THE UNIVERSITY OF QUEENSLAND

BACHELOR OF ENGINEERING THESIS

Optimisation of Prestrip Waste Material for Surface Mines Using Dozer Push as Main Method of Waste Removal

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ABSTRACT

In open pit strip mining the bulldozer has many uses, one of which is the ability to bulk dozer push overburden into an available dump space. When the use of a dragline is not feasible and the coal seam is very shallow, the dozer push combined with a truck and shovel prestrip method is usually the next best available option. For a dozer push operation, a typical cross section involves one or several prestrips which is removed by truck and shovel with a cost of ($4.00 per bank cubic meter, BCM), a dozer push removed by bulldozer with a cost of ($1.60 per BCM), and a wedge volume which is removed by truck and shovel but has a larger cost ($4.50 per BCM) then the prestrip.

This thesis examines the economic effect of a change in prestrip height on a strip mine operation that has a single bench prestrip with a bulk dozer push to top of coal. Porter mine is a strip mine that has a single bench prestrip and dozer push, it has six pits (A to F) with varying distances from surface to top of coal. By collecting data from Porter mine, prestrip, dozer push and dozer dump surfaces were able to be designed and created (in Vulcan) at three different prestrip heights for two consecutive strips for each pit.

Once these designs were created, two scenarios were evaluated. The first being the Porter mine case study, where the dozer dump volumes were limited by a final land form height. This meant that the dozer push operation filled the dump capacity and left behind a wedge volume that had to be removed via truck and shovel (larger cost of removal). The second case study was a general case study, where there was no limit applied to the dozer dump height, thus allowing all the dozer push material to be removed via the cheaper dozer push method. The second case study allows for the methodology to be applied across any mine site, since most sites do not have a limitation on dump height.

By generalizing the results from the case studies, it was found that the dozer push volume should be maximised if the dozer dump is not filled. If it is filled then as much of the remaining material should be removed in the prestrip then the wedge, as the wedge has a higher removal cost per BCM. The study looked at the economic effect of a change in prestrip height; it was found that neither an increase or decrease in prestrip height is the better option and that there are several factors which determine the optimal prestrip height.

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1. INTRODUCTION

1.1. BACKGROUND

In mining, there are a variety of bulldozers as well as applications in which they are used. This includes, dump levelling, tree and topsoil clearing, material pushing, as well as others. The D-575A-3 Super Dozer by Komatsu is the largest dozer in production, it tips the scales at 152.6 tonnes, and can move 70 cubic meters of material per pass, which can be dramatically increased with an optimal blade (Latimer, 2014). This project will focus on the use of dozers as a primary overburden waste removal method. Draglines are very commonly used in large operations to remove waste and uncover coal; however on smaller scale mine sites, where the depth to top of coal is relatively small, dozers which bulk/free push the overburden are a cheaper and more viable option.

Another piece of machinery used in surface mines are excavators; excavators are primarily used as some form of waste and ore removal, or a combination of both. Excavators are combined with trucks in prestripping, and are generally used to prestrip ahead of a dragline. The truck and shovel combination is well suited to complex geological conditions. This project will focus on the use of excavators as a prestrip overburden removal method.

A case study from a Wyoming mine has shown that “As deeper cover is encountered and dragline capacity first began to be exceeded, the mine initially attempted to compensate for dragline striping shortfalls through the use of shovel/truck prestripping. However the mines management soon concluded that dozer prestripping represented a more cost effective alternative to shovel/truck methods.” (Archibald and Bawden, 1993). This project will look at the effectiveness of changing the prestrip height in a bulk dozer push surface strip operation; doing so changes the volume of material assigned to both the excavator prestrip and the bulk dozer push.

1.2. Problem Statement

Figure 1 shows an example cross section of a prestrip dozer push operation, by adjusting the height of the prestrip level, waste material can be assigned to a different removal method (either excavator prestrip or dozer push). For example, if the total strip height is 20m, and the prestrip height is 10m, then the dozer push height is 10m. If the prestrip height changed to 15m, there would only be 5m of dozer push height. Thus by changing the height (or level) of the prestrip, the cost associated with waste removal of the strip will change. This project aimed to investigate the economic effect of changes in prestrip level in surface mines which utilise dozer push as a method of waste removal.

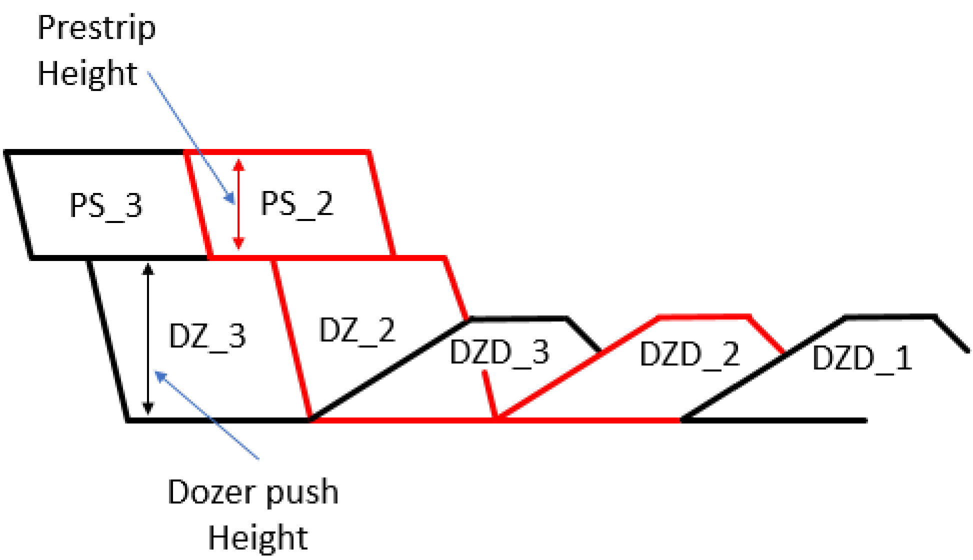

Figure 1. Example cross section of strips 1, 2, and 3

1.3. Project Aim, Objectives, and Milestones

The project ultimately aimed to investigate the economic effect of changing prestrip level in surface strip mines which utilise dozer push as the main method of waste removal. To achieve the aim of the project, a few objectives had to be defined and completed.

The objectives and associated milestones of the project were as follows:

1. Research on dozer push and excavator prestrip methods of Australian strip mines
    - Finding relevant books, journals, research papers, etc.
2. Research to find appropriate values to use for cost of prestrip, drill and blast, and dozer push operation per bank cubic meter (BCM)

- Finding relevant books, journals, research papers, etc.

3. Find appropriate case study

   - Researching mine sites that use dozer push as main waste removal method
   - Selecting specific site to use for case study

4. Collect any relevant Vulcan surfaces (topography, current surface, etc.), previous dozer push and prestrip designs

   - Achieving contact with company/site, and enquire about designs; and
   - acquiring permission from company/site.

5. Create dozer push and excavator prestrip designs at three different levels in Vulcan for the next two progressive strips, for all three pits

   - Learning to use design functions and tools in Vulcan;
   - determining design parameters (bench heights, berm widths, batter angles, etc.);
   - determining differentiating designs for different pits; and
   - factor in ramp designs and haul roads.

6. Create surfaces from the designs in Vulcan

   - Learning to use triangulation and surface creation tools in Vulcan;
   - factor in final land form and creek diversion vertical limits; and
   - ensuring all surfaces are valid surfaces, and properly reflect the design.

7. Calculate volumes between the designed surfaces to find the total volume of waste in each block, strip, pit

   - Learning to use volume calculation tools in Vulcan;
   - determining which surfaces to use for volume calculations; and
   - ensuring all volumes are appropriate and logical.

8. Calculate and re-evaluate cost of operation

   - Determining and learning program for cost evaluation (excel, Vulcan, other program);
   - calculating cost of each block, then strip, then pit, at all three prestrip levels; and
   - finding total cost of operation for all prestrip levels and determining cheapest.

9. Analysis of results of case study and generic study

10. Generalizing results from case studies to make a general statement regarding effect of prestrip level

There were a total of ten objectives, consisting of research, data collection, design, evaluation, discussion, and creating a general statement in regards to the project. It was ideal for the objectives to be completed in their order, which followed a typical project, research → data collection → design → results/discussion → concluding statements.

1.4. In Scope, Out of Scope, and Assumptions

Table 1 shows the items in scope and out of scope of the project.

Table 1.
In scope and out of scope

In scope	*Out of scope*
• Dozer push methodology; • excavator methodology; • estimation (cost/BCM) of waste removal methods; • wedge volume left behind by dozers; • inpit dump vertical limits; • creek diversion (vertical dump limit); • prestrip levels 10m, 12m, and 14m (Pit E and F); • prestrip levels 6m, 8m, and 10m (Pit A to D); • access ramp designs for dozer push; and • haul road design for prestrip and dozer push.	• Specific drill and blast design for each pit; • rate of waste removal (timeframe); • strip ratio; • coal removal method; • topsoil removal method; • drill and blast costs; • out of pit dump location and associated cost; • evaluating any equipment other than excavator and dozer (e.g. dragline, rope shovel); • haul road outside immediate pit; • inpit ash dumping; and • truck fleet operation.

There were factors which had to be assumed for the workload to be cut down or could be out of scope, but still played a role in the results; an example of which is the drill pattern design. In order for the blasting cost to play a role in the project, a drill/blast pattern would have to be designed for each bench, however this is out of the scope of the project. Other factors also played a role in the effect of the project, thus the following assumptions were made:

- Blasting cost is accounted for in the dozer push cost;
- all machinery cuts waste material to exact design; and
- topsoil was assumed to be waste and taken as part of the prestrip and not a separate topsoil removal level.

1.5. RESOURCES REQUIRED

The following are the resources required for the project to be successful:

- Vulcan software;
- Microsoft Excel^{TM};
- site approval;
- company approval; and
- Vulcan data.

1.6. ORIGINAL CONTRIBUTION

This project will research the effects of changes in prestrip levels for surface strip coal mines, where dozer push is the main method of waste removal. Research has not been done previously been done on this topic.

1.7. EXPECTED OUTCOMES

It is assumed that the dozer push method is cheaper per BCM than excavator prestrip method, thus by decreasing the height of the prestrip, more waste will be assigned to the dozer push operation and will decrease the overall cost, i.e. the shortest prestrip level will result in the lowest cost.

1.8. INDUSTRY RELEVANCE

Determination of the prestrip height is an important factor, as it has the potential to change the cost of waste removal. The research has the potential to save costing for companies that have strip mines with some form of bulk dozer push, as well as an effect on the scheduling and planning process. There is potential for the project to be further developed, by looking at the applicability of changing prestrip levels of any strip mine using any stripping method (not just dozer push).

2. BACKGROUND RESEARCH

2.1. Surface Coal Mining Methods

2.1.1. Open Pit Mining

Open pit mining is a large scale mining method with a high production rate, it is highly mechanized, capital intensive, with a low operating cost. It is applicable to both metallic and non-metallic ores, coals and other bedded deposits. Dimensions of the pit vary depending on the geology, equipment, geotechnical situation, and other factors. After the removal of waste overburden only (advanced stripping), mining starts at the top bench and continues until the bottom bench and the final pit outline is achieved; stripping of waste and ore mining are coordinated to ensure profitability.

The typical cycle of operations for an open pit mine are as follows:

- Drilling;
- blasting;
- excavation/loading; and
- haulage.

Other activities include slope stability, dust control, pumping and drainage, maintenance of equipment and haul roads. Open pit mining is applicable to most ore bodies, Table 2 shows the applicable conditions of the open pit mining method.

Table 2.
Open pit mining applicable conditions (MINE3122, 2016)

Parameter	*Description*
Ore strength	Any
Rock strength	Any
Deposit shape	Any
Deposit dip	Any (preferably low dip)
Deposit size	Large or thick
Ore grade	Can be very low
Ore uniformity	Prefer uniform ore, blending is possible
Depth	Shallow to intermediate

Table 3 shows the advantages and disadvantages of the open pit mining method.

TABLE 3.
Advantages and disadvantages of open pit mining (MINE3122, 2016)

Advantages	*Disadvantages*
High production rate	Depth limitations – stripping ratios
Low cost	High capital investment
Low labour requirements	Extensive reclamation requirements
Relatively flexible	Weather
Ideal for large equipment	Slope stability requirements
Simple development and access	Waste handling
Little support requirements	Environmental concerns – water pollution
Good recovery	Low operating cost is possible with large equipment
Good health and safety	

2.1.2. Strip Mining

Strip mining is a popular large scale mining method is a surface exploitation method that is mainly used for the extraction of coal and other bedded deposits. The main difference between open pit mining and strip mining is that overburden is not transported to a waste dump, instead it is moved directly into adjacent mined-out panels (strips). Reclamation can immediately follow mining as the mining activity is concentrated in a small area. Strip mining allows for a steeper highwall than other mining types, as the working face is only kept open for a relatively short time. As well as the general mining associated equipment such as water carts, graders, scrapers, main equipment used in strip mining include:

- Dragline;
- excavator;
- truck;
- bucket wheel excavators;
- crushers and conveyors;
- slushers and dragline hoppers;
- surface continuous miners;
- drill; and
- dozer.

(Mitra, and Serkan, 2012).

Table 4 shows the typical dimensions of a highwall.

TABLE 4.
High wall dimensions (Archibald, and Bawden, 1993)

Dimension	*Value*
Highwall height	30m to 60m
Width of cut	23m to 45m
Slope of highwall	60^{o} to 70^{o}
Slope of low wall (spoil pile)	35^{o} (natural angle of repose)

Table 5 shows the advantages and disadvantages of strip mining.

TABLE 5.
Advantages and disadvantages of strip mining (Lombardo, 2015)

Advantages	*Disadvantages*
High recovery rate	If strip ratio gets too large, can't mine
Faster than most other techniques	Investment is more of a gamble
Overall lower cost than open pit	Local water contamination
Safer	Environmental damage
Cost effective	Limited to shallow dip deposits
	Unexpected faults can cause deposit to disappear

Figure 2 shows the typical steps of a strip mining operation; the strip progression is to the right, and the steps are in order from right to left in the image. The cycle is outlined below:

1. Clearing and top soil removal;
    - vegetation is cleared, topsoil is removed and stockpiled usually by a scraper
    - where thickness allows, dozers assisting excavators to load trucks is plausible
2. fragmentation;
    - dozer used to rip ground to allow easier removal of waste
    - drilling and blasting is used to break up waste to allow easier removal
3. waste removal;
    - post fragmentation, overburden waste is removed
    - equip
4. waste replacement;
    - placement of waste is aimed to be reduced
    - waste is usually placed in previous strip void, thus reducing distance and cost
    - equipment used in this process can be dragline, truck/shovel, or dozer

5. coal mining; and
    - truck and shovel is commonly used
    - for thin seams dozer ripping can be used
    - for hard coal, more drilling and blasting may be required before extraction
6. mine restoration, maintenance, and eventual closure.
    - topsoil redistributed over mined-out strips and vegetation planted

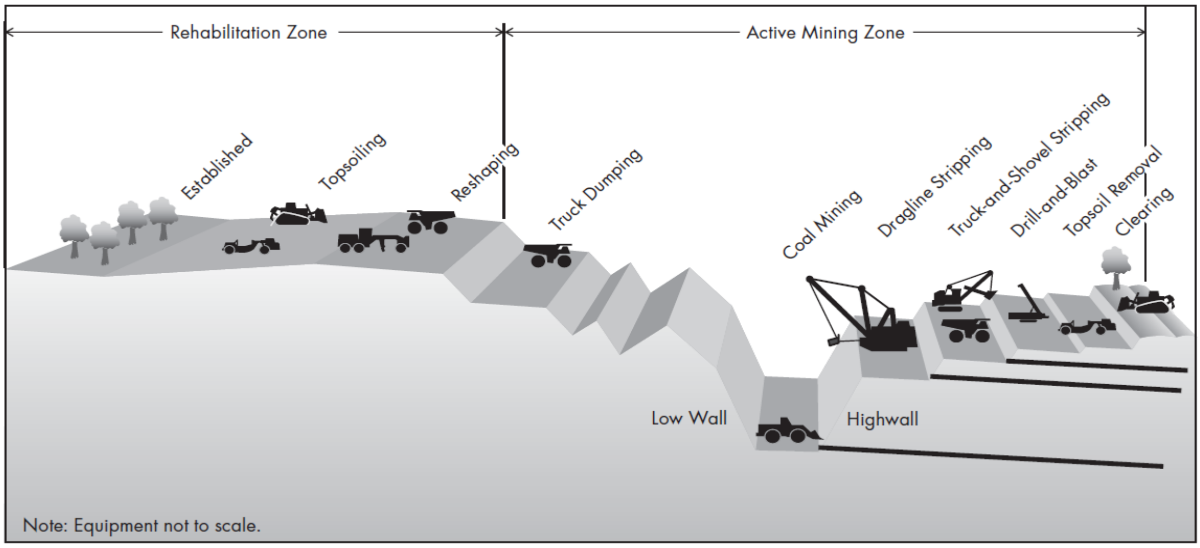

Figure 2. Generic strip mining cycle (MINE3122, 2016)

2.1.3. Highwall Mining

Highwall mining is done by boring openings beyond strip mine highwall limits, it is applicable after the strip ratio becomes too large, making strip mining uneconomical. Highwall mining requires the following conditions in order for the operation to work:

- Overburden thickness;
- fractures or jointing in the highwall;
- pit floor condition suitability for equipment installation;
- possibility of intersecting old underground workings; and
- coal seam continuity, thickness uniformity, and orientation less than 10^{o} pitch.

(MINE3122, 2016)

Table 6 shows the advantages and disadvantages of highwall mining.

TABLE 6.
Advantages and disadvantages of highwall mining (Chaman, 2013), (Shen, 2014)

Advantages	*Disadvantages*
Cheaper due to lower establishment	Low recovery rate
Very flexible	Low productivity
High mobility equipment	
No in-seam support required	
Can be remotely controlled	

2.2. DRAGLINE IN STRIP MINING

The dragline is the most common piece of machinery used for the removal of waste overburden and exposing of coal; it is generally the lowest cost overburden removal equipment used in surface mining. Like other mining methods, the deposit must have the correct conditions to allow for the potential use of the dragline, however the consequence for a deviation in conditions for the dragline will result in a costly increase in rehandled material.

Draglines operate in strips which are usually between 40 and 90m wide and a few kilometres long. The dragline excavates overburden and dumps it on the surface for the initial strip (box cut) and subsequently in adjacent mined out strips. The dragline beings at one end and advances strip by strip until it reaches the end of the deposit. Dragline operations are usually assisted by cast blasting and/or dozers to increase overburden removal capacity. Table 7 shows the applicable mining conditions for the dragline.

TABLE 7.
Dragline mining applicable conditions (MINE3122, 2016)

Parameter	*Description*
Deposit dip	Gentle dip, due to spoil instability in steeper dips
Deposit size	Large deposit to ensure adequate strip length and sufficient reserves to justify capital expenditure
Depth	Shallow depth, maximum 50m – 80m depending on dragline limitations

Table 8 shows the advantages and disadvantages of draglines.

TABLE 8.
Advantages and disadvantages of draglines (Mitra, and Serkan, 2012)

Advantages	*Disadvantages*
Direct cast (excavate and transport)	Constraints on dig depth and dump height
Low operating cost	Relatively inflexible
Can handle hard digging	Requires detailed planning
Low maintenance per cubic meter	High capital cost
Low ground pressure exerted, possible to move over dumps	Requirement of bench preparation
	Limitation to work only bottom seams
Lowest cost of overburden removal	Geological disturbances complicate field of operation
	Can only dump in pit

Depth to top of coal in many Australian coal mines have reached distances which draglines cannot handle without restriping equipment. Dragline geometries provide a relatively narrow operating envelope. The larger draglines have operating parameters:

- Dig depth of 60m;
- dump height 55m;
- dump radius 95m; and
- effective thickness of overburden allocated to the dragline system of about 80m.

2.3. Bucket Wheel Excavator

The bucket wheel excavator (BWE) consists of a tower, mast, boom, bucket wheel, travelling system, and discharge conveyor. It is a continuous mining system, as the bucket will constantly rotate and remove material. The BWE can be used to face mine both overburden and coal, and also recover coal or base metals from a stockpile. The BWE has multiple factors that affect its selection. These are:

- Insitu material strength;
- insitu material fractures;
- excavated material sizing;
- excavated material density;
- moisture content;
- physical properties in handling; and
- floor conditions for travelling.

TABLE 9.
Advantages and disadvantages of bucket wheel excavator mining method (MINE3122, 2016)

Advantages	*Disadvantages*
Continuous system	Suited to excavating softer materials
Lower operating costs than truck/shovel	Not readily relocated (poor flexibility)
Suits selective mining	Requires detailed planning for location
Ability to move material out of pit	Higher capital cost
	Performance depends on availability of separate components

2.4. TRUCK AND SHOVEL

The truck and shovel mining method combines the use of excavators (excavate) and trucks (transport and dump). The truck and shovel is a much more flexible mining method and thus more suitable for deposits with varying overburden depths, thicknesses, smaller deposits, and deposits with complex geology. Waste can be transported a long distance (to a dump) allowing rehandle to be a non-existent issue in the future of the operation. The truck and shovel are collectively cheaper than the dragline and as such do not require as much capital investment, however operating costs are much higher. Table 10 shows the applicable conditions for the truck and shovel mining method.

TABLE 10.
Truck and shovel applicable conditions (MINE3122, 2016)

Parameter	*Optimum description*
Deposit shape	Geologically complex, with irregular pit shapes, where draglines cannot mine effectively
Deposit dip	Steeply dipping deposits, where equipment cannot operate on seam roof and floor. Overburden initially dumped out of pit, then in pit when sufficient dump space is available
Deposit size	Small deposits which do not require high productivity of dragline. Basin deposits that combine steep dips at margins with short strike length and varying overburden depth along the strip

Table 11 shows the advantages and disadvantages of the truck and shovel mining method.

TABLE 11.
Advantages and disadvantages of truck and shovel (MINE3122, 2016)

Advantages	*Disadvantages*
Less capital outlay than dragline systems	High operating cost
Suitable for shorter term projects	Fairly high capital cost
Better flexibility and mobility	Weather can effect operation
Suitable in complex geological situations	
Options for different types of loading	
Ability to haul waste out of pit	

There are a few configurations in which the trucks can be loaded, these are single and double truck loading, drive by and modified drive by loading, and backhoe loading.

2.4.1. Single Truck Loading

In this configuration the loader is near the face of excavation, truck backs up next to the loader on the driver's side. The loader picks up a bucket full of material swings about 120^o and dumps into the truck. Process is repeated until truck is full, truck then leaves and another takes its place. Table 12 shows the advantages and disadvantages of single truck loading.

TABLE 12.
Advantages and disadvantages of single truck loading (MINE3122, 2016)

Advantages	*Disadvantages*
Simple Truck doesn't have to back tyres into the rockiest areas Shovel faces armour of the tracks into the dig face Shovel operator has optimized view of truck bed target	120^o swing angle increases cycle time Trucks backing into place takes more time Loaders expensive and idle Back time is unproductive Can form large ques due to trucks bunching Limited space available for oversize material Extension cord problems with electric equipment

2.4.2. Double Truck Loading

The double truck loading configuration is similar to the single truck loading configuration, only that trucks pull up on both sides of the loader. Table 13 shows the advantages and disadvantages of double truck loading.

TABLE 13.
Advantages and disadvantages of double truck loading (MINE3122, 2016)

Advantages	*Disadvantages*
Second loading spot allows a second truck to spot during loading operations Avoid dead time on loader Reduces que time of trucks	Electric extension problems Oversize boulder more severe Loader operator loads to a blind side

2.4.3. Drive by Truck Loading

In this configuration the loader lines up along the face, trucks pull forward and stop beside the loader, the loader is required to swing 90^{o} to 180^{o}. Table 14 shows the advantages and disadvantages of drive by truck loading.

TABLE 14.
Advantages and disadvantages of double truck loading (MINE3122, 2016)

Advantages	*Disadvantages*
Reduced spotting time – no back cycle	Trucks drive through spills, wears tyres
Cable doesn't cross truck paths	Lack of spotting can lead to long swings
Can set oversize beside and out of the way	Tracks are broadside to long face area
Machine marches on a steady advance	Problems with dipper swinging over driver's cab
Can do in a narrower space	

Figure 3 shows the drive by truck loading configuration.

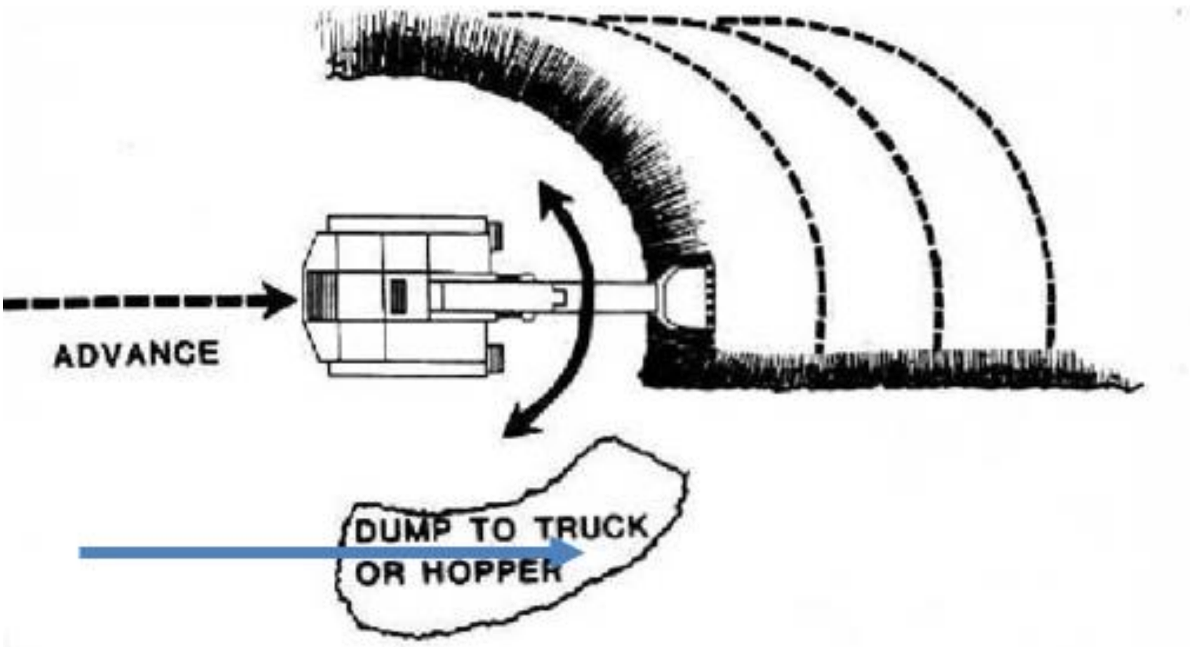

Figure 3. Drive by truck loading configuration (Paul, 2000)

2.4.4. Modified Drive by Loading

In the modified drive by configuration the truck drives up to the shovel as if it was a drive by configuration, however while the loader goes back for the next bite, the truck backs into a single load position (shortening the swing distance). The advantage is the positioning of the single truck load is optimized without the idle spot time. However the loader must dump onto a moving target, creating potential dangers for the driver.

2.4.5. Backhoe Loading

Figure 4 shows a backhoe loading configuration. Backhoe works below grade, it can allow work to be kept off a wet pit floor and can also provide multilevel loading. Backhoes generally need a good size machine relative to the bucket. Backhoes can work both double and single truck loads, as well as loading on multiple levels. Double loading configuration has extra room for oversize and still two trucks. It can also get 3 position loading, however not commonly required.

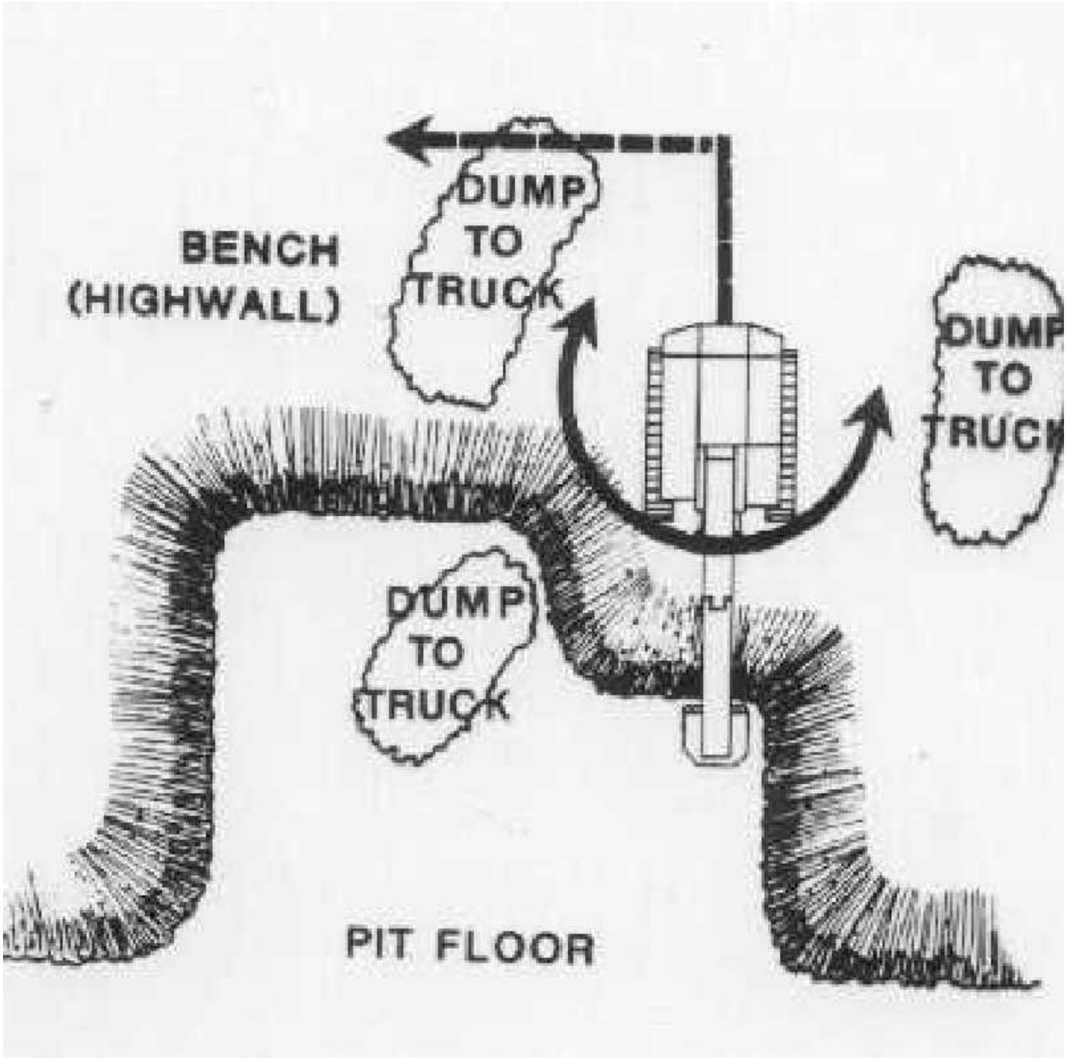

Figure 4. Backhoe loading configuration (Paul, 2000)

2.5. BULK DOZER PUSH

The unit cost of dozer push sits between the dragline and the truck and shovel. If dozer push replaces dragline prime, it's generally to speed up the rate at which coal is uncovered by the dragline. If geotechnical conditions are favourable and the dozer fleet is sufficient, dozer push should be considered to replace truck and shovel.

Dozers are a very low capital per unit of output, Table 15 shows a comparison of capital for dozer, truck and shovel, and dragline. People input for dozers is much lower than truck and shovel, three dozers will require three operators as well as an excavator operator, however a truck and shovel will require an excavator operator, several truck operators, a dozer operator, a grader operator, and a water cart operator. A common piece of equipment which accompanies the dozers in a bulk dozer push is a small excavator. These excavators are much smaller in size than regular mining excavators, they have a bucket capacity of around $10m^3$, rather than a truck and shovel excavator which has a capacity of $18m^3$ (Liebherr, 2017). The excavators are used to cut the highwall. Table 15 shows a capital comparison of the dozer, dragline, and truck and shovel methods.

TABLE 15.
Dozer, dragline, truck and shovel capital comparison (MECMining, 2016)

	Prime Production Rate (BCM/hr)	*Fleet Capital Cost ($M)*	*Capital intensity ($/BCM output)*
Dozer - D11/475	300	$2.3	$7,667
Dragline - 3000t	1250	$160	$128,000
Truck/Shovel - 300t / 180t	1000	$26.1	$26,100

Table 16 shows the advantages and disadvantages of the dozer push mining method.

TABLE 16.
Advantages and disadvantages of dozer push mining method (MECMining, 2016)

Advantages	*Disadvantages*
Lower capital cost	Limited to a maximum 20° coal dip
Ability to move greater material per operator hour than most excavator fleets	Rougher conditions for dozer operators
Highly flexible	Only viable in shallow mines where depth to top of coal is small
Ability to work in most wet weather event conditions	Cannot push over a large distance (maximum around 70m)
Simple and quick to mobilise a new dozer fleet	

Figure 5 shows the truck and shovel and dozer push cost distribution for a strip, it shows that dozer push is cheaper for all levels of the spoil.

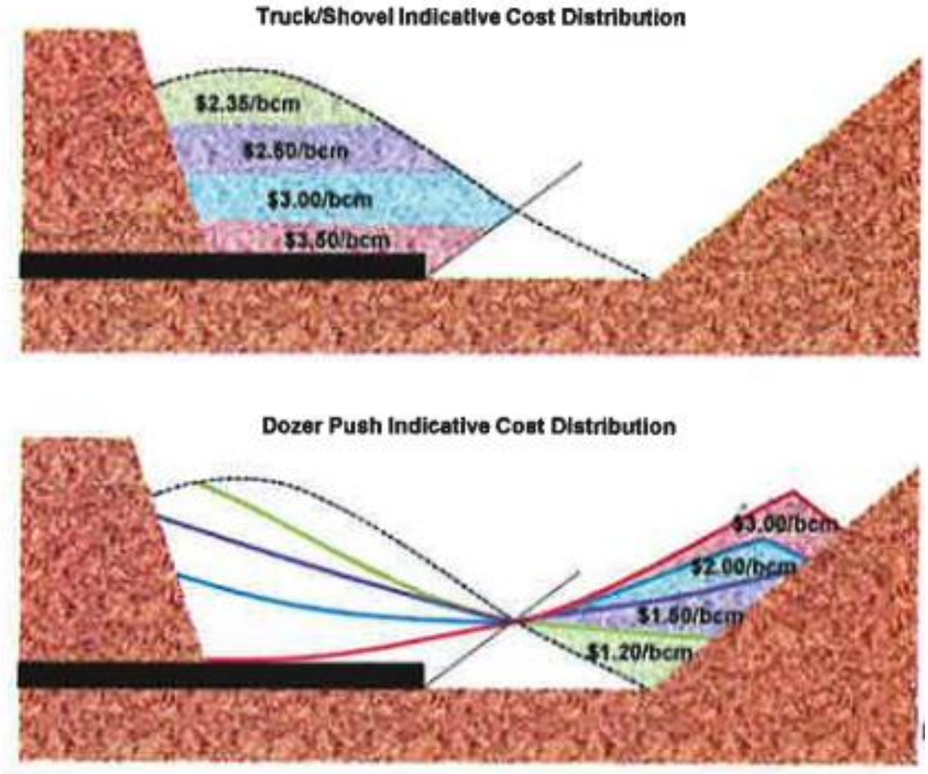

Figure 5. Truck and shovel vs dozer push cost estimation (MECMining, 2015)

The pivot point is a specific point in the dozer push that the dozers will target on the push downwards. The pivot point is the point where the blast profile intersects the final lowwall; cutting occurs on the highwall side, while filling occurs on the lowwall side. After the dozers push to the pivot point, they will start to push upwards, the pivot point dictates the point at which all material must be pushed past to maintain coal edge; pushing to the pivot point allows for zero rehandle. Dozing below the pivot point means additional handling of dozer material and less spoil room for bulk doze. Dozing above the pivot point (raising the pivot) creates more spoil room for bulk doze but some of this material will be rehandled. The pivot point is located 45^{o} from the bottom of the coal seam to the dozers cut line, as this allows for a clean coal edge to be established (MECMining, 2015).

Dozers operator more efficiently when the overburden material has been well blasted, oversize or frozen blasts are very bad. Blasts need to have plenty of movement, and explosive strength to target hard bands.

There are three segments of a bulk dozer push, these are cut, slide/carry, and dump. The cut is the first segment, with the blade pitched forward material is cut and rolled in the direction of travel. This requires the most power, and also has a lot of spillage and requires clean up. The slide/carry segment occurs next, when the blade is pithed back the material will slide forward. Less power is required so the dozer can travel faster, there is less spillage and less clean up. The dump is the final segment, with the blade pitched forward, material is rolled forward out of the blade, the dozer then reverses and begins the next cut (MECMining, 2015).

2.5.1. Dozer Push Methodology

There are a few different dozer push methodologies, these include flat push, back stacking, and slot dozing, slot dozing is the most common. Slot dozing is a method of moving large quantities of material with the dozer using the same path for each tip so that the spillage from the sides of the blade builds up along each side; afterward all material pushed into the sot is retained in front of the blade (Mindat, 1993). Figure 6 shows a top view of the slot dozing method.

Figure 6. Slot dozing (MECMining, 2015)

Slot dozing can double the amount of material that can be slid. The slot is kept up to the height of the blade shoulder, while material is kept in front of the blade and inside the slot. Slots should be parallel with each other and square to the highwall. The rill height is an important factor, if it’s too high, the dozer churns the rills, resulting in loss of speed and damage to the undercarriage. If it’s too low, there is a loss of blade load, constant cutting to refill the blade and loss of speed. Correct fragmentation is very important as it allows the dozer to achieve the highest productive slot doze. Correct fragmentation slots hold up well and are easily formed, over-fragmented dirt is too fluffy and will not form slots, under-fragmented dirt is difficult to manage and will be cumbersome for dozers to operate.

The slot dozing methodology is as follows:

1. Commence slot nearest to dump point (i.e. just behind pivot point)
2. Develop the length of the slot with each cut
3. Use cut and carry operation along the slot (blade tilt)
4. Create a series of slots with small sections (rills) between each slot
5. When slots complete, work from the back, doze the rills using the slots, only take out slots to the pivot point

The flat push dozer push methodology involves pushing material horizontally (zero degrees) at a level, and then progressing down to levels until all material has been moved. Flat pushing to an edge creates significant amounts of material that must be rehandled several times, this is a wasted effort. Rehandle costs add time and money. In slot dozing there is no elevation change, thus no gravity assistance like in other dozer push methods. Figure 7 shows a cross sectional view of the flat push method.

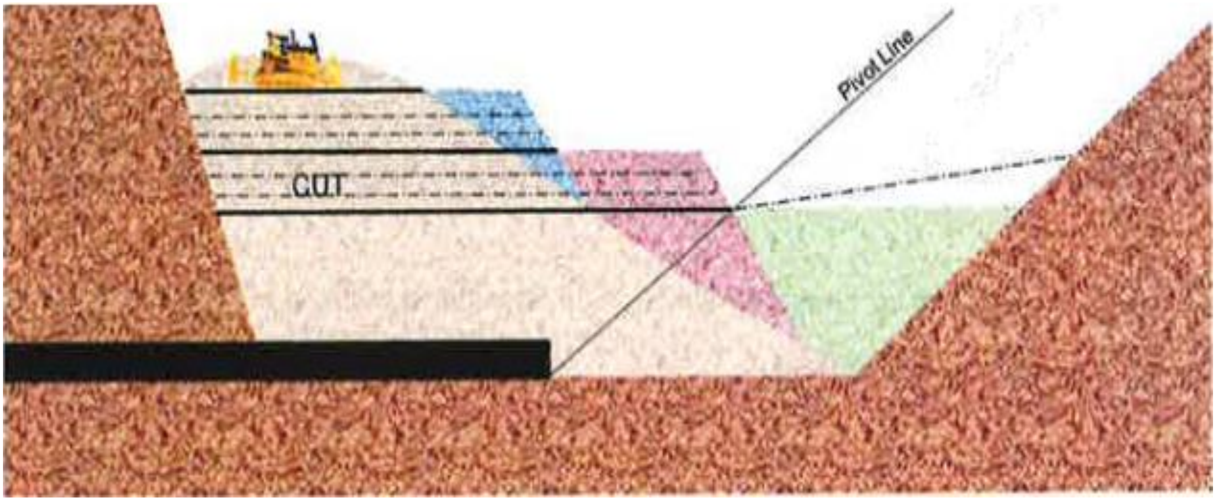

Figure 7. Flat dozer push (MECMining, 2016)

Back stacking is a dozer push method in which sections are taken and dumped by loads. The methodology is as follows:

1. Commence cut just behind pivot point
2. Push load to furthest dump point
3. Continue working back from the pivot point, stacking loads one behind the other
4. Aim to fill one dump layer from one cut
5. Next slice pushes to the back of the dump over previous row of back-stack plies

The cut to dump distance should be relatively constant. For the first slice, there should be short deep cuts as there is a short dump length. As depth increases, shallower longer slots should be cut as there is a long dump length.

The first cut should commence as close to the pivot point as possible and travel down to the bottom. The second cut and following cuts start just far enough back to gain a full blade. The load should be slid to a point behind the last dumped load. The cut to dump distance will remain relatively the same. When material is dumped to the pivot point, material is slid and dumped over the top. Figure 8 shows the first step in the back stacking method.

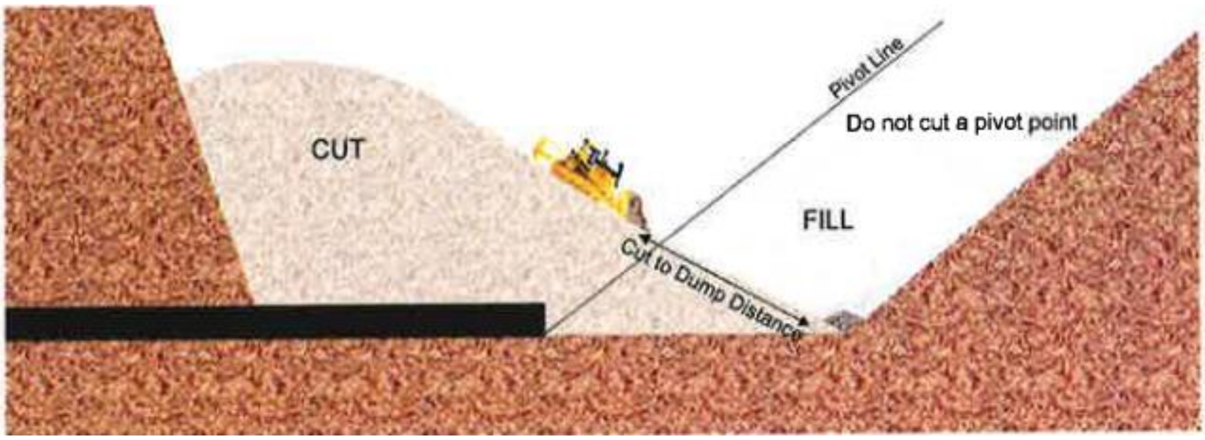

Figure 8. Back stacking dozer push (MECMining, 2016)

2.6. DRILL AND BLASTING

Drilling and blasting is an essential part of the mining cycle. It is very important as it helps to ease the loading ability of all equipment. Blasting is the process of fracturing material by the use of a calculated amount of explosive so that the predetermined volume of material is broken (Hem and Phifer, 2012).

Cast blasting is a blasting technique in which holes are drilled at a specific angle to allow the propulsion of the waste material in a specific direction. It is aims to reduce the amount of overburden material that must be moved by other machines (excavator, dragline, etc.). Since the material must be blasted regardless, it is generally more economical to cast blast; however cast blasting requires accurate planning, as well as accurate drilling, and priming of holes. The casting moves around 20% - 50% of the overburden into the mined-out pit, while the remaining spoil is removed by other methods such as dragline, dozer push, truck and shovel (MINE3122, 2016).

3. DOZER PUSH CURRENT RESEARCH

3.1. HOW MUCH CAN BULK DOZER PUSH SAVE YOU?

MECMining has a few pages regarding bulk dozer push, when to consider using it, benefits, and how to plan it. As it is not a journal paper, the information lacks detail and depth; however the website does provide a good basis on the capability and applicability of the bulk dozer push method of waste removal. It states that bulk dozer push can be applied in most situations where the coal dip is less than 20^{o}; in conventional strip mining, both single and multi-seam geometries are applicable. For steeply mines, the strips can be orientated at an angle to the coal dip to create a void and a moderate apparent strip floor angle, creating a scenario in which cast blasting and bulk dozer push can significantly reduce the waste costs. The website makes statements about the applicable situations for bulk dozer push, however has no solid evidence or any form of data analysis on the applicability and effectiveness (MECMining, 2015).

The website provides cost estimates per BCM, theses are between $1.30 and $2.00 per BCM; in comparison it claims truck and shovel have costs of up to $4.00 per BCM (depending on haul routes). Capital per unit of output is also shown, dozer push is compared to truck/shovel, and dragline; again no depth is shown (raw data not provided) only a results. These were:

- Dozer - $11,500 per BCM/hr of output;
- truck and shovel - $21,000 per BCM/hr of output; and
- dragline - $90,000 per BCM/hr of output.

Also provided are conditions which allow dozers to work best, and where they are better than truck/shovel; these include wet weather, flexibility, and supplementation of dragline production. The website provides what a website should provide, which is a brief summary of the desired knowledge to provide for customers.

The website provides a good basis for the proposed project, the cost estimates per BCM will be useful knowledge for the second half of the project (cost evaluation), however they need to be more detailed and inclusive of further costs. Other information provided by the website relates to the project however is more general information regarding dozer push, and does not change the methodology or other factors of the project.

3.2. Using Dozers to Remove Coal Overburden

The paper looks at the application of track-type dozers and their ability in comparison to other mining equipment in removing coal overburden. The paper reviews the methodology of different techniques in which dozers can be used, as well as their applications. However does not discuss the use of dozers (over other systems) in detail.

The paper talks about the effectiveness of using dozers in combination with draglines as a system to optimise value, as well as cast blasting, and truck and shovel. The paper also looks at the criteria to determine whether a dozer should be utilised or not; it states that these are:

- Production requirements – dozer may fit job requirements better than a second dragline;
- product support – availability of parts, service, and technical expertise;
- labour situation – costs associated with operator; and
- resale opportunity – recovery percentage of capital cost.

(Hayes, 1997)

The paper discusses the applicability of the bulk dozer push in regards to distances. It effectively looks at the economical means of moving material by cast blasting, dragline, and bulk dozer push; stating that all three systems share a common value – *"they are all sensitive to distance"*. The paper states that regardless of the application, all mining systems have an economic range, and exceeding the range will affect both productivity and cost.

The paper could investigate more on the effectiveness of the dozers in different situations where variables are altered. It is short and concise, and does not give details or explanations on subjects which seem important and could be further developed to a greater extent.

The paper provides relevant discussion on dozer push, and is relevant to the proposed project. A few details regarding the costing of dozer push could be extracted and used in the second half of the project (cost evaluation). However the paper does not provide any other information that would affect the methodology or outcomes of the project.

3.3. THE ECONOMICS OF EXTENDED PRE-STRIP STRIPPING

This paper looks at economic evaluation of changes in prestrip stripping widths of a mine in the Bowen Basin. The paper has a similar concept to that proposed in the project proposal, however instead of adjusting prestrip height, the paper looks at the effects of changing prestrip width. The paper does not investigate the effects of a different strip depths, bench angles, and other variables that can affect the cost. It only looks at changing prestrip width in a single situation, which would make it difficult to apply to other sites.

The paper looks at a simulation model, economic evaluation, and evaluation drivers; it investigates timing effect on costs. In the simulation model, Microsoft Excel™ and Project™ were used to generate volumes, production, and schedule. As stated by the paper "*the model generated volumes based on user inputs and complex trigonometry*". The use of these programs to calculate output volumes creates opportunities for equation errors, it may also take a long amount of time. A CAD program would have been better as it does not allow for an opportunity to type an equation incorrectly; an additional benefit would be the ability to visualise the volumes being calculated.

The economic evaluation looked at cost benefits and annual cost variance. The cost benefit section looked at net present cost for the production base case, and a net present cost for the extended prestrip case. It shows two graphs, total net present cost and net present cost variance to base case. This section of the paper is short, yet shows the reader exactly what needs to be shown; it effectively delivers the result in a concise manner.

The evaluation drivers section looked at productivity effect, timing effect, and the best production case. It effectively presents the productivity effect on net present by a prestrip production case by case analysis, showing graphs of cumulative prestrip waste variance compared to the base case.

The paper concludes that a significant cost saving can be achieved when a prestrip width of 90m is selected, saving A$8.4 million over 20 strips of minimal length. It states that the cost saving was directly related to the number of free dragline strips exposed in time, as well as annual discount applied to cash flows. *"There is an economic trade-off point or width where the benefit of fleet relocation outweighs the additional costs generated in stripping waste in* *advanced"* the paper has made a conclusion based off the results, however this may be to general as only one case study was used (Nel, and Kizil, 2013).

The paper fails to look at alternative methods of prestrip removal, it only looks at dragline and truck/shovel; it could investigate dozer push, and cast blasting as well. The paper is very specific to its topic and doesn't expand on much else. The paper contains relevant concepts which relate to the project, they are similar but not exactly the same.

3.4. Development of Dozer Push Optimisation Software

The journal looks at the development of dozer push optimization software, the journal briefly goes through a comparison of bulk dozer push versus truck/shovel as a method of prestrip waste removal, looking mainly at the advantages and disadvantages of dozer push. The software created is called *Dump Designer*, the software was created with the purpose of maximising the amount of overburden moved with dozers.

It uses two methods to create optimum dozer waste dumps, the first being based on pivot point height and the second on the level the dozers will push to.

The journal explains the methodology used, it consists of;

- Gathering necessary end of month data to build existing waste dumps;
- collecting low wall data;
- coal dip data; and
- calculating pivot point for all necessary blocks.

The program uses a trial and error process until the optimal pivot point height is found. Cost factors were estimated using estimation guides and other sources, with adjustments being made for the specific mine site equipment; including capital, fuel, lubrication, parts, maintenance, overhaul, tyres/tracks, ground engineering costs, and operating costs (excluding labour).

The journal briefly discusses the issues that could lead to errors in the program, however should go into more detail in explaining; diagrams would give a good visual representation and help explain the issues to the reader. The trial and error process could also be improved to reduce time the program takes to run (if possible), no coding or details on the dump designer software itself are shown, only methodology of how it works theoretically.

The results of the dozer push analysis from dump design found that on average, by pushing 100m the dozer waste dump capacity increases by 7%. The journal briefly states the benefits as well as negative impacts of the extra 25m push; including improved dump capacity, improved production costs, as well as decreased in productivity. It does not go into detail on the numbers that back the statements. The results show the operation cost per hour for the different pits and different pushes (75m and 100m), as well as the total dozer volumes and effect of coal dip. The results are concise and perfectly interpret the data collected (Uren, and Nehring, 2015).

A section is included on the analysis of the program itself, including the advantages and disadvantages of running the program on site. The advantages being:

- Allowing for the understanding of the effects the coal dip has on dump design; and
- easy to use, quick in generating range diagrams and accurate volumes.

The disadvantages being:

- dump designer being constrained to the geometry of mining block; and
- only top section of highwall can be analysed as dozer material.

(Uren, and Nehring, 2015)

Sufficient discussion is reported in regards to the advantages and disadvantages; though visual representation would be helpful. The journal is very relevant in regards to dozer push, but does not show specific effects of changes in variables in the schematic diagram, e.g. a change in face angle causes the pivot point to shift by “x“ amount; though the journal does compare two different coal dips (Uren, and Nehring, 2015). The journal is very relevant to the proposed project.

3.5. Dozer Side-Cutting Highwall in a Bulk Dozer Push Operation

This research project looks at the removal of the waste that remains against the highwall after a blast; and the viability of removing it with a dozer (side-cut) over an excavator (side-cast). This project uses a mine site as a case study, it develops designs and calculates productivity for a dozer compared to an excavator. This is very similar to the project proposed, with the exception being that prestrip removal is compared, rather than blasted material against the highwall.

Data in the form of dozer positioning from GPS was collected from a site which performs dozer side cutting on a highwall. The dozer data was broken into separate activities, including bulk push, highwall cutting, rehandle, standby, and tramming. Using position and time, the production rate for highwall cutting was calculated, and verified with operators (Sinclair, and Nehring, 2016). This section is very detailed, includes images and is easy to understand.

Dozer bulk push designs were created in a design software; a cost and productivity model was generated using inputs and variables for each design scenario. The cost and productivity model is not provided in the research project, however equations are shown and detailed. Brief statement provided regarding alternate methods, with good reasoning as to why they weren't chosen over current method (Sinclair, and Nehring, 2016).

The results provided are well detailed and include graphs and tables of the results for each 45m, 55m, and 60m bench width. A decision matrix is provided showing when to use excavators during the dozer push operation, it is large and clear providing the reader with a clear idea of when to use excavators (Sinclair, and Nehring, 2016).

3.6. Gaps In Dozer Push Knowledge

Gaps which have not been thoroughly researched include:

- Optimum number of dozers to utilise in a push;
- slot dozing - where to place the dozers and when to change to next slots; and
- the proposed topic - optimisation of prestrip of mines using bulk dozer push.

No clear research has been found on the optimum number of dozer to utilise in a push. Factors that would effect this topic would be the size of the dozers used, pushing distance, height of bench, etc. Research into this topic could reduce the capital cost, as well as optimise the production of a site.

There is also a gap in knowledge in regards to slot dozing. There is no research in regards to the placement of the dozers in a slot dozing sequence and when to change slots. Filling in this gap could have the potential to increase productivity and reduce costs. As well as these two, the proposed topic has not been researched.

4. RISK ASSESSMENT AND CONTINGENCY PLAN

4.1. RISK ASSESSMENT

The risk assessment identified potential hazards and analysed the impact of the occurrence of the hazard. There were no physical risks associated with the project that could affect any humans, however there were some risks towards the data, and the project.

These were:

- File corruption;
- data loss;
- insufficient data;
- no submission;
- software not available for use;
- site permission denied;
- company permission denied; and
- requested data unavailable.

Table 17 and 18 show the likelihood ranking and impact ranking criteria for the project. They were both on a 1 – 5 scale, 1 had the least impact, and 5 had the most impact on the project.

TABLE 17.
Likelihood ranking criteria

Rating	*Likelihood of occurrence*
1	Very unlikely (will occur once or less in the time frame of the project)
2	Unlikely (will occur once)
3	Neutral (will occur twice to three times)
4	Likely (will occur monthly)
5	Very likely (will occur weekly)

TABLE 18.
Impact ranking criteria

Rating	*Impact*
1	Does not cause an issue, project will go on as if unaffected
2	Minor impact on project, set back in time or quality of project
3	Moderate impact on project, small effect on time or quality of project
4	Major impact on project, major effect on quality of project
5	Catastrophic impact on project, project is unable to be completed

Table 19 shows the likelihood, impact, and overall ranking of all the risks associated with the project.

TABLE 19.
Overall ranking of risks

Risk	*Likelihood ranking*	*Impact ranking*	*Overall ranking*
File corruption	3	4	12
Data loss	2	5	10
Insufficient data	3	3	9
No submission	1	5	5
Software not available for use	1	5	5
Site permission denied	1	5	5
Company permission denied	1	5	5
Requested data unavailable	1	3	3

To reduce the chance of any of the risk occuring, or to mitigate the risk, the following controls were put in place:

- Backed up data on work computer, university computer, and personal computer;
- backed up data on multiple hard drives;
- regularly kept in touch with company and mine site on site possibility of site return;
- regularly kept in touch with company and mine site on data availability; and
- allowed for plenty of time to complete data collection, design, and evaluation.

The implementation of these controls helped to reduce the likelihood rating of all the risks.

4.2. CONTINGENCY PLAN

For some of the risks associated with the data there was an extreme impact if the risk occured. In the event that they did occur, a contingency plan was required. In the event that all data was lost, the return to site must be completed; this included all backups of the data. If no other means of data recovery was available, a return to site had to be done, and data collected off the site computers. If site computers no longer contained data, new data needed to be collected from the mine and new designs created for the following strips.

In the event that Vulcan could no longer be used, another program had to be learnt and utilised to complete the research project. These included:

- Deswik;
- Microsoft Excel™;
- Datamine; or
- other similar software.

5. CASE STUDY: PORTER MINE

5.1. PORTER MINE BACKGROUND

The mine site name has been changed to Porter mine to prevent any connection of this paper to the actual mine. Porter mine is a strip mining operation which currently uses scrapers to remove topsoil, excavators to prestrip, drill and blasting to loosen dirt for dozers; dozers to dozer push waste, and excavators to remove any wedge left behind by the dozers; coal is taken by excavators. Like all mine sites, the removal of waste is an undesirable cost and like all costs, it is aimed to be reduced.

Porter mine has six pits named from Pit A to Pit F. Table 20 shows the mining position of each pit as of the 17th February, 2017.

TABLE 20.
Mining location of Porter Mine (as of 17/02/2017)

Pit	*Strip*	*Block*
A	2	1
B	1	1
C	1	1
D	1	1
E	4	1
F	4	1

Porter Mine has 70^{o} highwalls and 15^{o} low wall. The topsoil is assumed to be part of the prestrip. The dozer push dump is limited in vertical extend by a final land form height which cannot be breached due to community agreement.

Porter mine uses different bench widths for each pit, due to depth, blasting, geology and other factors. Table 21 shows the current prestrip level and bench width. The strip width (50m) remains the same for all strips.

TABLE 21.
Prestrip height and bench width for all pits.

Pit	*Prestrip height (m)*	*Bench width (m)*
A	8	10
B	6	50
C	6	50
D	6	50
E	12	15
F	12	15

At Porter mine the dozer push operation is more efficient than if there were a dragline, this is due to the geology of the coal and waste.

5.1.1. Geology

The coal mined from Porter mine is from the Jurassic age. The geology at the mine consists of an 8m upper layer of alluvial overlying a thin coal seams with mudstones, siltstones, and sandstone beds interbedded. This overlies the predominant coal seam, which is 9 m to 10 m thick and consists of many thin grey tuffaceous bands. The finer grained sediments slake on exposure to air and water and most are dispersive, they also contain high sodium levels that is often associated with slaking and dispersive clays. Some highwalls are covered in a veneer of clay that has been derived from the slaking of insitu fine grained sediments. The base of weathering extends to 16m below original ground surface level.

The predominant coal seam dips at angles of 2^{o} to 4^{o} towards the north-west; the floor dip can vary locally. Faults within the pit are mainly small normal faults. There is a distinct change in the dip direction of the strata between pits A to D, and E to F, where the strata dip towards the North West. There are a number of dykes throughout the mine, typically less than 1m in width; they have no impact geotechnically, however alter coal quality. Dykes are indicative of a tensile stress regime at some stage during the basin development.

5.1.2. Dozer Push Wedge Volume

The "wedge" is a volume of material that is left behind by the dozer push operation if the volume of space available in the dump is smaller than the swelled volume of dozer push overburden. Figure 9 shows an example of a strip where there is a wedge left behind. It shows the dozer push has a volume of 350 m^3 that needs to be remove in order to uncover coal, however there is only 300m^3 available in the dozer dump. This means that 50m^3 of waste material is still required to be removed, this is called the wedge. As there is no more room in the dozer dump, the wedge must be removed by truck and shovel; it is hauled to any available dump space on site. As the wedge is deeper in the pit compared to the prestrip, it has a higher cost of removal ($4.50 per BCM) compared to the prestrip ($4.00 per BCM). The wedge is an unwanted volume as it adds further truck and shovel costs.

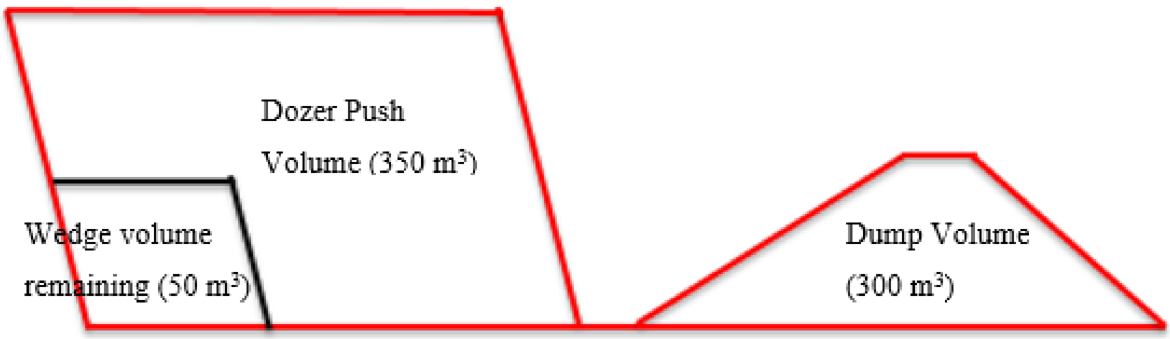

Figure 9. Cross section of dozer push with wedge volume

Due to the nature of the coal surface, topography, and final land form, there are areas where the distance to top of coal is larger or smaller than others; and areas where the dozer dump volume differs. As such, the volume of wedge material varies across the mine site. The wedge volume has a higher cost of removal per BCM compared to the prestrip, due to it being deeper and trucks having a longer haul route. This wedge volume needs to be factored into the overall strip cost as it is waste that must be removed, in order to uncover the underlying coal.

5.2. Data Collection

The case study implementation in the next section looks at creating excavator prestrip and dozer push designs in Vulcan at different prestrip levels. In order to complete these prestrip and dozer push designs the following data required collecting:

- Topography surface;
- final land form height;
- end of month surfaces;
- coal seam roof and floor surfaces;
- strips and blocks grid; and
- previous designs for the excavator prestrip and dozer push for all pits.

All the listed data was collect on site with permission from the site and company.

6. CASE STUDY: IMPLEMENTATION

6.1. GENERIC EXCAVATOR PRESTRIP DESIGN

The prestrip design is always kept the same, only the height changes. The following are required for the prestrip design:

- Strips and blocks grid;
- topography surface; and
- end of month surface.

The methodology for the prestrip design in Vulcan is as follows:

1. Load topography surface and translate it down by desired prestrip height (e.g. 6m)
2. Load strips and blocks grid and project strip line up at 70^{o} to the surface created from 1. (this gives the desired highwall for the dozer)
3. Trim line to match the current strip (as shown by end of month scan)
4. Berm the project line from step 3 backwards by the prestrip width and bench width if necessary
5. Project the line from step 4 up at 70^{o} to topography
6. Draw rectangular polygon that connects the lines from steps 3 and 4
7. Project the endwall lines of the rectangle from step 5 up at 70^{o} to topography
8. Connect all lines from steps 3-7

Figure 10 shows the sequence in the steps as well as the completed surface.

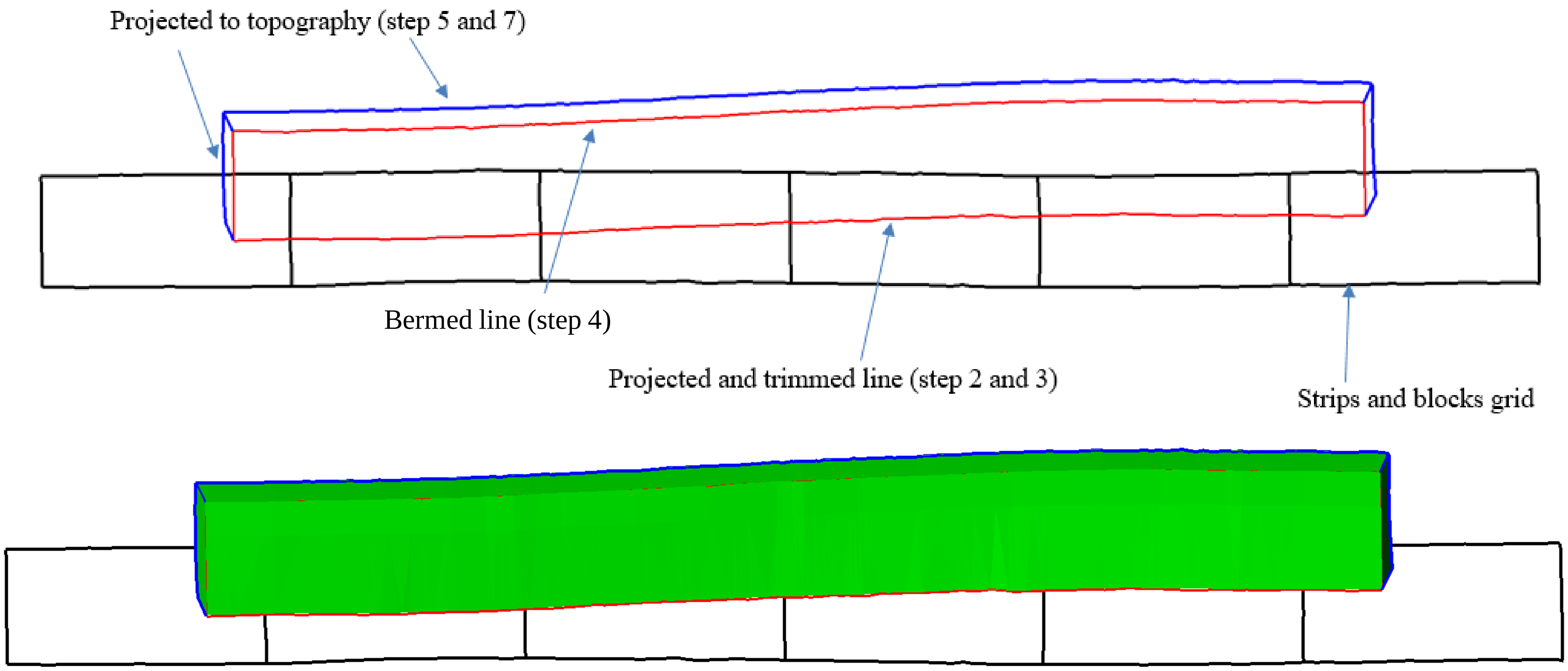

Figure 10. Excavator prestrip design

6.2. GENERIC DOZER PUSH DESIGN

Due to a dip in the coal and other geological factors, Porter mine has different prestrip and dozer push design for each pit. Pit B, C, and D have the same design, as does Pit E and F, and Pit A has its own design.

Sections 6.2 to 6.4 detail the designs for each pit. The following are required for the prestrip design:

- Strips and blocks grid;
- topography surface;
- end of month surface;
- prestrip surface;
- coal seam surfaces; and
- final land form with creek diversion surface.

The methodology for the dozer push design is as follows:

1. Load topography surface and translate it down by desired prestrip height (e.g. 6m)
2. Load strips and blocks grid and project strip line up at 70^o to the coal roof surface
3. Trim line to match the current strip (as shown by the end of month)
4. Berm the line created in step 2 back backwards by 50m (this line will be the same as if the back of the strip had been projected up by 70^o)
5. Draw rectangular polygon that connects lines from step 3 and 4
6. Project line from step 4 at 70^o to translated topography surface from step 1
7. Project endwall lines of the rectangle from step 5 up at 70o to translated topography surface from step 1

Steps 1 to 7 are the design steps that show the finishing surface after the overburden material will be removed. The next steps show the dump design for the dozer push, they are as follows:

8. Project line from step 2 down to coal floor at 90^o
9. Project line from step 8 up to coal roof at 45^o (this is the pivot point)
10. Project line from step 9 up by R+6.7m at 15^o (this is the dump limit)
11. Project line from step 10 up by R+20.1m at 15^o (this is the push limit)
12. Project line from 11 down to previous dump (end of month surface) at 37^o (angle of repose)

Figure 11 shows the dozer push design and it's features. The dump limit is an arbitrary point which helps dozers determine the accuracy towards the dump profile, it is located 25m horizontally from the pivot point. The push limit is the physical point at which the dozers should not push past, it is located 75m from the pivot point.

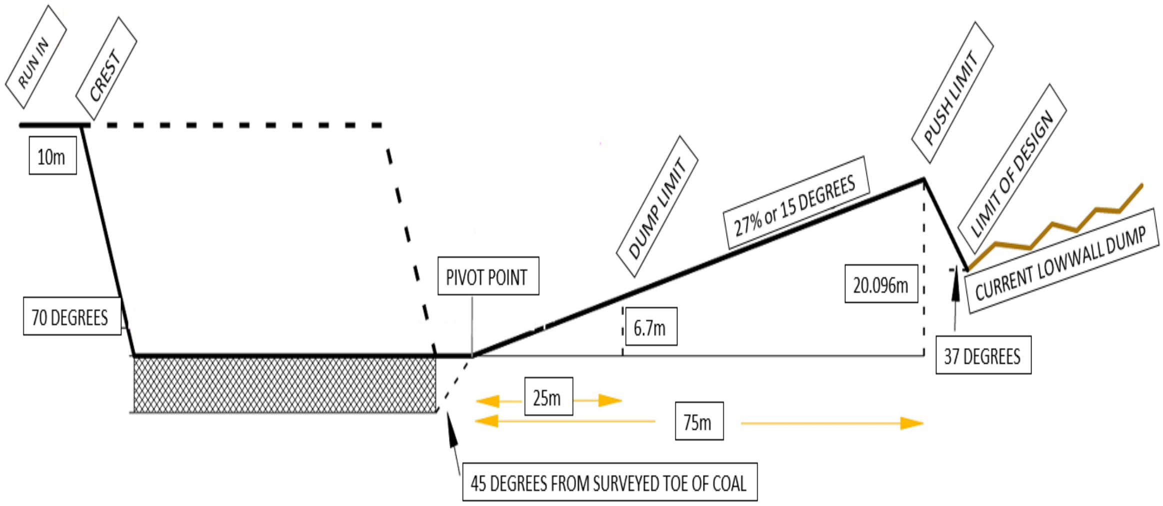

Figure 11. Dozer push design

Steps 8 to 9 are the design steps that show the dump design for the dozer push, however these may not be the final design. Three things may need to be considered in the design, these are a ramp access to the coal, ramp access to the prestrip, and final land form.

6.2.1. Ramp access to coal

At Porter mine the general case is that a strip is split into smaller strips and mined out in a sequence. The methodology for the ramp access to coal is as follows:

1. Determine haul road width extents and position using end of month surface
2. Draw a line from top of the top of coal at the edge of the dozer push design to the previous ramp (from end of month surface)
3. Check the grade of the ramp, if it is not within ± 10% then adjust the level of the side that connects with the previous ramp (the road simply needs be regraded)
4. Berm the line from step 2 by the haul road width (27m)
5. Project the haul road lines from step 2 and 4 up to the dozer push dump surface at 37^{o}
6. Connect the lines

6.2.2. Ramp access to prestrip

The methodology for the ramp access to prestrip is as follows:

1. Determine haul road width extents and positioning using end of month surface
2. Draw line from existing haul road to prestrip level
3. Check the grade of the ramp, if it is not within ± 10% then add a flat bit to the top part of the ramp to increase grade, or start the ramp at further back to decrease the grade
4. Berm the line from step 2 by the haul road width (27m)
5. Project the haul road lines from step 2 and 4 down to the dozer push dump surface at 37^{o}
6. Connect the lines

6.2.3. Final Landform Restriction

Porter mine is restricted vertically by a final land form that was originally agreed upon with the community and government. No long term material can remain above the final landform. To design a dozer dump that doesn't go above the final landform, the dozer surface must simply be cut by the final landform surface. The final landform surface is not a flat surface, it has a creek and multiple changes in elevation.

6.3. PIT A

Figure 12 shows the typical strip for Pit A, as can be seen, Pit A has a ramp down to the coal, and consists of a 15m ramp into the prestrip. It does not require a full advanced prestrip, as the distance to top of coal is smaller than other pits. The depth from the prestrip highwall crest to top of coal ranges from 24m – 30m.

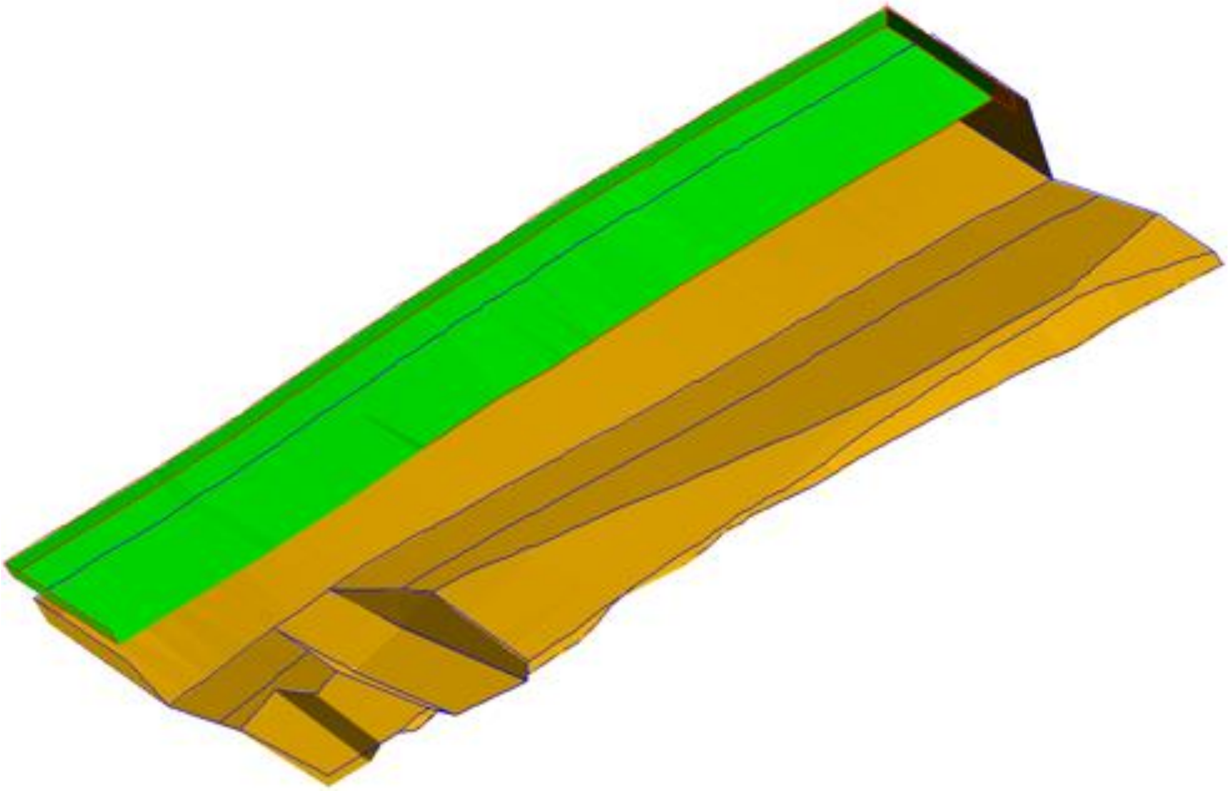

Figure 12.Pit A general strip

6.4. PIT B, C, AND D

Pits B, C, and D, all have the same prestrip design, consisting of a 50m prestrip advance (the bench is 50m). There is necessity to fully prestrip in advance, due to the larger distance to top of coal. A larger distance top of coal means more bench is necessary for safety reasons. Pit B consists of a ramp up to the prestrip level; Pit C consists of a ramp down to the top of coal and D has neither. Figure 13 shows the prestrip and dozer push design for pit B.

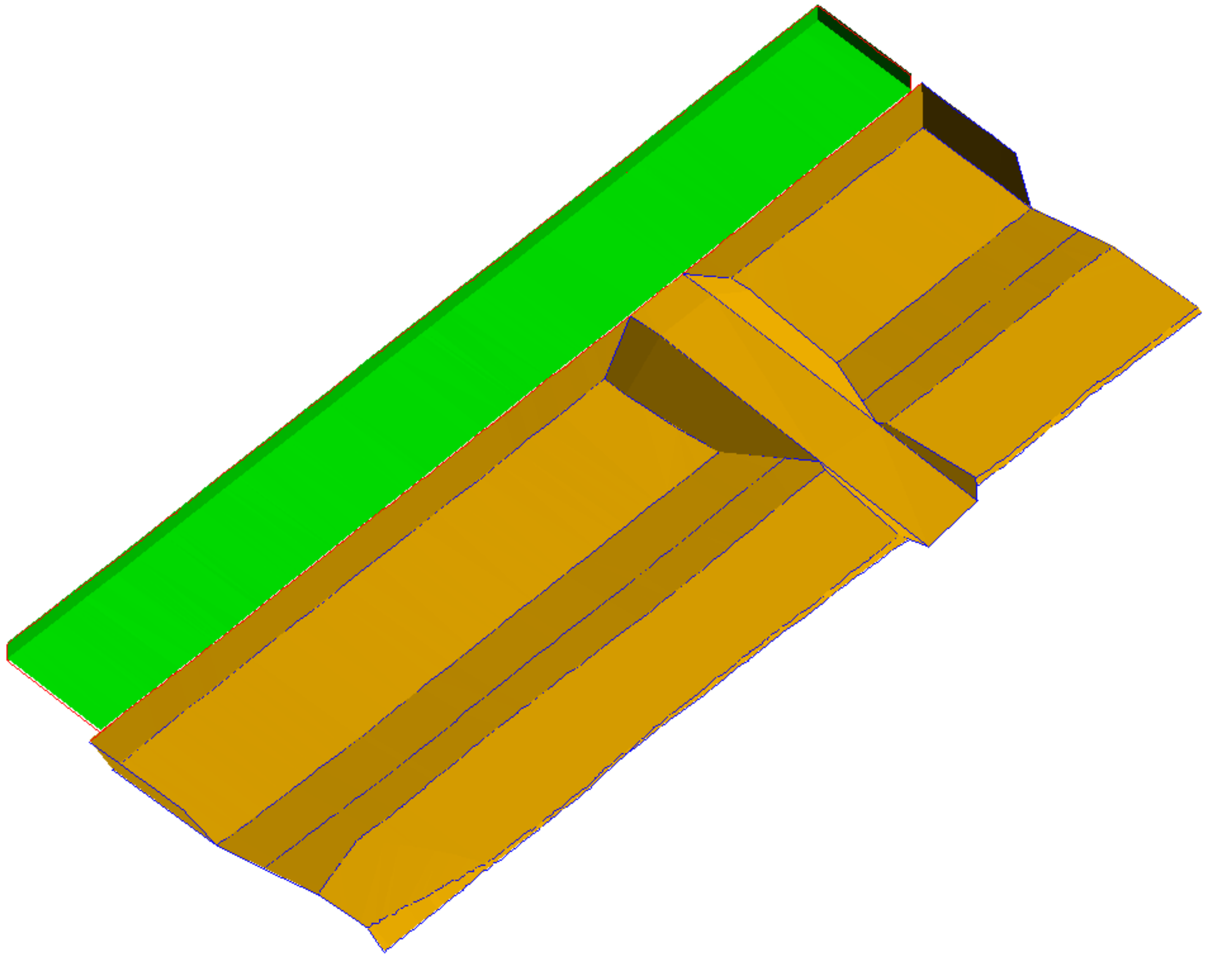

Figure 13. Pit B general strip

6.5. PIT E AND F

Figure 14 shows the prestrip and dozer push design for Pit E, it consists of a ramp down to the coal and a prestrip entrance. It does not require a full advanced prestrip, as the distance to top of coal is smaller than other pits.

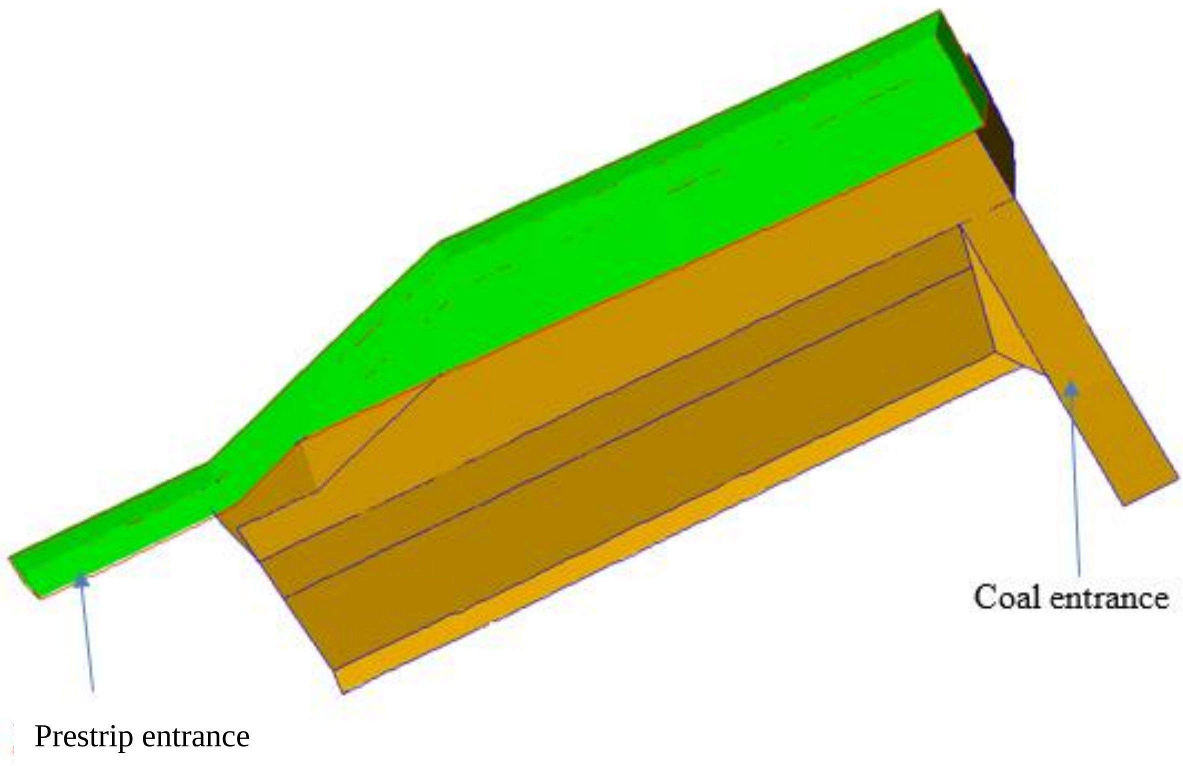

Figure 14. Pit E general strip design

7. CASE STUDY: RESULTS AND ANALYSIS

7.1. OVERVIEW

From the Vulcan surfaces created, volumes for the prestrip, dozer push, wedge, and dozer dump were able to be calculated. The cost of removal for the prestrip was determined to be $4.00 per BCM, as it is removed via truck and shovel, and is unblasted (MECMining, 2015). The dozer push and dozer dump waste material is removed via bulldozers and is blasted material, thus the costing of $1.33 per LCM is used rather than the researched $1.60 per BCM; this is to account for a 20% swell) (Porter, 2017). Equation 1 shows the total cost for a dozer push using bank cubic meters, and is the same as Equation 2 which shows the total cost using loose cubic meters (blasted material) with a 20% swell.

$$\frac{\$1.60}{BCM} * 500{,}000\ BCM = \$800{,}000 \qquad \text{(Equation 1)}$$

$$\frac{\$1.33}{LCM} * 500{,}000 * 1.2 = \$800{,}000 \qquad \text{(Equation 2)}$$

The wedge material is removed via truck and shovel, it is removed post blasting and thus it is blasted material; however the wedge is usually not as well fragmented as the rest of the blast profile as it is located deeper and close to the final highwall, thus a cost of $4.50 per BCM is used rather than $4.00 per BCM (longer haul distance factor) (Porter, 2017).

7.2. VOLUME RESULTS

It is important to note that the volume of overburden material varies across the pits as well as each strip due to the coal dip and topography. The height from the top of coal up to the prestrip highwall crest (i.e. overburden material height) is roughly representative of the volume of overburden in each pit, this is due to similarities in the strip lengths between the pits. The height from top of coal up to the prestrip highwall crest for each pit are as follows:

- Pit A varies from 15m to 30m;
- Pit B varies from 15m to 25m;
- Pit C varies from 25m to 30m;
- Pit D varies from 15m to 20m;
- Pit E varies from 35m to 50m; and
- Pit F varies from 40m to 50m.

Table 22 shows the prestrip cut, dozer push cut, and wedge cut volumes for the three different prestrip heights for Pits A, B, C, and D. The volumes were calculated in Vulcan, from the Vulcan designs created (see Section 5 - *Case Study Implementation*). The dozer push volumes remain constant across each pit/strip, this is because the dozer dump in the majority of the designs is fully utilised (i.e. dump is full); this leaves a wedge volume behind. Pit D strips 1 and 2 are an exception to this; it is the only pit where the dozer dump capacity is not reached and thus no wedge is left behind. Prestrip heights evaluated for Pits A, B, C and D were 6m, 8m, and 10m.

TABLE 22.
Case study volume results Pits A, B, C, and D.

Pit/strip	*Prestrip height (m)*	*Prestrip volume (MBCM)*	*Dozer push volume (MLCM)*	*Wedge volume (MLCM)*
A/2	6	0.155	0.235	0.270
A/2	8	0.196	0.235	0.217
A/2	10	0.239	0.235	0.163
A/3	6	0.139	0.289	0.187
A/3	8	0.184	0.289	0.131
A/3	10	0.230	0.289	0.075
B/1	6	0.148	0.250	0.205
B/1	8	0.197	0.250	0.147
B/1	10	0.246	0.252	0.089
B/2	6	0.138	0.248	0.216
B/2	8	0.182	0.249	0.161
B/2	10	0.228	0.251	0.106
C/1	6	0.131	0.203	0.210
C/1	8	0.173	0.203	0.161
C/1	10	0.217	0.203	0.111
C/2	6	0.142	0.197	0.207
C/2	8	0.183	0.197	0.157
C/2	10	0.224	0.197	0.107
D/1	6	0.156	0.243	-
D/1	8	0.196	0.196	-
D/1	10	0.236	0.148	-
D/2	6	0.125	0.194	0.021
D/2	8	0.167	0.168	-
D/2	10	0.210	0.120	-

Table 23 shows the prestrip cut, dozer push cut, and wedge cut volumes for the three different prestrip heights for Pits E and F. All dozer push dumps are fully utilised, leaving behind a wedge volume in all cases. The prestrip heights evaluated for Pits E and F were 10m, 12m, and 14m; this is greater than the other pits due to the greater distance from the prestrip crest to top of coal.

TABLE 23.
Case study volume results Pits E and F.

Pit/strip	*Prestrip height (m)*	*Prestrip volume (MBCM)*	*Dozer push volume (MLCM)*	*Wedge volume (MLCM)*
E/4	10	0.110	0.103	0.320
E/4	12	0.123	0.103	0.305
E/4	14	0.138	0.103	0.289
E/5	10	0.129	0.104	0.383
E/5	12	0.154	0.104	0.356
E/5	14	0.180	0.104	0.328
F/4	10	0.192	0.273	0.522
F/4	12	0.222	0.273	0.486
F/4	14	0.254	0.273	0.449
F/5	10	0.198	0.197	0.530
F/5	12	0.237	0.197	0.487
F/5	14	0.276	0.197	0.443

7.3. COST RESULTS AND ANALYSIS

The cost for all pits were calculated using the volume results from Section 7.2 *Volume Results* and the cost factors found during research. The costs factors from Section 7.1 *Overview* were used, and are:

- Prestrip truck and shovel: $4.00 per BCM;
- Dozer push: $1.60 per BCM, $1.33 per LCM; and
- Wedge truck and shovel: $4.50 per BCM, $4.20 per LCM.

Table 24 shows the prestrip, dozer push, wedge and total cost for the three different prestrip heights for Pits A, B, C, and D. It is important to note that the total volume of overburden material moved is the same within each pit/strip and that it is cost factor that determines the total cost of waste removal. The lowest total cost prestrip height for each pit/strip is highlighted in red.

TABLE 24.
Case study cost results Pits A, B, C, and D.

Pit/strip	*Prestrip height (m)*	*Prestrip cost ($M)*	*Dozer push cost ($M)*	*Wedge cost ($M)*	*Total cost ($M)*
A/2	6	0.619	0.312	0.270	2.066
A/2	8	0.786	0.312	0.217	2.008
A/2	10	0.957	0.312	0.163	1.954
A/3	6	0.555	0.384	0.187	1.723
A/3	8	0.738	0.384	0.131	1.672
A/3	10	0.921	0.384	0.075	1.619
B/1	6	0.593	0.332	0.205	1.787
B/1	8	0.788	0.332	0.147	1.738
B/1	10	0.985	0.335	0.089	1.693
B/2	6	0.550	0.330	0.216	1.786
B/2	8	0.728	0.331	0.161	1.735
B/2	10	0.911	0.334	0.106	1.689
C/1	6	0.522	0.270	0.210	1.675
C/1	8	0.694	0.270	0.161	1.638
C/1	10	0.868	0.270	0.111	1.603
C/2	6	0.567	0.262	0.207	1.696
C/2	8	0.730	0.262	0.157	1.651
C/2	10	0.894	0.262	0.107	1.606
D/1	6	0.625	0.324	-	0.948
D/1	8	0.784	0.261	-	1.044
D/1	10	0.945	0.197	-	1.142
D/2	6	0.502	0.259	0.021	0.848
D/2	8	0.670	0.223	-	0.893
D/2	10	0.838	0.159	-	0.998

Table 25 shows the prestrip, dozer push, wedge, and total cost for the three different prestrip heights for Pits E and F. The cheapest total cost prestrip height for each pit/strip is highlighted in red.

TABLE 25.
Case study cost results Pits E and F.

Pit/strip	*Prestrip height (m)*	*Prestrip cost ($M)*	*Dozer push cost ($M)*	*Wedge cost ($M)*	*Total cost ($M)*
E/4	10	0.439	0.137	1.345	1.921
E/4	12	0.493	0.137	1.280	1.911
E/4	14	0.552	0.137	1.213	1.901
E/5	10	0.514	0.139	1.609	2.261
E/5	12	0.617	0.139	1.493	2.249
E/5	14	0.721	0.139	1.378	2.238
F/4	10	0.769	0.363	2.192	3.324
F/4	12	0.889	0.363	2.040	3.292
F/4	14	1.016	0.363	1.885	3.264
F/5	10	0.792	0.262	2.228	3.282
F/5	12	0.947	0.262	2.044	3.253
F/5	14	1.103	0.262	1.859	3.225

The results from Tables 24 and 25 generally show the same result, that the largest prestrip is the most cost effective. The dozer push cost for all pits (except Pit D) is the same across the prestrip heights; this is because for these pits, the dozer push dump is completely fill in all cases, i.e. the dump holds the same volume, regardless of the prestrip height. For all pits (except Pit D) the largest prestrip has the most expensive prestrip cost (i.e. largest prestrip → most quantity of material to be moved → largest prestrip cost). For all pits (except Pit D) the largest prestrip has the cheapest wedge cost (i.e. largest prestrip → less material in the wedge → cheapest wedge cost). The reason for the largest prestrip having the lowest cost is that the cost of removing the wedge material ($4.50 per BCM) is more expensive than the cost of removing the prestrip material ($4.00 per BCM). The dozer push cost is the same across the prestrip heights, thus the remaining material is assigned to either prestrip or wedge, the balance between these two costings results in the cheaper prestrip height, in these cases the largest prestrip.

The results of Pit D differs from the other pits, this is because the dozer dump does not reach capacity (with the exception of strip 2, prestrip height 6m), this means there is no wedge material and no wedge cost. Thus the cheapest prestrip height is determined by the balance of costing between the prestrip and dozer push material. Due to the significantly cheaper cost of the dozer push versus prestrip, the shortest prestrip height resulted in the cheapest total cost for Pit D.

7.4. SENSITIVITY ANALYSIS

A sensitivity analysis was completed for all pits, with the sole aim of determining the cost per BCM that the prestrip must be increased (or decreased) to, in order for the cheapest prestrip height to be changed.

Table 26 shows the results from the sensitivity analysis of Pits A, B, and C. The recommended prestrip height for all these pits were the largest prestrip (10m), on average an increase of around $1.00 per BCM is required in order for 8m to be the cheapest prestrip height. Similarly, an increase of $1.15 is required in order for 6m to be the cheapest prestrip height.

TABLE 26.
Case study sensitivity analysis for Pits A, B, and C.

Pit/strip	*8m prestrip height cost per BCM*	*6m prestrip height cost per BCM*
A/2	$5.30	$5.40
A/3	$5.10	$5.15
B/1	$4.90	$5.10
B/2	$5.00	$5.20
C/1	$4.85	$4.90
C/2	$5.10	$5.15

Table 27 shows the results from the sensitivity analysis of Pit D. For Pit D strip 1 the cheapest prestrip height is 6m, this changes to 8m when the prestrip cost decreases from \$4.00 to \$3.30 per BCM, and 10m when the cost changes to \$2.10 per BCM. For strip 2 a similar pattern is shown, recommended prestrip changes to 8m when prestrip cost is reduced to \$2.25 per BCM, and 10m when cost is \$2.20 per BCM. Similarly when the dozer cost increases to \$3.00 per LCM, and 10m at \$3.60 per LCM. For Pit D strip 1, the cheapest prestrip height is 6m, this changes to 8m when dozer cost increases to \$3.35 per LCM, and 10m at \$3.40 per LCM.

Pit D differs from the rest of the pits, because (for most prestrip heights) there is no (or very little) wedge volume left behind; the shortest prestrip is also recommended in Pit D and thus a decrease in price is required for the larger prestrips be cheaper.

TABLE 27.
Case study sensitivity analysis for Pit D.

Pit/strip	*8m prestrip height cost per BCM*	*10m prestrip height cost per BCM*
D/1	\$3.30	\$2.10
D/2	\$2.25	\$2.20

Table 28 shows the results from the sensitivity analysis of Pits E and F. The recommended prestrip height for all these pits were the largest prestrip (14m), on average an increase of around \$0.70 per BCM is required in order for 12m to be the cheapest prestrip height. Similarly, an increase of \$0.80 is required in order for 14m to be the cheapest prestrip height. This a slightly smaller increase than the results from the other pits (Table 26) due to the difference in prestrip heights, and generally larger overburden volume.

TABLE 28.
Case study sensitivity analysis for Pits E and F.

Pit/strip	*12m prestrip height cost per BCM*	*10m prestrip height cost per BCM*
E/4	\$4.70	\$4.80
E/5	\$4.45	\$4.50
F/4	\$4.90	\$5.10
F/5	\$4.70	\$4.75

The sensitivity analysis shows that the cost of the truck and shovel prestrip needs to be increased in order for the shortest prestrip to be the most economic option. As the removal cost per unit increases, it is less desirable to remove more of that material, thus the prestrip should shorten. This allows the site to have a larger variability when taking into account costs for prestrip removal. For example, if a cost of \$4.00 per BCM with an 8m prestrip was planned for, but the actual cost turned out to be $4.50 per BCM, then the site can alter the prestrip height to a shorter prestrip to account for the increase in cost. Alternatively, if a cost of $5.00 per BCM for a 12m prestrip was planned, but actually turned out to be $4.00 per BCM, then the prestrip height can be increased to decrease the cost of the operation. There is limitation to this, as a specific excavator can only reach up to remove material from a certain height. Thus the ability to increase or decrease the prestrip height is capped.

The sensitivity analysis also allows the operation to have more flexibility in the mine planning technique. If a planned budget allowed for $5.0 M per year for prestripping at a 10m height, but the operation changed the prestrip height to 12m and found a lower cost ($4.5 M), the $0.5 M could then be spent elsewhere to improve the operation. Equipment can also be optimized to fit the operation, purchase of excavators with a greater reach will allow the prestrip height to be increased in the operation, giving the operation greater flexibility if a change in prestrip was required.

8. GENERIC CASE: RESULTS AND ANALYSIS

8.1. OVERVIEW

A generic case study was completed, it aimed to find results for a generic dozer push case that can be applied to all sites. This was completed using the same data from Porter mine, however the generic study did not have a restriction on dozer dump volume (i.e. infinite dozer push dump volume); this makes the Porter mine site data more generic (due to the removal of the final land form height). It is important to note that even though there is the assumption of infinite dozer push dump volume, there are still assumed limitations on the equipment (i.e. drilling and blasting equipment, and dozers) that would not allow the entirety of the overburden material to be removed via dozer push.

The cost of removal for the prestrip was determined to be $4.00 per BCM, as it is removed via truck and shovel, and is unblasted (MECMining, 2015). The dozer push cost was found to be $1.60 per BCM (MECMining, 2015). The cost per BCM can be used in the generic case study, as no material needs to be converted to LCM due to the absence of the dozer dump.

The removal of the restriction on dozer dump volume, results in all the dozer push material being moved to the dump, and no wedge volume being left behind. Thus theoretically the cost of the strip should be reduced, due to the cheaper cost of the dozer push versus the truck and shovel prestrip per BCM.

8.2. VOLUME RESULTS

The volume results were calculated using the Vulcan dozer push and prestrip surfaces that were designed and created. These are the same as the Porter mine case study with the exception being that the dozer push dump was infinite. Tables 29 and 30 show only the prestrip and dozer push volume, as there is no wedge volume and infinite dozer dump volume.

Table 29 shows the prestrip and dozer push volume results for Pits A, B, C, and D for the generic case study, with prestrip heights of 6m, 8m, and 10m. It shows that as prestrip height increases, prestrip volume increases, and dozer push volume decreases.

TABLE 29.
Generic case volume results for Pits A, B, C and D.

Pit/strip	*Prestrip height (m)*	*Prestrip volume (MBCM)*	*Dozer push volume (MBCM)*
A/2	6	0.155	0.421
A/2	8	0.210	0.376
A/2	10	0.267	0.332
A/3	6	0.139	0.396
A/3	8	0.184	0.350
A/3	10	0.230	0.303
B/1	6	0.148	0.379
B/1	8	0.196	0.331
B/1	10	0.246	0.284
B/2	6	0.137	0.386
B/2	8	0.181	0.342
B/2	10	0.227	0.298
C/1	6	0.131	0.345
C/1	8	0.173	0.303
C/1	10	0.217	0.262
C/2	6	0.142	0.336
C/2	8	0.183	0.295
C/2	10	0.224	0.253
D/1	6	0.156	0.203
D/1	8	0.210	0.163
D/1	10	0.264	0.124
D/2	6	0.125	0.179
D/2	8	0.167	0.140
D/2	10	0.210	0.100

Table 30 shows the prestrip and dozer push volume results for Pits E and F for the generic case study, with prestrip heights of 10m, 12m, and 14m. It shows the same relationship as the other pits that as prestrip height increases, prestrip volume increases, and dozer push volume decreases.

TABLE 30.
Generic case volume results for Pits E and F.

Pit/strip	*Prestrip height (m)*	*Prestrip volume (MBCM)*	*Dozer push volume (MBCM)*
E/4	10	0.110	0.353
E/4	12	0.133	0.340
E/4	14	0.158	0.326
E/5	10	0.129	0.406
E/5	12	0.154	0.383
E/5	14	0.180	0.360
F/4	10	0.192	0.662
F/4	12	0.240	0.632
F/4	14	0.290	0.601
F/5	10	0.198	0.606
F/5	12	0.237	0.570
F/5	14	0.276	0.533

8.3. COST RESULTS AND ANALYSIS

The cost for all pits were calculated using the volume results from Section 8.2 *Volume Results* and the cost factors found during research. The costs factors from Section 8.1 *Overview* were used, and are:

- Prestrip truck and shovel: $4.00 per BCM;
- Dozer push: $1.60 per BCM, $1.33 per LCM; and
- Wedge truck and shovel: $4.50 per BCM, $4.20 per LCM.

Table 31 shows the prestrip, dozer push, wedge and total cost for the three different prestrip heights (6m, 8m, and 10m) for Pits A, B, C, and D. It is important to note that the total volume of overburden material moved is the same within each pit/strip and that it is cost factor that determines the total cost of waste removal. The lowest total cost prestrip height for each pit/strip is highlighted in red.

TABLE 31.
Generic case cost results for Pits A, B, C, and D.

Pit/strip	*Prestrip height (m)*	*Prestrip cost ($M)*	*Dozer push cost ($M)*	*Total cost ($M)*
A/2	6	0.619	0.673	1.292
A/2	8	0.786	0.602	1.388
A/2	10	0.957	0.531	1.487
A/3	6	0.555	0.634	1.189
A/3	8	0.738	0.560	1.297
A/3	10	0.921	0.485	1.405
B/1	6	0.593	0.607	1.200
B/1	8	0.788	0.529	1.317
B/1	10	0.985	0.454	1.439
B/2	6	0.550	0.618	1.168
B/2	8	0.728	0.547	1.274
B/2	10	0.911	0.476	1.387
C/1	6	0.522	0.551	1.073
C/1	8	0.694	0.485	1.179
C/1	10	0.868	0.418	1.286
C/2	6	0.567	0.538	1.105
C/2	8	0.730	0.472	1.202
C/2	10	0.894	0.405	1.299
D/1	6	0.625	0.324	0.949
D/1	8	0.784	0.261	1.045
D/1	10	0.945	0.198	1.143
D/2	6	0.502	0.287	0.789
D/2	8	0.670	0.223	0.893
D/2	10	0.838	0.160	0.998

Table 32 shows the prestrip, dozer push, wedge and total cost for the three different prestrip heights (10m, 12m, and 14m) for Pits E and F. The lowest total cost prestrip height for each pit/strip is highlighted in red.

TABLE 32.
Generic case cost results for Pits E and F.

Pit/strip	*Prestrip height (m)*	*Prestrip cost ($M)*	*Dozer push cost ($M)*	*Total cost ($M)*
E/4	10	0.439	0.564	1.003
E/4	12	0.493	0.544	1.037
E/4	14	0.552	0.522	1.074
E/5	10	0.514	0.650	1.164
E/5	12	0.617	0.613	1.230
E/5	14	0.721	0.576	1.298
F/4	10	0.769	1.060	1.829
F/4	12	0.889	1.011	1.900
F/4	14	1.016	0.962	1.978
F/5	10	0.792	0.970	1.762
F/5	12	0.947	0.911	1.859
F/5	14	1.103	0.853	1.956

The results from Table 31 and 32 show that the shortest prestrip has the lowest cost for all pits. This is due to there being no dump restriction and thus no wedge volume, meaning that all the dozer push material is dozer pushed. In the Porter mine case study the dozer push material was being both dozer pushed and then truck and shovelled (because there was wedge volume left behind). The generic case study shows that if there is no limitation on the dozer dump volume, then the shortest prestrip should be utilised, due to the much cheaper cost of the dozers ($1.60 per BCM) versus the prestrip ($4.00 per BCM).

8.4. SENSITIVITY ANALYSIS

A sensitivity analysis was completed for all pits in the generic case study, with the aim of determining the cost per BCM that the prestrip must be increased (or decreased) to, in order for the cheapest prestrip height to be changed.

Table 33 shows the results from the sensitivity analysis of Pits A, B, C, and D. The recommended prestrip height for all these pits was the shortest prestrip (6m), on average a decrease of cost from $4.00 to $1.60 per BCM is required in order for 8m to be the cheapest prestrip height. Similarly, a decrease to $1.55 is required in order for 10m to be the cheapest prestrip height.

TABLE 33.
Case study sensitivity analysis for Pits A, B, C, and D.

Pit/strip	*8m prestrip height cost per BCM*	*10m prestrip height cost per BCM*
A/2	$1.70	$1.65
A/3	$1.65	$1.60
B/1	$1.55	$1.50
B/2	$1.60	$1.55
C/1	$1.55	$1.50
C/2	$1.65	$1.60
D/1	$1.65	$1.55
D/2	$1.55	$1.50

Table 34 shows the results from the sensitivity analysis of Pits E and F. The recommended prestrip height for all these pits was the shortest prestrip (10m), on average a decrease of cost from $4.00 to $1.55 per BCM is required in order for 12m to be the cheapest prestrip height. Similarly, a decrease to $1.45 per BCM is required in order for 14m to be the cheapest prestrip height.

TABLE 34.
Case study sensitivity analysis for Pits E and F.

Pit/strip	*12m prestrip height cost per BCM*	*14m prestrip height cost per BCM*
E/4	$1.50	$1.45
E/5	$1.45	$1.40
F/4	$1.60	$1.50
F/5	$1.55	$1.50

The sensitivity analysis for the generic case study differs from the sensitivity analysis of the Porter mine case study. This is because a decrease in cost of prestrip is required in order for the larger prestrip heights to be the cheaper option. Whereas in the Porter mine case study, the largest prestrip height was already the cheaper option, and cost had to be increased in order for the smaller prestrip heights to become the cheapest option.

The sensitivity analysis shows that prestrip costs needs to significantly decrease in order for the larger prestrips to be the more economic option. Alternatively dozer push costs could increase significantly to have a similar economic effect. This leaves less room for flexibility in a short term mine planning perspective, as an increase in prestrip height will result in a significant increase in cost.

8.5. GENERIC CASE STUDY VS PORTER MINE CASE STUDY

Overall the cost of the generic case study is lower than that of the Porter mine case study, this is due to the ability of the dozers in the generic case to push all of the dozer push material into the dump and leave no wedge behind. The two case studies allow for the coverage of two situations that can be applied to surface mine sites using dozer push to uncover coal, these situations are:

- Dozer push operation has no limitation on dozer dump height, and thus dozer dump volume is very large, in which case shortest prestrip is recommended;
- dozer push operation is limited to a dump height, and thus dozer dump volume is limited;
    - dump volume is completely filled, in which case larger prestrip is recommended; and
    - dump volume is not filled, in which case shorter prestrip is recommended.

Comparing total cost for each prestrip for the two case studies (Table 24 vs Table 31, and Table 25 vs Table 32) found that the generic case study is much cheaper than the Porter mine case study, with an average of $0.35 M difference in cost for Pits A to D (generic case study $0.35 M cheaper), and $1.2 M difference in Pits E and F. Again, this is due to the fact that the dozer push volume assumed to hold infinite volume in the generic case study.

9. CONCLUSIONS

This project aimed to investigate the optimisation of prestrip waste material for surface mines using dozer push as main method of waste removal. Extensive research was conducted, investigating strip coal mining methods, different types of equipment and methodologies, current research on prestripping and dozer push, and most importantly cost per BCM/LCM for each method.

A risk assessment was completed, no physical risks towards humans were determined as the project didn't require any field or lab work, only data and software utilisation. However risks to the data and project were identified, the risks with the highest rankings were:

- File corruption – risk ranking 12;
- data loss – risk ranking 10; and
- insufficient data – risk ranking 9.

A contingency plan was created, in the case that one of the risks were to occur. To prevent the three risks above, the contingency plan stated to back up data on work, university, and personal computers as well as on multiple hard drives. In the event that the risks occurred, a site return was necessary to collect more data or recollect existing data. It is important to note these risks if an attempt to repeat the project is completed.

Both a case study (Porter mine) and a generic case study were used to investigate the topic. Site data from Porter mine was collected and Vulcan was used to design and create prestrip and dozer push surfaces. These designs included three different prestrip levels, these were:

- Pit A – 6m, 8m, and 10m;
- Pit B – 6m, 8m, and 10m;
- Pit C – 6m, 8m, and 10m;
- Pit D – 6m, 8m, and 10m;
- Pit E – 10m, 12m, and 14m; and
- Pit F – 10m, 12m, and 14m.

Following the creation of the surfaces, volumes and associated total costs were calculated for each pit, strip, and prestrip height. Prestrip cut, dozer push, wedge cut, and dozer dump volumes and costs were calculated in the Porter mine case study, while only prestrip and dozer push cut were found in the generic case study.

In the Porter mine case study, the dozer push dump was always fully utilised (except for Pit D), this resulted in a near identical dozer push cost for all prestrip heights. The resulting wedge volume was assigned a higher cost ($4.50/BCM) of removal compared to the prestrip ($4.00/BCM), due to it being blasted, deeper in the pit, and having longer haul routes. This meant that the cheapest prestrip height was determined by the balance of the cost and volume of the wedge/prestrip material to be removed.

The Porter mine case study found that due to limitation on available dozer dump volume, the largest prestrip height was determined to be the cheapest (10m for Pits A, B, and C, and 14m for Pits E and F). The exception being Pit D, where the inability to fill the dozer dump volume resulted in the smallest prestrip height to be the cheapest (6m).

In the generic case study, it was assumed that the dozer dump volume was infinite and all the dozer push material could be moved via dozer push, i.e. no wedge volume left over. This case study found that due to the much lower cost of removal of the dozer push method ($1.60 per BCM) compared to the truck and shovel prestrip method ($4.00 per BCM), it is desirable to assign more material to the dozer push; hence the shortest prestrip resulted in the lowest overall cost for all pits (6m for Pits A to D, and 10m for Pits E and F).

From the analysis of the case studies (Section 7 and 8), a generalization can be made regarding the thesis topic. 100% utilisation of the dump space results in a wedge, this case has shown that as prestrip height increases, the overall cost of removal decreases. In the other case where dump space is not fully utilised, a decrease in prestrip height results in a reduction of overall cost. Thus the generalization is that a change in prestrip height (whether it be an increase or decrease) has the ability to reduce or increase cost; the determination of which happens is related to the available dump space and consequential wedge volume.

10. RECOMMENDATIONS AND FUTURE WORKS

From the research undertaken, and from the analysis of the Porter mine case study and generic case study, a recommendation can be established. The bulk dozer push method of waste removal was found to have a lower waste removal cost ($1.60 per BCM) than the truck and shovel method ($4.00 per BCM for prestrip and $4.50 per BCM for wedge).

The generic case study found that as long as there was sufficient room in the dozer push dump, it would be desirable to have a smaller excavator prestrip. This allows for more waste to be assigned to the cheaper dozer push method, and thus reduce the cost of an operation. However as shown in the Porter mine case study, if there is insufficient room in the dozer push, then prestrip level should be increased to reduce the wedge volume left behind by the dozer push.

In general, dozer push should be fully utilised if possible (i.e. completely fill the dozer dump) as it is the cheaper method of waste removal, next assign as much of the remaining overburden to the prestrip (as it is the next cheapest), and finally the rest to the wedge volume.

Future work to improve this thesis is to look in depth into the effect that drill and blast costs has on the operation, as this cost was simply inserted into the dozer cost in this thesis.

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