequent dragline stripping (After Commissioner of Taxation, 1994)

In some cases, extended pre-strip passes have been taken up to 120 m in width. Extended pre-stripping allows truck-shovel operations to use double-side loading, which is known to be more productive. Taking an extended pre-strip pass increases the interburden bench width, which provides more room for drill and blast activities, including on-bench loading of explosives. The downside to extended pre-strip passes is the cost associated with additional material movement. More waste material is moved in the short term with little or no increase in coal recovery and associated revenue.

Aside from the known productivity increase realised with wider pre-strip passes, there is a fundamental lack of understanding of the net economical effect these extended passes have on an operation's bottom-line. A Net Present Cost (NPC) evaluation was conducted on a range of pre-strip widths to derive this net economical effect for a typical pit at a multiple seam surface coal mine. In completing the evaluation, data was obtained from an established surface coal mine within the Bowen Basin in Queensland to derive a generic pit model and pit design. The pit model simulated each pre-strip production case using volumes generated for the study pit.

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PRE-STRIP MINING

Dragline stripping

Draglines are large single-bucket stripping machines and are extensively used for direct side casting of waste material (Atkinson, 1992). The most common form of dragline is the walking dragline which has emerged as the dominant overburden removal machine in surface mining operations in Australia (Mirabediny and Baafi, 1998).

Although used almost exclusively for overburden and interburden removal at established surface mines, draglines have been used in initial boxcut excavation and pre-stripping scenarios. The reason being that draglines can be used for a wide variety of rock types and strengths however rely on blasting to fragment competent rock. In addition to their ability to dig multiple rock types, a number of digging sequences can be employed depending on the seam dip, overburden depth and economic constraints of the operation.

Truck-shovel stripping

Truck-shovel systems are better suited to more complex geological conditions than its stripping counterparts with the ability to remove overburden in deeper, uneven and multiple seam situations (Holfeltz and Kunz, 1983). Being one of the preferred methods of overburden removal for most deposits, truck-shovel systems excavate a number of passes establishing benches whenever a certain depth of cut is achieved. The conventional method of stripping overburden with shovels or excavators is through exposing the coal seam in narrow strips similar to that of dragline methods (Porterfield, 1973). Truck-shovel systems are usually also employed in excavating the initial box cut to initiate mining.

Scott, *et al*., (2010) suggested the main advantages of truck-shovel systems are:

- Less capital outlay then dragline systems;
- Suitable for shorter term projects;
- Better flexibility and mobility; and
- Suitable in complex geological situations.

Truck-shovel systems however, have lower production rates, higher operating costs and require more ancillary equipment than draglines (Scott, *et al*., 2010). The term truck-shovel system refers to any one of the following equipment setups:

- Trucks and electric rope shovels;
- Trucks and hydraulic excavators/shovels; and
- Trucks and front-end loaders.

Double-side loading

Double-side loading of trucks is known to be more productive in opencast mining methods. The technique involves loading a truck on either side of the shovel leading to reductions in cycle times and increases in loading productivity. Figure 2 illustrates a typical double sided loading scenario.

Double-side loading substantially improves production per shift by improving truck productivity and has been proven to reduce individual truck spotting time by 30 s (Tasman Asia Pacific, 1998).

STRIPPING CONFIGURATION

Introduction

Strip mining requires careful consideration of the pit configuration to ensure waste movement can occur on schedule and at minimum cost. Stacked and offset pit configurations are commonly used in surface coal mines across Queensland. The study assumes an offset pit configuration to ensure some parallels can be drawn between the case study operation and the study pit.

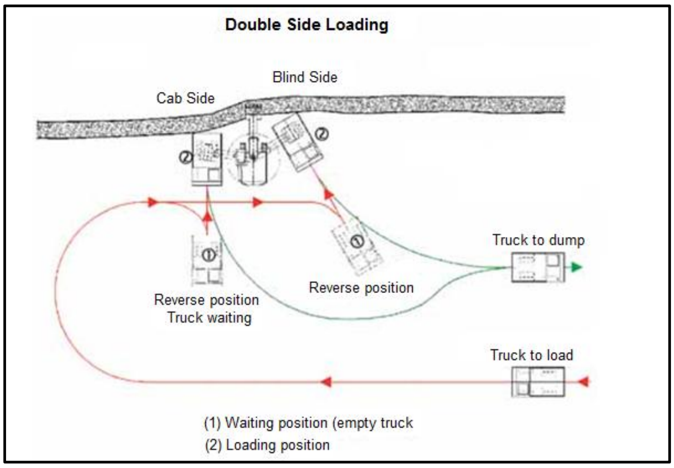

Figure 2 - Double-side truck loading (Fiscor, 2007)

Double dragline pass offset

Due to their operating cost efficiency, draglines commonly excavate the waste passes immediately overlying the valuable coal seams. As such, deep pits containing two coal seams are usually mined using a pre-strip pass and two dragline passes. The first dragline pass excavates the overburden overlying the upper coal seam with the second dragline pass excavating the interburden and exposing the lower coal seam. These two passes require some form of offset to ensure operational safety and flexibility. The offset applied to these passes most commonly amounts to a full dragline strip width plus an additional distance to allow for efficient drilling and blasting of the bench. Figure 3 illustrates the indicative dragline bench offsets applied in the study pit.

Pre-strip pass offset

A pre-strip pass offset is also required in many open cut strip mines. The pre-strip offset performs a similar role as the dragline pass offset in that it facilitates the efficient drilling and blasting of the subsequent bench. The offset also allows for safe pre-strip digging away from the free dragline bench highwall. Figure 4 shows the typical pre-strip offset applied in the study pit design.

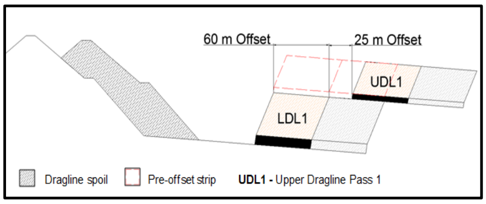

Figure 3 - Indicative dragline pass offset for the study pit

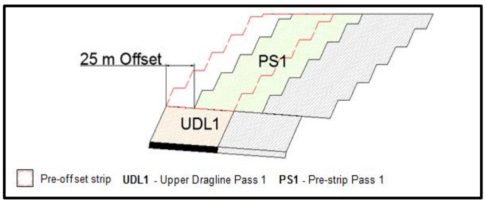

Figure 4 - Indicative pre-strip pass offset for the study pit

Study pit final strip configuration

Combining the two offsets together results in the final pit configuration which was adopted for the study pit. Figure 5 illustrates the final pit configuration which was used in designing the study pit.

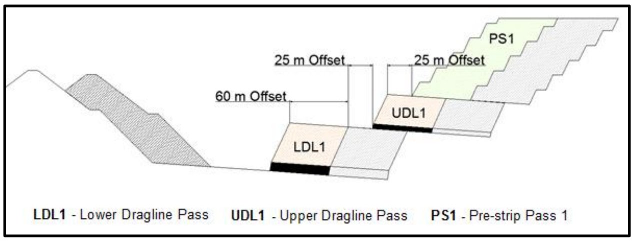

Figure 5 - Indicative final strip configuration

GENERIC PIT MODEL

A generic pit design and model was created to facilitate the evaluation of each pre-strip production case. A key driving force behind the use of a generic model over the actual pit layout and design of the case study mine was the need to generate results applicable to various mining situations. The established case study mine has a very unique pit setup and as such the evaluation implemented only the generic strata attributes, mining methods, machine productivity and costs currently in use at the site. In completing the generic pit model, data was generated using a Microsoft Excel^{TM} pit configuration tool which generated accurate strip volumes based on user input of the basic pit layout and geotechnical considerations. It was deemed necessary to also design the pit and validate the results generated through the use of the Microsoft Excel^{TM} tool. The study evaluated 20 future strips and relied on historical productivity and cost data from the case study mine. Table 1 outlines the key design variables used in designing the study pit (Figure 6).

Table 1 - Study pit design variables

Item	Unit	Value
Dragline strip width	(m)	60
Pre-strip width	(m)	60 - 120
Lower dragline bench height	(m)	40
Upper dragline bench height	(m)	30
Dragline highwall angle	(˚)	65
Pre-strip bench height	(m)	15
Pre-strip bench angle	(˚)	65
Upper coal seam thickness	(m)	5
Lower coal seam thickness	(m)	9
Coal seam dip	(˚)	4
Coal seam highwall angle	(˚)	80
Strip length	(m)	1000
Initial strip depth (Topography to lower seam)	(m)	130
Dragline dig depth (In-pit bench elevation)	(m)	45
Dragline dump height	(m)	40
Spoil lift 1 repose	(˚)	45
Spoil lift 2 repose	(˚)	37
Spoil berm	(m)	10
Max. pre-strip dump height above topography	(m)	60
Max. ramp grade	(%)	10

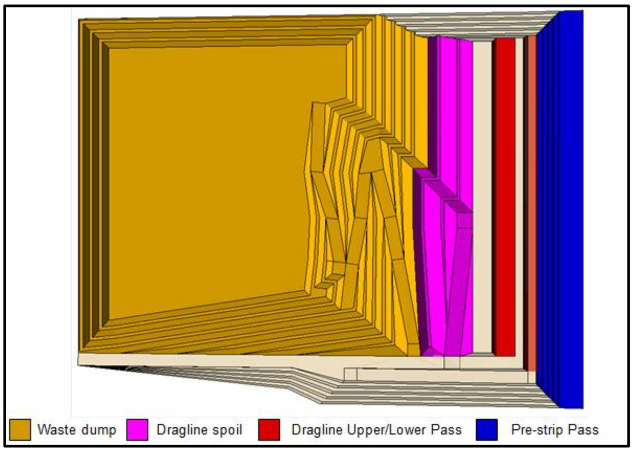

Figure 6 - Study pit design and layout

With the focus of the study being on the cost attributable to pre-strip activities, all subsequent mining activities were held constant for each pre-strip production case. This ensured that any variance in NPC was directly related to the increase in material moved and changes in productivity realised in the truck-shovel system.

One key assumption made in completing this project was that the operation had multiple active mining areas or pits. As such, truck-shovel fleets were able to relocate to different pits when a certain pass was completed ahead of schedule. With any operation, it is preferred to defer costs as far as feasibly possible into the future whilst receiving the maximum revenue in the current period. This is facilitated through the relocation of the truck-shovel fleets. Taking an extended pre-strip pass effectively exposes a free dragline strip in the future at which point further pre-strip stripping becomes unnecessary at that point in time to sustain the current dragline path.

In essence, if the truck-shovel fleet were to continuously excavate its strips until it completes its final strip, the amount of dragline bench exposure would far exceed the required amount, thus increasing unnecessary upfront cost. Hence, as the fleets relocate to another pit, a gap in the pre-strip schedule for the focus pit is created which occurs when a free dragline strip is exposed. This free-strip essentially equates to the benefit perceived from extended stripping with the cost equating to the additional upfront waste stripping.

Pre-strip production cases

The base pre-strip production case of 60 m was extended in 10 m increments to form six additional extended cases. Figure 7 outlines the pre-strip configurations for each of the production cases evaluated in the study.

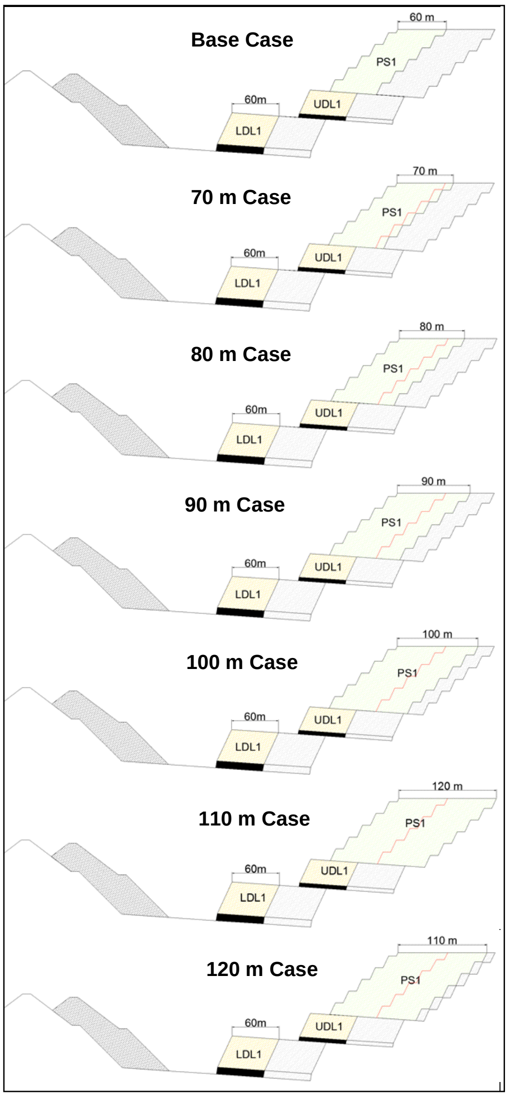

Figure 7 - Pre-strip production cases

Free-strip benefit

Summarising the number and timing of each free-strip was essential in accurately assigning delays in the scheduling and to ultimately capture the intrinsic discounted value of the pre-strip production gaps. Table 2 summarises the frequency and timing of free-strips under each of the production cases.

Table 2 - Free-strip distribution

UDL Strip Number	Pre-strip Production Case (m)						
	60	70	80	90	100	110	120
1							
2							■
3				■	■	■	
4			■				■
5					■	■	
6				■			■
7		■				■	
8			■		■		■
9				■		■	
10					■		■
11						■	
12			■	■			■
13					■		
14		■				■	■
15				■	■		
16			■			■	■
17							
18				■	■	■	■
19							
20			■		■	■	■
Number of free strips	0	2	5	6	8	9	10
■ Free-strip		UDL	Upper Dragline Pass				

PRODUCTIVITY AND COST CONSIDERATIONS

Case study fleet benchmarking and cost

Productivity and cost estimates were obtained from an established leading coal producer in the Bowen Basin. Data was collected for the year commencing January 1st, 2011 and involved both individual machine and fleet productivities. Dragline stripping productivity was estimated to be 2000 BCM/h after assigning applicable delays and a rehandle factor of 65.5 % which was determined from dragline section analysis. Dragline cost was estimated to be A$1.7/Prime BCM.

The study assumed a constant mining fleet for each production case over the nominal 20-strip mine life. For this reason, pre-strip and coal mining fleet productivity was constrained by the loading unit productivity. Figure 8 illustrates the loading unit productivity assigned to each digging unit with EXD, SHD and SHE referring to excavator, hydraulic shovel and rope shovel respectively.

Drill and blast rates and costs were estimated to closely match the case study operation with a constant A$0.7/Prime BCM being applied to all clearing, drilling and blasting activities. On-bench loading of explosives and blast preparation activities were assigned a nominal duration which was held constant for each production case.

Coal mining was assigned a productivity level of 1100 BCM/h and a unit cost of A$6.8/t hauled. Truck-shovel stripping was determined for the base production case. Excavator stripping used in excavating the initial tertiary material and the final wedge exposing a level dragline bench was assigned a productivity of 1200 BCM/h. The base production case involved a shovel productivity of 2000 BCM/h. The total truck-shovel stripping cost for the base case was estimated to be A$3.1/Prime BCM.

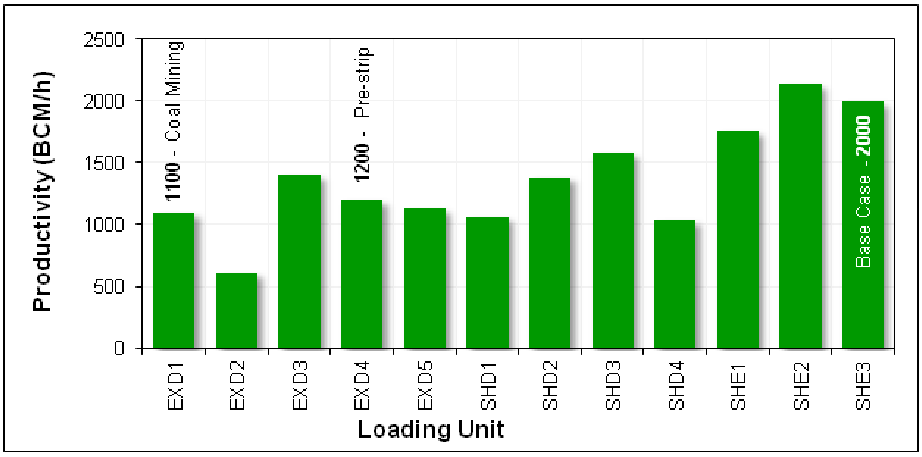

Figure 8 - Loading unit productivity analysis

Productivity and cost escalation

Indicatively, increasing the pre-strip width yielded different shovel productivities and unit costs. Productivity increases for the shovel were attributed to the transition from single-side to double-side loading and the increase in manoeuvrability and flexibility seen in wider pre-strip benches. It was assumed that unit cost was negatively correlated with productivity. This was due to constant trucking numbers for each pre-strip production case and the elimination of machine modifications.

All other unit costs applied in the base case were held constant for each pre-strip production case. Although truck-shovel unit costs reduced incrementally with increases in pre-strip width, an escalation factor was required for ancillary activities cost.

A preliminary haulage analysis yielded marginal incremental increases in cost and as such was excluded from the study. The net result of the decreasing shovel cost and increasing ancillary cost yielded an overall increase in truck-shovel system cost when pre-strip width was increased (Figure 9).

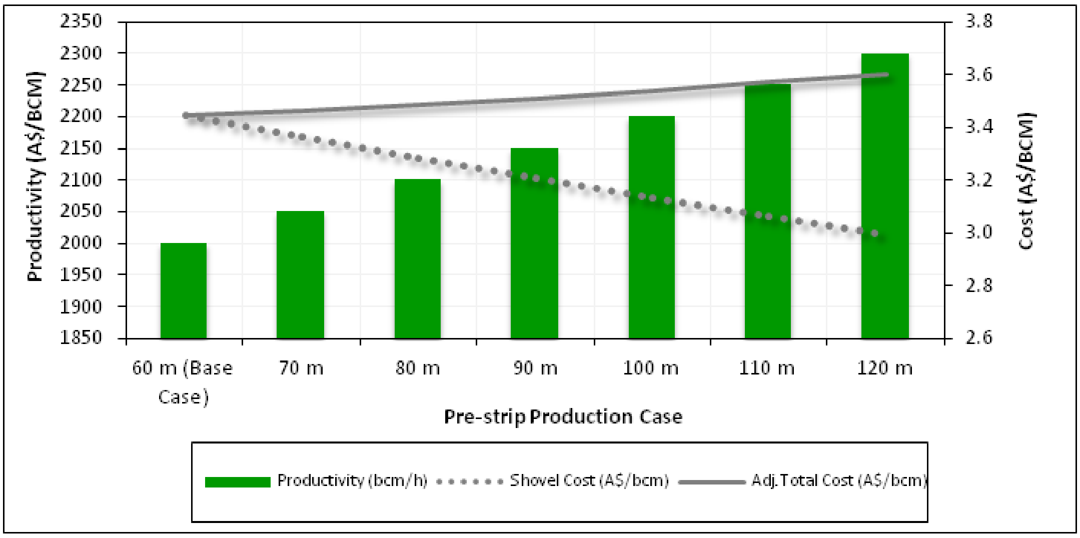

Figure 9 - Shovel unit productivity and cost escalation

SIMULATION MODEL

Pit configuration tool

A suitable Microsoft Excel™ tool was created to efficiently generate waste and coal volumes for each of the production cases. The model generated accurate volumes based on user inputs and complex trigonometry and allowed for a large number of scenarios being tested in a relatively timely manner.

Valuation model

The final stage in the project involved the economic modelling of the material movements for each production case. As such, a NPC valuation model was created in Microsoft Excel™ to accurately capture the cost-benefit of each production case. The model utilised the material movements scheduled using Microsoft Project™.

Material scheduling

The cost evaluation involved the use of Microsoft Project™ to schedule all material movements for the study pit. The scheduling strategy involved breaking the pit into equally spaced segments known as blocklines. These blocklines were spaced 100 m apart and facilitated the accurate scheduling of each activity from initial tertiary excavation to the mining of the lower seam coal (Figure 10).

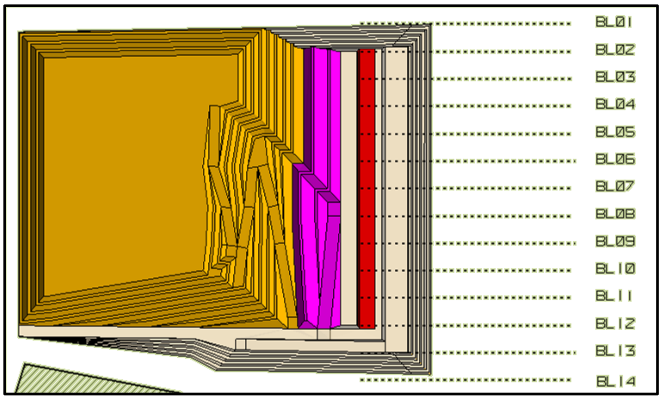

Figure 10 - Study pit blocklines

To create manageable schedules, the holistic mining operation was grouped into a number of key tasks or activities. These activities were chosen on the basis of their criticality to the overall mining process and are shown in Table 3. Each of the key activities was assigned the total number of strips required as sub-tasks which in turn were assigned blocklines as sub-tasks.

Table 3 - Scheduling tasks

Scheduling Task Hierarchy	Machine/Fleet	Reason
Upper pre-strip	Truck-excavator	Remove initial 10 m tertiary material
Middle pre-strip drill and blast	Drill and blast	Fragment shovel material
Middle pre-strip	Truck-shovel	Remove blasted material
Lower pre-strip	Truck-excavator	Remove wedge above upper dragline pass
Upper dragline drill and blast	Drill and blast	Fragment upper dragline pass material
Upper dragline	Dragline	Remove blasted material
Upper coal drill and blast	Drill and blast	Fragment coal prior to removal
Upper coal mining	Truck-excavator	Removal of fragment coal
Lower dragline drill and blast	Drill and blast	Fragment coal prior to removal
Lower dragline	Dragline	Remove blasted material
Lower coal drill and blast	Drill and blast	Fragment coal prior to removal
Lower coal mining	Truck-excavator	Removal of fragment coal

Importing the scheduled tasks into the Microsoft Excel™ models allowed for intensive data modelling and analysis. The first area of focus was the overall pre-strip material movement for each case. Figure 11 shows an example of the cumulative pre-strip waste production of the 90 m production case (the Best Case) compared to the base case.

The drill and blast material movement formed a key component of the study since additional pre-strip stripping is directly related to the amount of blasting required for efficient digging of the shovel.

The dragline material movement, although necessary to effectively schedule the pre-strip activities, falls outside of the study scope and as such has been excluded. Similarly, coal movements were constant for each production case and have not been included in this paper.

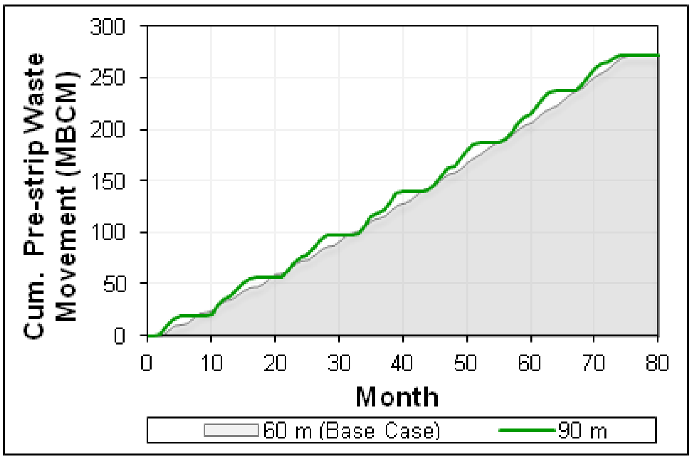

Figure 11 - Cumulative pre-strip production of 90 m production case compared to the base case

ECONOMIC EVALUATION

Cost benefit

The main aim of the project was achieved through the determination of the cost-benefit of extended pre-strip stripping. The different pre-strip production cases yielded variable NPCs with two cases yielding a lower cost than the base production case. Figure 12 illustrates the final outcomes of the evaluation models generated for each production case.

Setting the base case NPC to zero yielded the present cost variance of each case (Figure 13). The results suggest that a net saving of A$8.4 million is achievable through modifying the pre-strip width to 90 m for the life of the schedule. Marginal savings were also potentially available when a 110 m pre-strip width is adopted. The remaining extended pre-strip production cases yielded a NPC higher than that of the base production case.

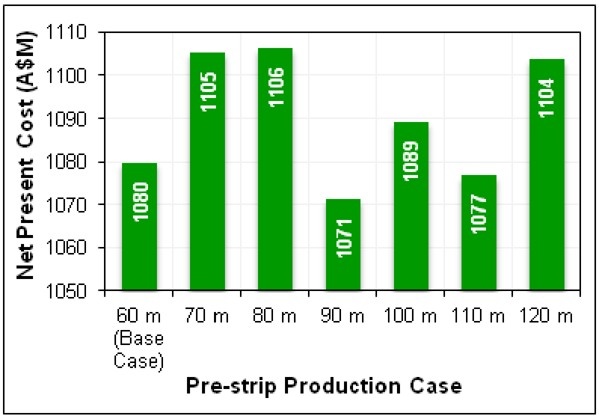

Figure 12 - Total net present cost per production case

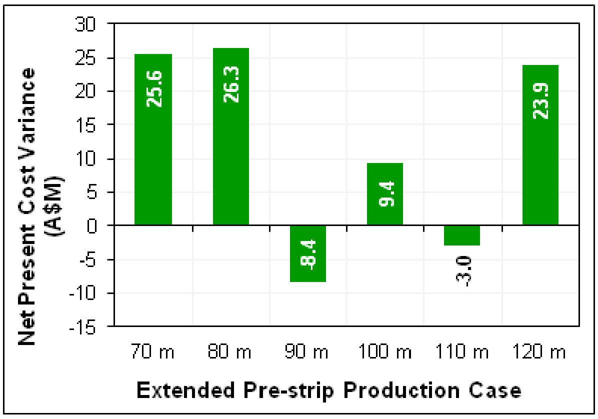

Figure 13 - Net present cost variance to base case

Annual cost variance

Discounted cash flow analysis yielding a single NPC was insufficient in explaining the implied benefit or cost associated with extended waste stripping. As such, an analysis was conducted targeting annual cost implications associated with the additional waste stripping seen in the extended pre-strip production cases. Figure 14 illustrates the annual cost variance to the base case when a 70 m pre-strip production case was adopted.

Cost variance for a 70 m production case appeared sporadic in nature with cost reductions seen in years two, five and seven. Similarly, Figure 15 illustrates the annual cost variance to the base case when an 80 m pre-strip width was adopted. An 80 m production case yielded a large increase in cost in year two with a diminishing cost saving from year three onwards. Figure 16 shows the annual cost variance to the base case when a 90 m pre-strip strip was implemented. Implementing a 90 m pre-strip strip width resulted in an incremental increase in cost over the base case for the first three years. Year four onwards realised significant cost reductions. Figure 17 shows the annual cost variance to the base case of a 100 m pre-strip production case.

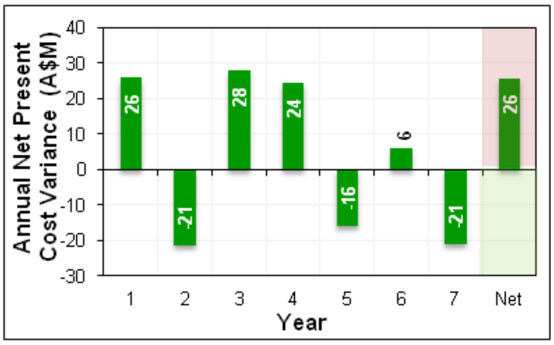

Figure 14 - 70 m production case annual cost variance

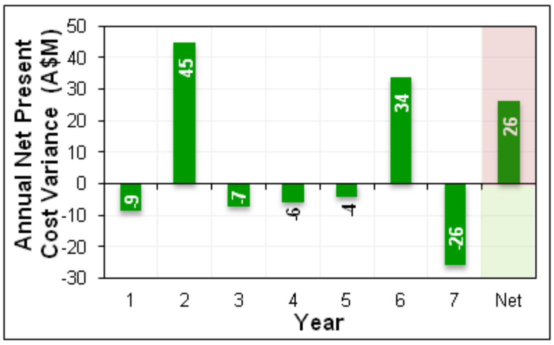

Figure 15 - 80 m production case annual cost variance

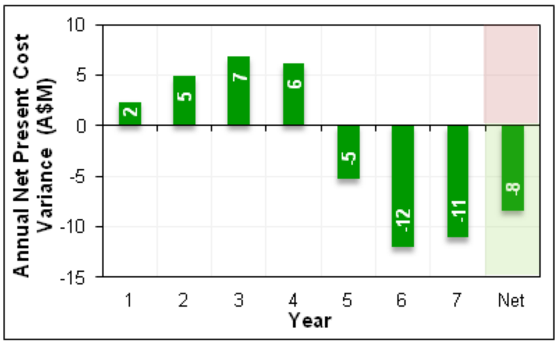

Figure 16 - 90 m production case annual cost variance

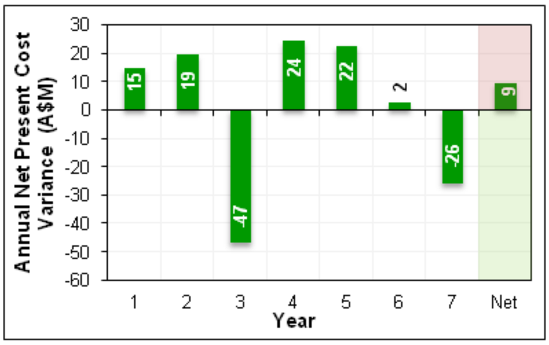

Figure 17 - 100 m production case annual cost variance

Under a 100 m pre-strip production case, a large cost reduction was evident in year three when compared to the base case. When considering the 110 m pre-strip production case, cost reductions were possible in years two, five and seven resulting in a net cost saving of A$3 million over the life of the schedule (Figure 18). Similarly, Figure 19 illustrates the cost variance per year when adopting the 120 m pre-strip production case. The cost variance under this production case followed a regular pattern of positive-negative fluctuation. Notably, this production case yielded the greatest magnitude in variance with an additional A$52 million of cost experienced in year three.

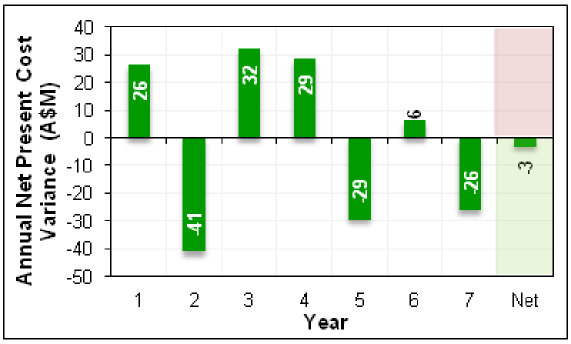

Figure 18 - 110 m production case annual cost variance

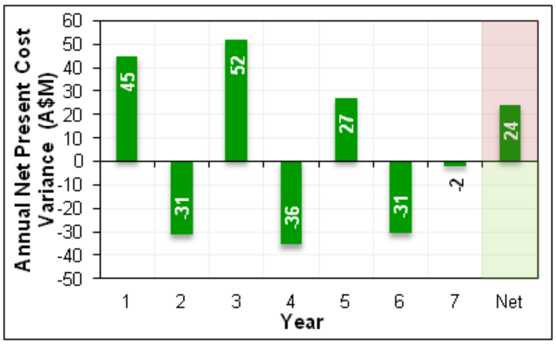

Figure 19 - 120 m production case annual cost variance

EVALUATION DRIVERS

Productivity effect

In order to evaluate the net effect that the change in productivity had on each production case NPC, the productivity effects were removed from the schedules and models to yield the NPC values in Table 4.

Table 4 - Productivity effect on net present cost

Pre-strip Production Case	NPC (A$M)	Adjusted NPC (A$M)	Productivity Effect (A$M)
60 m (Base Case)	1079.7	1079.7	0.0
70 m	1105.2	1118.9	(13.7)
80 m	1106.0	1102.5	3.5
90 m	1071.2	1055.4	15.8
100 m	1089.0	1072.8	16.3
110 m	1076.6	1071.4	5.2
120 m	1103.6	1111.5	(7.9)

The change in productivity from the base case to the 70 m and the 120 m case had an overall reducing effect on final NPC. In terms of the 70 m case, only two free-strips are realised over the life of the pit with waste production continuously exceeding that of the base case. Considering that the increased productivity led to the free-strip being exposed slightly earlier in the schedule, it is clear that the reduction in NPC through increased productivity is a result of a higher weighting being applied to the free-strip benefit under the time value of money assumption. The same understanding can be applied to the 120 m production case whereby an increased productivity yields an earlier and higher weighted free-strip benefit. This concept can be easily explained through plotting the cumulative pre-strip waste variance of each case to the base case (Figure 20).

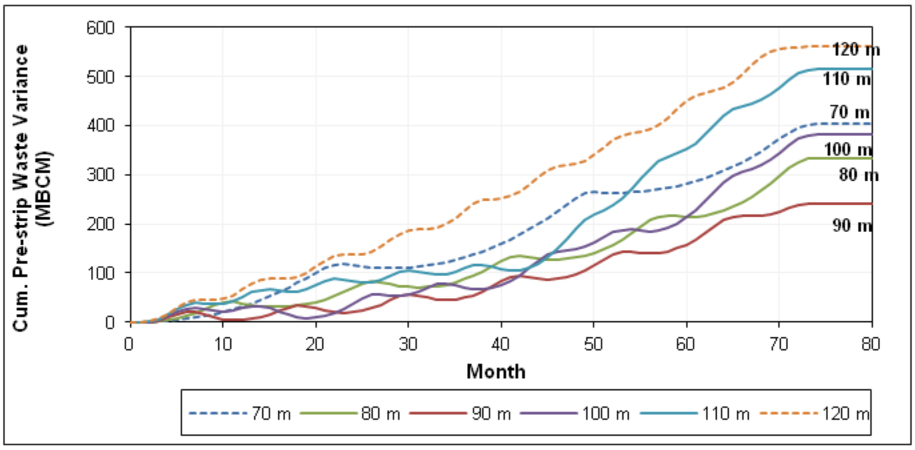

Figure 20 - Cumulative pre-strip waste variance to base case

In essence, any additional pre-strip waste moved in the extended production cases resulted in positive waste variance. Comparatively, exposing a free-strip at some point in the schedule would yield negative waste variance in that the base case would continue pre-strip stripping and the extended case will relocate and leave a gap in production for the schedule. In the case of the 70 and 120 m production cases, a large amount of positive waste variance is seen earlier in the schedule, attracting a higher discount factor and leading to an increase in NPC.

Timing effect

The timing effect on the value of money was evaluated by removing the discount factor applied to future cash flows or more simply, by setting the annual discount rate to zero. By doing this, the adjusted NPCs revealed large cost reductions when discount factors were applied (Table 5).

It is evident that the inclusion of a discount rate in the economic modelling yielded a lower NPC. This is due to the discount rate assigning a lower weighting to future cashflows, which by definition, reduces NPC. Figure 21 illustrates the timing effect compared with the productivity effect for each production case.

Table 5- Timing effect on net present cost

Pre-strip Production Case	NPC (A$M)	Adjusted NPC (A$M)	Timing Effect (A$M)
60 m (Base Case)	1079.7	1396.9	(317.2)
70 m	1105.2	1497.1	(391.9)
80 m	1106.0	1385.2	(279.2)
90 m	1071.2	1337.1	(265.8)
100 m	1089.0	1359.7	(270.7)
110 m	1076.6	1339.1	(262.5)
120 m	1103.6	1301.0	(197.4)

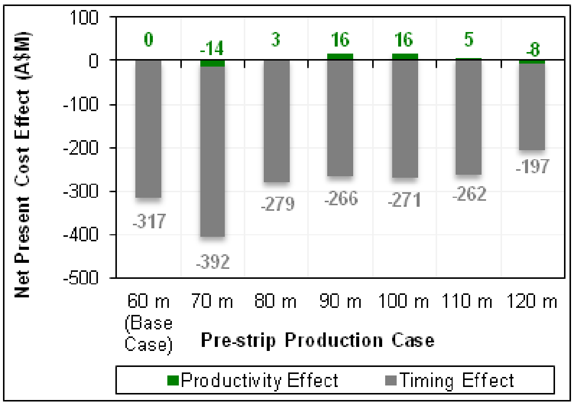

Figure 21 - Productivity and timing effects

When the base case is ignored, the timing effect trend shown in Figure 22 suggests that the amount of discounting applied in the model reduces with pre-strip width. This can be directly attributed to the increasing number of free-strips per production case. It follows that with wider pre-strip passes; more free-strips will be exposed, the time increment involved in realising those free-strips will be shorter and more weight will be applied to both additional upfront waste and subsequent free-strip production gaps.

Best production case

The 90 m pre-strip production case yielded the lowest NPC out of all of the cases in the study. Understanding why and how this result was generated formed a key component of this project. The 90 m pre-strip pass yielded a total of six free-strips over the 20-strip life with the strips being exposed in regular time intervals. Figure 22 illustrates the monthly cashflow variance for the 90 m production case when compared to the base case of 60 m.

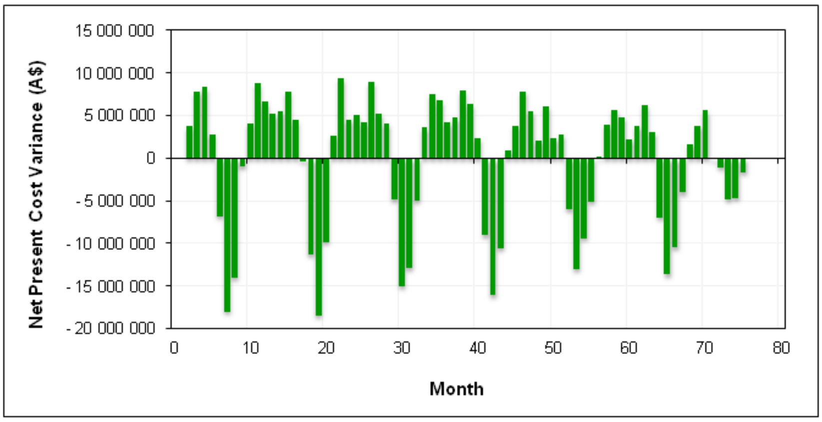

Figure 22 - Monthly cost variance for 90 m production case

The magnitude of the negative cost variance outweighs the magnitude of the positive cost variances thus leading to a reduction in NPC. The 90 m production case strikes a balance between the timing of free-strips and the additional upfront waste stripping that the other cases cannot achieve. The regularity and size of the production gap brought on by the free-strip's exposure and fleet relocation ultimately lead to significant cost reductions over the long term.

CONCLUSIONS

The evaluation suggested that a significant cost saving can be achieved when a pre-strip width of 90 m is selected. A total saving of A$8.4 million was achieved over 20 strips of minimal length. Marginal savings are also achievable when a 110 m pre-strip width is adopted.

The cost savings generated through the implementation of a 90 m pre-strip width instead of the base case was directly related to the number of free dragline strips exposed in time and the annual discount applied to cashflows. The results suggest that there is an economic trade-off point or width where the benefit of fleet relocation, through free-strip exposure, outweighs the additional costs generated in stripping waste in advance. This width has been identified as 90 m.

The project has the potential to be re-examined on a higher level with actual case study pit designs and scheduling to yield more probabilistic and specific results. Similar research has been conducted into optimum dragline strip widths however no previous economic studies have been published to evaluate different pre-strip stripping widths. Although theoretically accurate, the results presented should not be implemented at any operation without further analysis that incorporates site-specific constraints and variables.

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