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A REVIEW ON EXISTING OPENCAST COAL MINING METHODS WITHIN AUSTRALIA

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Currently almost 65 % of the coal in Australia is being produced by opencast mining methods. Mining equipments such as draglines, dredgers or bucket wheel excavators, trucks and shovels, and dozers are the main equipments employed for overburden removal and coal extraction. The choice of equipment for a particular mine depends on geological, geotechnical and economic factors and other site issues. This paper provides a general review of the main equipments used in Australia, including examples of some existing mines and the reasons for their choice of equipment. In addition, the paper discusses major geo-mechanical issues encountered and how these may influence the selection of appropriate equipments used in open cut mining operations.

Coal mining, surface mine, opencast mining machines

INTRODUCTION

Surface or opencast mining contributes to about 65 % of coal production in Australia. The majority of surface mines are located in Queensland and New South Wales. This paper provides a general review of this mining method in Australia.

There are a number of different mining equipments and techniques which can be employed in open cut mining and, as with underground mining, the development of technology is playing a large part in the productivity and costs involved with each technique [1]. The main advantage of open cut mining is improved mine personnel safety as there is no risk of mine roof collapse. However, there are also disadvantages such as the need to remove overburden before coal can be exploited, as well as the high capital costs involved with the large, usually imported, machinery [2]. Generally, surface mines are only economical when the coal seam is relatively close to the surface, and the recovery rate of coal is higher than underground methods.

Surface coal mining operation can be thought of as consisting of two distinct stages, overburden removal and coal exploitation [3]. Within Australia there are a number of equipments and mining methods currently being utilized for both purposes. The methods used will depend on a number of factors and any site related issues for a particular mine, and the technique used for coal exploitation can be the same or different from that used for overburden removal.

The machinery predominantly used for overburden removal includes draglines, dredgers, dozers, and truck and shovel operations, whilst the same methods can also be applied for coal exploitation, with the exception of draglines. Overburden removal plays a key part in surface mines, accounting for up to half the total cost involved in coal exposure, extraction, washing and transportation [4].

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1. CURRENT STATE OF THE AUSTRALIAN COAL MINING OPERATIONS

In order to gain an understanding of current coal mining operations in Australia, a broad overview of methods and their suitability for coal mines is discussed.

In Australia, open cut mining produces the most amount of coal for both export and domestic uses. In 2004 for example, 81.5 million tons of coal was mined using underground methods, whilst 296.3 million tons were obtained from open cut mines [5]. This is of no surprise as nearly two thirds of all operating mines within Australia are open cut, as can be seen from Table 1 and Fig. 1.

Within Australia, brown coal is typically found in the southern part, while black coal is mainly found in the basins of New South Wales and Queensland.

As mentioned, surface mining or opencast coal mining is the predominant method used in Australia, and so is focused on within this paper. Opencast coal mining on a large scale first commenced in Australia in the 1960's.

Today, draglines and truck and shovel operations, or a mixture of the two, are the predominant types of equipment used in open cut mines, as seen in Fig. 2.

TABLE 1. Types of Mines Operational within Australia [6 – 12]

State	Mine types by state		
	Underground	Surface	Total
Queensland	10	30	40
New South Wales	27	25	52
Western Australia	0	6	6
Tasmania	1	2	3
Victoria	1	7	8
South Australia	0	1	1
Total	39	71	110

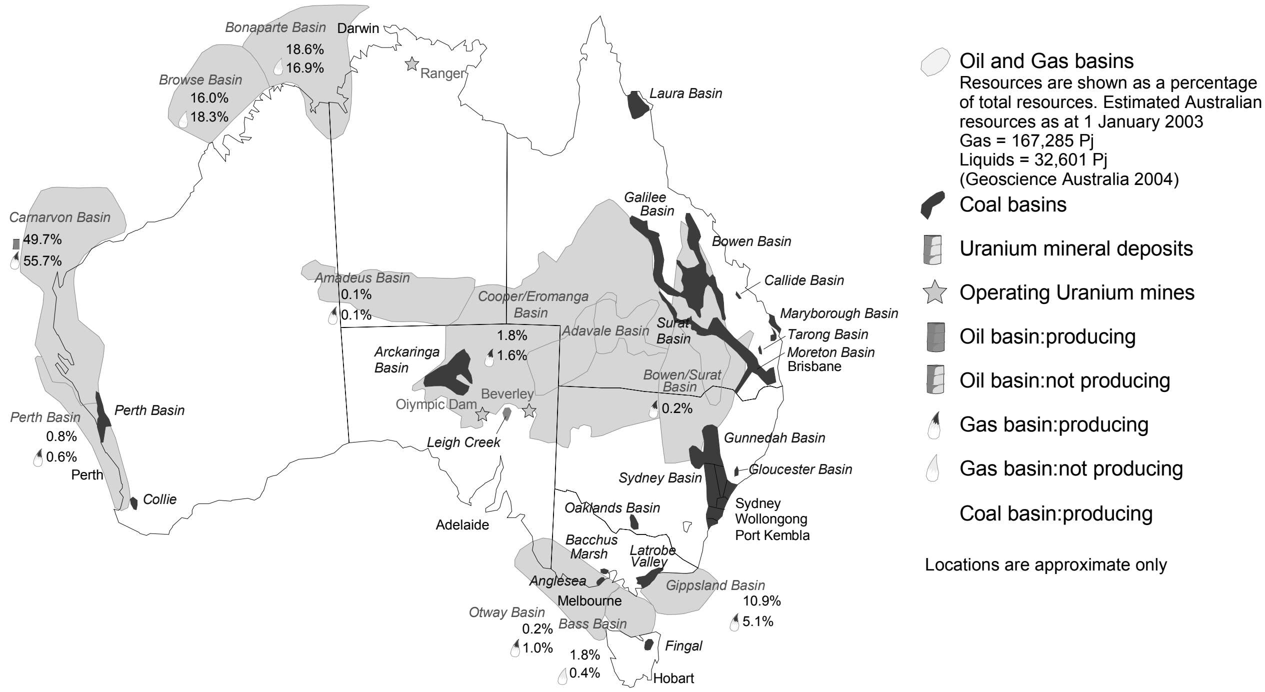

Fig. 1. Map of Australian coal basins [12]

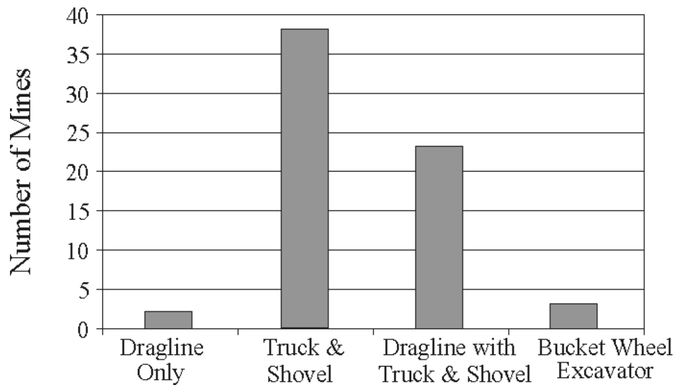

Fig. 2. Open cut coal mining equipment used in Australia [13]

2. ABOVE GROUND / OPEN CUT COAL MINING ALTERNATIVES

The present paper is focused primarily on the surface, or open cut or opencast methods commonly used in coal mining within Australia, with an emphasis on what conditions would best suit a particular method. Again, issues such as geotechnical conditions, as well as production and productivity will also be discussed.

As open cut mining operations can be divided into two separate categories, overburden removal and coal exploitation, this section will be split accordingly. Overburden removal is an important aspect to consider in open cut mines as it "accounts for a high percentage of total mine investment and operating costs" [14].

2.1. DRAGLINES FOR OVERBURDEN REMOVAL

The selection of a mining method is based on careful consideration of a number of important factors, including geographic and geologic information, deposit size and shape, coal seam distribution, mine life, production rate required, equipment availability and its compatibility with other equipment to be employed on site. It is only when all these factors have been considered that a decision on the open cut mining method to be implemented can be reached so that the most favorable engineering economics are met.

The use of draglines is the first of the two major methods to be discussed regarding removal of overburden for open cuts, followed by truck and shovel operations.

2.1.1. GEOTECHNICAL FACTORS AND ISSUES

The key to operating a successful coal mine, whether it be underground or open cut, or any other type of mine for that matter, is effectively managing risk. As there are large uncertainties and likely problems which can result in massive losses without warning, conducting extensive research and making correct decisions based on the research results are vital for a successful mining operation. This is particularly true when dealing with geotechnical risks. Minor mistakes or oversights can have catastrophic consequences, and so it is important to ensure all geotechnical risks are identified, before it is too late.

Overburden removal by use of a dragline unit is one such technique to which the above statement applies. It is very huge and expensive equipment, which is utilized in opencast mines, where the strip ratio is generally less than 20:1. It has a fairly low operating cost, is much less versatile than truck and shovel operations and, as Westcott, [13] states, is generally restricted to:

— large deposits with adequate strip lengths, where the vast capital expenditure can be justified,

— gently dipping deposits, to ensure soil stability, which is compromised when working on steeper dips,

— uncomplicated geology and fairly flat terrain to ensure overburden thickness remains fairly constant along a strip, and

— shallow deposits with thick coal seams, as dragline dump reach and height limitations usually restrict the overburden depth to a maximum of 60 – 70 m.

Other geological issues which should be considered before implementing draglines to a mining operation include rainfall and temperature statistics. As wet overburden is difficult to handle, pit and dump slopes become difficult to maintain, affecting the stability of the benches and pads on which a dragline stands [15]. This is also an issue for truck and shovel operations as haul roads can become difficult to maintain, and so careful planning is required with regards to climatic conditions [16].

It is obviously essential that an experienced coal geologist undertakes a detailed exploration plan before any decision is made on whether or not draglines should be introduced to an open cut mine. The results from this would include information on the identification of different materials in the stratigraphic column, which is found from the inspection of drill cuttings. The results would only be approximate as time and cost constraints usually do not allow for massive numbers of boreholes to be studied, and therefore inevitable seam variances such as dips and thickness changes, or divisions may not be clearly identified.

The geologist will use a number of logging tools such as gamma rays, density logs, calliper logs, neutron logs and resistivity logs in order to produce topography and structure contour maps, isopachs, isopleths and resource stripping ratio contours so that a review can be undertaken to establish whether or not the site geology suits the proposed mining equipment. This is not just restricted to proposing dragline equipment, but is relevant to all proposed mining developments.

Once the geologic data has been studied, key parameters such as surface terrain, groundwater, overburden depth, coal seam thickness, density of overburden and coal, proposed bench angles and dip must be defined which may restrict draglines from being implemented. These parameters will however, at times, dictate the overall mine plan and hence a larger production rate than previously expected, thus highlighting the importance of careful selection. Britton [14] provides an example: "depth of overburden above a coal seam may require a very large dragline with sufficient digging depth and dumping reach to uncover the seam. Since burden removal is likely the greatest unit cost of this operation, the most favorable production rate will be the rate at which coal can be uncovered. To produce coal at a lesser rate would require the dragline to occasionally stand by to wait for coal production to catch up. Dragline standby would penalize overall economics of the operation."

It can be seen from this statement that selecting the appropriate equipment is an extremely important decision for open cut coal mines, and proper geological and geotechnical research with proper planning and design is a critical aspect of reaching the correct decision.

Along with what has been discussed in this section, there are a number of geotechnical risks associated with draglines. These can arise at any stage of the mine life, from planning through to actual operation. It is not logical to expect that all these risks can be identified prior to them becoming an issue, and it is for this reason that all personnel within a mine site are capable of identifying clues which signal potential hazardous situations.

Simmons, [17] identifies the most common sources of geotechnical risks within mines operating draglines as:

— incomplete geological knowledge or inadequate interpretation of ground conditions,
— instability of excavated faces and slopes,
— instability of dump faces and slopes, and
— loosening and movement of isolated rocks.

As previously stated, the first point is always going to be relevant due to budget and time constraints. Instability of excavated and dumped faces and slopes is generally due to inadequate material strength, which at times can be related to the first point of incomplete geological knowledge. Design of dump and excavation techniques and locations is necessary to ensure stable faces and slopes, as well as experienced, well-trained operators who can identify potential hazards and risks.

The loosening and movement of isolated rocks can occur without warning at any time from either excavated faces or dumped waste surfaces [18]. This loosening and potential movement is usually due to the occurrence of rain, wind or blast vibrations [19]. In some instances however, rocks may be dislodge from excavated faces after weakening of small intact rock "bridges" that connect rocks with pre-existing fractures. Time-related weakening can also be a cause for unstable faces, slopes and dumps within mines operating draglines, however this is difficult to predict and can occur with little or no warning [17].

A major issue with mines operating draglines is failure along the dragline bench. The loading of in-pit benches by draglines, where weak surfaces are evident, can lead to severe stress distributions, which results in a number of potential failure mechanisms. This is an area which requires both detailed planning at the development stage, as well as ongoing monitoring by all personnel throughout the operation of the mine [20]. Two examples referring to poor monitoring and planning are cited below.

Firstly, in 1999 a dragline actually slid off a bench, causing an immediate interest in risk management of draglines on benches throughout the industry. An investigation into this incident proved that tub failure, not bench failure, was the main cause of the slide, and that had established work procedures been followed the incident could have been avoided.

Another incident which occurred more recently at a separate mine involved cracking being observed along a bench. The dragline was stepped back from the area in question and a very rapid bench face failure occurred almost immediately afterwards, again emphasizing the importance of continual observation on behalf of operators, engineers and geologists. This bench was thought to be a typical section with no apparent abnormalities, but the subsequent investigation found that failure had occurred in the specific location of a former box-cut pit sump, with the issue arising due to the proximity of the weak mud in the sump which had been overlooked during planning.

Both of these small examples demonstrate the importance of proper geological surveys and monitoring, as well as the consequences if either is not properly addressed.

This section has discussed a number of geological and geotechnical obstacles applicable to opencast mines utilizing draglines. It is a difficult process to assess all the geological and geotechnical issues associated with this particular type of mining as each individual site is likely to present new and different challenges, and thus this section has dealt with the more common, major difficulties and conditions traditionally encountered.

2.1.2. OTHER ISSUES AND CONSIDERATIONS

As each site is different, it is difficult to recommend certain "templates" for mines utilizing draglines (and other mining methods for that matter). The main parameters influencing the development of an opencast mine utilizing draglines can be divided into three groups: geological (already covered), equipment specifications and operational.

The important point of equipment specification is that it must satisfy the constraints of the geological parameters, as these are generally fixed. The working radius of the dragline is one aspect which should be dealt with in detail as it is related to the geological parameters that impact the immediate working area. If the geology or planning of the site doesn't allow dumping to be conducted relatively close to the excavation face, then draglines may not be suitable for the site. As they generally have standard specifications with little room for modifications, physical limitations are relevant to the immediate working area. Draglines do, however, have variable boom length and angles which can be adjusted to suit particular areas, although the maximum suspended load will alter as these are changed. The major influence on the safe working distance from the bench crest with regards to draglines is the overall weight of the dragline. This is due to the geological issue of bench stability. Detailed calculations and geological evaluations are required for proposed areas of dragline placement as bench failure can cause extreme risks. The actual base of the dragline can be increased, if required to reduce the applied ground pressure when working on less consolidated material to partially negate this issue.

Thus, the crucial parameters relevant to equipment selection include digging reach, maximum load, ground pressure, operating and clearance radii, dump height and work cycle time, all of which implementation is largely reliant on the geological conditions of the site.

Another major parameter influencing the development of an open cut mine utilizing draglines is the operational factor. These are partly dictated by the equipment specification, which in turn is influenced by the geological parameters. For example, the depth of overburden is the major factor influencing the selection of a dragline, where a number of different sizes and/or production rates are available. The issue with the dragline selection however is that it should match the specific coal production rates. A dragline should not get so far ahead of coal production that it must stop and stand around idle, as this is wasting a valuable resource, however it should not allow the coal extraction to catch up to the overburden removal area, as coal extraction must halt until it has been exposed. Thus, a balance needs to be found when selecting appropriately sized draglines with regards to bench height, varying panel width, dig-out length, boom length and angle, and bucket size, so that a favorable mine design can be estimated.

A study undertaken by Tasman Asia Pacific in 1998 compared 8 open cut coal mines in Australia utilizing draglines with 5 in the USA in order to identify common issues and areas for improvement within Australian mines. Table 2 summarizes the key characteristics of the participating mines.

Interesting notes from this study include:

— Although the re-handle factor in the US coal mines is much higher than the others, particularly NSW, this does not necessarily mean a productivity decrease due to the dragline being required to move in order to re-handle the overburden. Draglines with high re-handle factors may spend significantly less time digging benches as opposed to those with lower factors, and the productivity may actually increase due to shorter swinging required by the dragline.

— The average amounts of overburden required to be moved varied throughout the mines.

— Mines in Queensland utilizing draglines were considered best practice, operating at 19 and 25 percent higher production levels than US and NSW operations respectively.

TABLE 2. Characteristics of Dragline Operations (Average per Mine)

Location	Prime overburden moved, million bcm	Re-handled overburden moved, million bcm	Total overburden moved, million bcm	Re-handle factor (re-handled/prime overburden percent)	Powder factor (kg explosives per bcm)
Queensland, AU	27	10	37	0.38	0.26
USA	14	6	20	0.45	0.38
NSW, AU	20	5	25	0.27	0.38

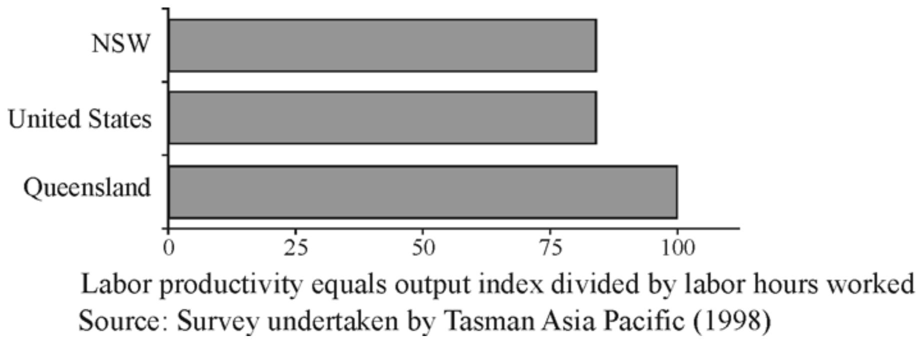

Fig. 3. Labor productivity (output index divided by labor hours worked) in dragline operations (index: Queensland = 100)

A number of factors were found to have the largest influence on production levels.

The first of these was the labor productivity, where labor accounts for around 20 % of dragline input costs. As can be seen from Fig. 3, Queensland performed best in this component, with the paper identifying this as one of the prime reasons why Queensland mines had such high production levels. Excellent operator training and work practices were identified as the main causes of this higher labor productivity.

Another reason was the percentage of idle times in shifts. This is influenced by mine planning and workplace culture. In general, the Australian mines had roughly the same amount of breaks throughout a shift as US mines, however 12 hour shifts are worked in the US as opposed to 8 hours within Australia. Most of the additional idle time within NSW mines, demonstrated in Figure 4, was due to extended breaks during meal times, which had a substantial effect on the overall productivity.

Other factors which influenced higher production rates included low blasting requirements in Queensland mines due to geology of the overburden, and other equipment productivity such as the use of dozers to re-handle overburden.

Table 3 identifies a number of indicators which demonstrate the performance of the participating mines in a number of areas. It is noted that NSW mines outperformed Queensland mines in three areas; electricity, dozer and diesel productivity. This did not have much of an influence over the total production and cost results as they are such small components of the overall dragline operation.

These results from Tasman Asia Pacific, 1998 summarize some of the key parameters influencing dragline productivity, and have been identified as key points to address in order to aim for best practice when operating open cut coal mines utilizing draglines.

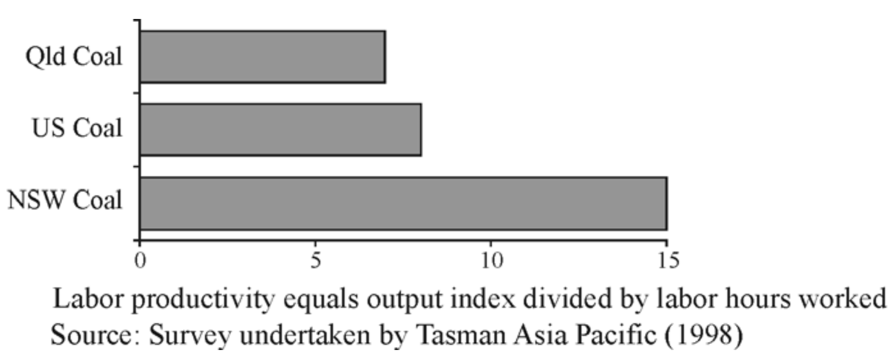

Fig. 4. Percentage of idle time in shifts

TABLE 3. Productivity Indicators (Index: Queensland Coal = 100)

Productivity valuation area	QLD, AU	USA	NSW, AU	Average share of costs, %
Dragline (000 bcm per loose cubic meter of dragline capacity)	100	85	81	38
Explosives (000 bcm per kg explosives)	100	70	69	21
Labor (bcm per labor hour worked)	100	84	84	21
Electricity (000 bcm per megawatt hour)	100	107	110	12
Dozer (000 bcm per kilowatt of dozer capacity)	100	95	120	4
Diesel (bcm per liter of fuel used)	100	34	139	3
Drill (000 bcm per centimeter of drill capacity)	100	47	45	2
Other equipment (000 bcm per kilowatt of other equipment capacity)	100	57	15	< 1

Another important area in which dragline productivity can be influenced is through the use of advanced and sophisticated technology with proper execution. It has been estimated that increasing the productivity of a dragline by around 4 % would save a typical Australian coal mine around $3 million dollars a year [21], and so these developments are critical in ensuring Australia remains competitive in the international coal market. Technology advances in automatic swing control and digging simulation particularly, have been said to have the potential to save the industry hundreds of millions of dollars per year through greater production levels being attainable, more efficient operator training, reduced equipment and component damage, unscheduled downtime, and safety risks. Much time and money has been spent on these technology advancements in order to alleviate the skills constraint on production growth and productivity improvement sought by coal producers during a period of booming demand for exports [22].

2.1.3. COSTS

Westcott [13] identifies typical costs associated with draglines and truck and shovel operations, as presented in Table 4. Discussion with various industry employees with relevant knowledge and experience in both dragline and truck and shovel operations confirmed the general accuracy of these figures. This was undertaken to ensure the validity of these costs.

The following assumptions were taken in order to obtain these costs:

— dragline is 80 bcm bucket and incorporates dozer assist and throw blast,

— the truck / shovel component includes hydraulic excavator loading 220 ton trucks in 4 passes,

— drill and blast is included in price,

— all support equipment such as dozers, graders etc. are included within the price,

— the capital cost is based on a commercial leasing agreement.

As can be seen from Table 4, dragline capital costs are much higher than truck and shovel, however operating costs are halved.

TABLE 4. Typical Costs for Removing Overburden (Dragline versus Truck and Shovel Operations) [9]

Index	Dragline	Truck/shovel
Nominal prime capacity, Mbcm	26	11
Capital cost, $A millions	80	34
Cash operating cost, $A/bcm	0.80	1.60
Capital and operating costs, $A/bcm	1.30	2.50

Again, the choice on whether to implement a dragline in place of a truck and shovel fleet is dependent on a number of factors, primarily:

— Ground Conditions: Is the material likely to be able to withstand the weight of a dragline? Are quality haul roads able to be constructed in order for large haul trucks to operate? Are the ground conditions complex, thus requiring greater flexibility within the operation, therefore eliminating dragline utilization?

— Required Production Rate: Will the dragline be able to keep up with coal extraction, or will it fall too far behind? Conversely, will it dig too fast and then be required to sit around for a large amount of time, thus wasting such an expensive resource?

— Mine Life: Is it practical outlaying such a large capital cost if the life of the mine is only short?

2.2. TRUCK AND SHOVEL OPERATION FOR OVERBURDEN REMOVAL

2.2.1. GEOTECHNICAL FACTORS AND ISSUES

The major points regarding geological and geotechnical suitability for truck and shovel operations can be summarized as:

— it is a method most suited to geologically and geo-technically complex deposits with resultant irregular pit shapes. This is due to the flexibility of truck and shovel operations when compared to draglines, as they are more versatile and can be relocated or diverted around geological intrusions, faults etc. more easily if required,

— it is preferred to use truck and shovel over dragline in steeply dipping deposits, where the equipment can not operate on the seam top and bottom. Initially, the overburden is dumped ex-pit followed by in-pit when sufficient dump room is available. Coal is exposed as a series of benches which are excavated within the pit by truck and shovel. The depth of each bench extends from the floor of the lowest seam to the down dip economic pit limit,

— sites with smaller deposits resulting in a short mine life should lean towards truck and shovel operations, as these situations do not justify the capital expenditure required for a dragline [13],

— the coal is sufficiently covered by overburden material that it is beyond the digging depth of draglines, and

— situations, where the overburden is not at a level of stability that a dragline could safely rest on [14].

In general, truck and shovel operations are a fairly safe technique to implement with minimal geotechnical risks when compared to draglines. If issues with ground stability arise, it is often not a major problem in relocating the fleet. Some time would be lost, however this would be minimal in relation to the relocation time of a dragline.

Major issues when operating truck and shovel fleets are similar to some of those discussed in the dragline section. Geological issues such as rainfall and temperature statistics are important to consider for reasons outlined in the Dragline Geotechnical Suitability and Issues section, as is the requirement for an experienced coal geologist to undertake a detailed exploration plan before any decision is made on whether or not truck and shovel operations should be introduced to an open cut mine. Excavator slip should also be identified as a potential hazard with this technique. Similar to dragline slip, this occurs when unstable benches are evident due to inadequate materials strength. If weak surfaces are evident severe stress distributions can occur, which results in a number of potential failure mechanisms, as outlined in the dragline section.

This highlights the importance of adequate geological knowledge and pad and bench design. As is the case with draglines, experienced, well-trained operators who can identify potential hazards and risks are also necessary to reduce the potential of this problem occurring [17].

Geological issues such as frequent occurrences of heavy rainfall events can also severely impact on truck and shovel operations as much time is lost during wet weather. The large, heavy machines cannot operate in muddy conditions as they can get stuck, halting the operations and costing large amounts of money due to lost production. Excavators can also become stuck in wet, muddy conditions and it is for these reasons that some mines, particularly those in the wetter southern states such as Victoria, operate at the highest possible production in the summer months in order to get a long way ahead of the coal extraction machine, so that operations can slow down during winter months. This method of operation requires extensive planning and ultimately reduces costs within a company as less time is lost during wet periods in winter.

Conversely however, when there is not enough rain and the climate is extremely hot, as is the case in the northern Australian states such as Queensland, dust issues can arise. These conditions can lead to environmental issues, and the dust must be suppressed appropriately [23]. The most common method of dust control involves the use of water trucks or sprinklers, and depending on the mine size, upwards of 3 or 4 may be required on the one site.

Another issue which has been applicable to truck and shovel operations over a number of years is truck rollover. This can result in large repair costs and in some situations can be fatal. It generally occurs due to a combination of reasons such as overload of truck tray, excessive truck speed, topography of surface or dump design. Overloaded trucks can be a problem as the excess weight can cause the operator to lose control of the movement of the truck, causing it to topple. When this situation is evident in cases of uneven surfaces, particularly around the dump location, the truck can become unbalanced. Generally, large dump trucks tend to experience rollover when taking corners at a speed too fast for the truck to handle, and so it is important speed limits are adhered to, and haul roads are in good condition. It is also not uncommon for dump trucks to topple backwards onto the back of the tray when hoisting and dumping loads at the dump location. This is generally due to poor positioning of the truck at the dump site, and is both the mine engineer and operator's responsibility to ensure appropriate dumping techniques are being followed. To minimize the risk of truck rollover or toppling, the following statement should therefore be noted. Trucks should be loaded at the designated Safe Loading Limit, with the material distributed evenly across the area of the tray. Safe speed limits should be in place, monitored and adhered to by operators, and haul roads should be in good condition and as non-undulating as possible. Dumping techniques should be developed, communicated and adhered to by operators, and extra caution should be taken in extreme weather conditions where visibility due to dust or traction due to wet weather is restricted. In some cases, operations should halt if these weather conditions become too excessive.

Haul roads should be maintained throughout the life of the mine, and should be constructed of a material sufficient to handle the constant weight of the loaded dump trucks. Clay is a typical material utilized for this, and is generally available on most mine sites. It should be sufficiently compacted, sometimes achieved by operating the trucks on the surface, and should be wide enough to comfortably allow two trucks to pass each other.

2.2.2. OTHER ISSUES AND CONSIDERATIONS

The major issue regarding truck and shovel operations, as is the case with all other mining techniques, is productivity levels and operating costs. The major factor affecting this in a truck and shovel sense, and the focus of this section, is selecting the appropriate truck and shovel fleet such that the overall cost and production of materials handling is optimized. As mining is such a dynamic nature, with production scheduling altered in an instant depending on demand, the fleet must be able to cope with such situations. Equipment selection is therefore vital as even small improvements in operation efficiency can result in considerable savings over the mine life, due to the usually large scale of operations.

Truck and shovel arrangement is such a complex element of mining, however its optimization can save large sums of money. There are numerous modeling methods available throughout the industry which attempt to predict truck and shovel productivity for equipment selection, including Queueing Theory (the study of the waiting times, lengths and other properties of queues), Bunching Theory (the study of the tendency of moving objects to bunch together when moving in a line), Linear Programming and Genetic Algorithms, however these tend to be consistently inadequate [24]. There are also a number of techniques which incorporate these methods, including Classical Methods, Operations Research and Artificial Intelligence techniques, however a number of common weakness are evident within each. These include:

— Fleet Homogeneity: this element assumes that only one type of truck should be within the fleet. In reality however, numerous truck types and sizes are utilized within fleets for various reasons such as truck availability and quantity.

— Loader or Truck Type Pre-selection: This requires an engineer of high skill and experience to select a type of loader or truck dependent on geological conditions. This can be an expensive and timely process, and generally optimization is not completely achieved.

— Restricted number of passes (from loader to truck): There is currently no evidence suggesting restricted number of passes is a reasonable constraint.

Burt et al. [24] discusses one such model, which does take these points into account, and demonstrates that heterogeneous fleets can result in savings for particular mining operations. However, in the paper, they state that "a clear and simple method of determining the optimal truck and loader has not yet presented itself in literature" and identifies the selection criteria for a truck to be highly complex, with a number of factors including: material characteristics of the mine, mine and dump plan restrictions, truck and loader availability restrictions, truck and loader life constraints, truck queueing effect, loading equipment, haul route requirements, manoeuvring space, dumping conditions, capacity, engine power and altitude limitations, and two or three axle configuration.

Each of these obviously plays an individual part in affecting the possible productivity levels achievable by a fleet and as such should be considered in models attempting to identify equipment selection. The complexity of each of these individual factors is beyond the scope of this paper, however the knowledge of their importance is required in attempting to establish an optimal fleet arrangement. Models such as those mentioned above are of a very complex nature, and there is no generally accepted model by the mining industry at the present time. Having said that however, these models are commonly applied to the equipment selection problem within the industry, although many assumptions are applied, affecting the overall optimality of the fleet.

The study undertaken by Tasman Asia Pacific [25] identifies a number of other issues relevant to the truck and shovel overburden removal for coal exploitation industry within Australia.

A study of 22 truck and shovel mines, with characteristics as shown in Table 5, was undertaken in 1997 to establish the traits of best practice mines in order to present what factors differentiate them from the lesser performing sites

TABLE 5. Key Characteristics of Participating Mines with Truck/Shovel Operations [25]

Characteristic	Queensland, AU	NSW, AU	USA
Number of seams (average)	3.5	8.0	1.7
Seam thickness, m	9.2	1.9	39.0
Powder factor (kg explosive per ton moved)	0.20	0.20	0.22
Proportion of coal and ore in total material excavated, %	30	10	40
Average size (Mt of coal and waste moved)	26	48	29
Average size (Mt of coal/ore moved)	8	5	11

It was concluded that coal mines within NSW and Queensland that operated truck and shovel for overburden removal purposes were well below the production levels of Australian metalliferous mines and US coal mines. As an example, Queensland mines were 17% below US coal mine productivity levels, and NSW were at levels 38% lower. When compared to Australian metalliferous mines, Queensland was 14% lower and NSW 35%. The major reasons for these differences included:

— excessive labor resources (over-staffing) in NSW and Queensland mines,
— higher truck utilization in US coal and Australian metalifferous mines,
— higher productive shovel loading practices in US coal and Australian metalifferous mines, and
— geological differences.

Low labor and truck productivity were considered the biggest factors influencing production levels throughout the sampled mines. Over-staffing was a particular problem in lower performing mines, which stemmed from both excessive numbers of equipment and too many operators of non-core equipment and in general duties.

The low truck productivity element was mainly a result of low utilization and poorer work and truck loading practices. These points again reiterate the importance of selecting optimal fleet sizes in order to improve production, as well as extensive operator training, so that best practices can be taught and put into practice.

This study also noted that although the overall results of Australian truck and shovel coal operations were much below US mines, some were however at or near best practice, whilst the others were well below. Table 6 identifies some of the key attributes of these better performing Australian truck and shovel coal mines, demonstrating what changes may be required from lesser performing mines in order to boost production levels and minimize costs.

As can be seen from Table 6, productivity is much less in the moderately performing mines due to a number of factors. Efficient mines use their resources intensively, particularly the labor force and truck and shovel fleet. As the results in Table 3 indicate, over-staffing, work practices, equipment utilization and loading techniques all are much better in the best practice mines. Best practice mines tend to use effective hot seat changes, take meal breaks in the field at staggered intervals and refuel during breaks. Moderately performing mines tend to not implement these practices, and have more equipment than they need, thus requiring additional staff and increasing capitalization. The better performing mines also use efficient excavation techniques such as double-sided loading of trucks, allowing significantly more excavation per shift. Spotting times under trucks were much less in these mines that use double sided loading, with up to 2,500 production hours gained per year in a typical mine with 3 excavators. These factors therefore demonstrate issues involving truck and shovel operations which, if addressed, can substantially improve productivity within coal mines.

TABLE 6. Key Attributes of Australian Best Practice and Moderately Performing Truck and Shovel Coal Mines [25]

Attributes	Best practice	Moderate practice
Total productivity	100	60
Resource levels		
Staffing levels: ratio of labor hours worked to equipment hours worked	1.5	2.1
Work time in shifts: time excluding leaving and joining shifts, meal and other breaks (percent)	92	85
Utilization of truck fleet:	45	40
Utilization of major digging equipment	50	40
Work practices		
Hot seat changes	Yes	Yes
Meal breaks in the field	Yes	No
Staggered meal breaks	Yes	No
Operators move between equipment within shifts	Yes	Rarely
Haulage equipment fuelled in breaks	Yes	No
Clean-up equipment does not impede production	Yes	No
Other indicators	> 50	0
Efficient truck loading practices: incidence of double-sided or some other efficient truck loading method (percent)	35	65
Spotting time of trucks under shovels (seconds)	185	135
Truck loads per shovel per 8-hour shift	0	20
Industrial disputes: days lost per thousand hours worked	20	50

As with draglines, technology is playing its part in truck and shovel coal operations, although admittedly it is not on as large a scale. One major step in increasing productivity is the advancement of larger trucks. Tyre technology is now the limiting factor restricting loads to around 250 tons, however 300 ton trucks are currently under trial throughout Australian coal mines. These are approximately the same cost as a 250 ton truck and offer a possible 20 % increase in productivity [26].

Another project currently being trialed throughout Australian coal mines is an automated system that can automatically measure the volume of material in the tray of haul trucks. Traditionally, the volume carried by a truck has been established from volumetric surveys of the actual mine and then divided by the number of loads, as recorded by the truck operator. This obviously leads to inaccuracies as different trucks are loaded at different levels, and this method does not take into account swelling.

This new technology consists of computer located in the field and two inexpensive scanning lasers, operational in all mining environments. The lasers are placed 3 – 4 m above the loaded truck and a 3D profile is constructed. The volume is then calculated by subtracting the 3D image of the empty tray from that of the fully loaded one. The technology is currently at a stage, where its reliability and speed is almost suitable for use on site. The in-situ volume of every haul truck can be measured without requiring the truck to stop, and resultant productivity can increase in a number of different ways, as stated by [27]: "Reschedule trucks: A mine with a variety of trays, trucks and shovels will benefit by rescheduling different haul trucks to different shovels depending on the nature of the material that is being hauled.

— Comparison of tray designs: Trays have been designed to carry material of known bulk density. In a mine these properties change and it is possible to observe how different trays can carry different material.

— Automation of dispatching systems: If both volume and weight are available to the mine-management (in real-time) then changes in truck utilization can trigger changes in dispatching. For example, if a shovel starts to dig material with a high bulk density then trucks with smaller tray should be dispatched, or vice versa."

Other uses for this technology also include load distribution characteristics, which can be used for maintenance and shovel design, load profile characteristics, which can be used to estimate utilization of the tray, and fragmentation characteristics.

As mentioned previously, technology advancements in truck and shovel operations are not as active as those dedicated to draglines, however much effort is still being put into constantly improving the method.

2.2. BUCKET WHEEL EXCAVATORS FOR OVERBURDEN REMOVAL

The final method to be discussed for overburden removal in open cut coal mines is the utilization of bucket wheel excavators, or dredgers. This will only be a brief discussion, as they are an expensive, aging technology not widely used in industry during this day and age.

The high capital involved in the purchase of a dredge, as well as its limitations in flexibility similar to draglines, make it less popular than other equipment. It is a high productivity machine, adaptable to all hauling and materials handling systems, however has long maintenance outages up to 4 months. It is a risky investment due to its low flexibility in market changes, as well as damage costs. One example of this involves a recent fire (November, 2006) in the Hazelwood open cut mine in Morwell, Victoria, which demolished a large dredge worth approximately $100 M.

Dredgers vary in size, and Australian usage is predominantly within the brown coal mines of the Latrobe Valley area in Victoria. They are generally limited to excavating material with a cutting resistance of less than 70 kg/cm, and can be used for both overburden and coal excavation.

There are a number of operational methods available for use by dredgers. They include frontal or face mining, full block mining and half block mining. Each method can then utilize either a horizontal cutting technique (terrace cutting) or alternatively, a vertical cutting technique (drop cutting). Each method and subsequent cutting technique has specific uses and affects mine design differently.

For example, the frontal method is generally used in separating soil or sub-layers requiring special placement in the backfill. It requires a long boom crowd and can also be used if stable bench slopes can be maintained and if material can be cast directly to the spoil side of the pit.

Full block mining is generally used for removal of large, thick deposits of loosely to semi-consolidated material. The dredger continuously slews across the face while the boom is crowded into the face. Terrace cutting is the more common cutting technique utilized with this method.

The face block method is commonly used when extensive layers of overburden are required to be removed using the terrace method. This method requires machines with long bucket wheel booms and is useful in the selective excavation of topsoil requiring preferential placement [14].

One mine currently still utilizing dredgers for both overburden removal and coal extraction is located within the Latrobe Valley. The mine itself is 175 m deep with a coal seam thickness of 180 m. The overburden thickness ranges from 5 – 24 m and the age of the coal seams are around 15 – 30 million years. The annual output of this particular mine is in excess of 30 Mt per year.

TABLE 7. Advantages and Disadvantages of Open Cut Overburden Techniques

Dragline	
Advantages	Reduced operating costs compared to truck and shovel. Higher overall production can be achieved. Ideal for mines with a long life.
Disadvantages	Size and capital intensive. High level of operator's skill is required. Limited to certain geological and geotechnical conditions.
Truck and Shovel	
Advantages	Less capital intensive. Ideal for mines with a shorter life. More forgiving and versatile than dragline. Can cope with irregularities in mine geology.
Disadvantages	Less production than draglines. Higher operating costs.
Bucket Wheel Excavator	
Advantages	High production can be achieved. Reduced operating costs compared to truck and shovel.
Disadvantages	Size and capital intensive. Large maintenance costs, including long term outages (approx 3-4 months). Ageing technology. Limited to certain geological and geotechnical conditions.

Dredgers are implemented on this site for the main fact that at the time, around 50 years ago, they were the best alternative due to the large coal deposits resulting in a long mine life.

3. OPEN CUT OVERBURDEN REMOVAL COMPARISONS

The above sections on overburden removal options for open cut mines have outlined the issues, considerations, advantages and disadvantages of each technique. The aim is to provide an overview of the different techniques. A summary of the basic advantages and disadvantages of the methods, when compared to each other, is shown in Table 7. It should be noted that this does not include core geotechnical risks or risks expected to be encountered with individual sites.

As can be seen, the major points regarding dragline mining are the higher production rates and lower operational costs achievable, as well the higher capital costs involved when compared to truck and shovel. They are also less flexible than truck and shovel operations and require high levels of operator skill to achieve maximum potential.

Truck and shovel operations require less capital expenditure and are generally suited to mines where a short life is expected. Operational costs are higher, however flexibility is greater when certain geological conditions are encountered or market changes take place.

Bucket wheel excavators are an ageing technology with massive capital outlays and long, expensive maintenance outages, however can achieve high productivity.

The main factors to consider when selecting equipment for overburden removal in open pit coal mines include geographic and geologic information, deposit size, coal seam distribution, mine life, production rate required, equipment availability and its compatibility with other equipment to be employed on site.

4. OPEN CUT COAL EXTRACTION OPTIONS

The previous sections on open cut coal mines have discussed the various techniques available for overburden removal. As has been made apparent in these sections, many factors influence the final equipment selection. This is also true with regards to coal extraction. Within Australia, the predominant method utilized is truck and shovel operations, comprising of either an electric shovel or loader, and large (generally 240 tons) coal hauling trucks. Bucket wheel excavators are also used for coal extraction, however not as commonly. As a rule, coal extraction should be planned so that it matches overburden removal in order for the particular mine to achieve a suitably balanced production cycle. As overburden stripping cycles are generally more responsive to small changes in a cost sense than coal hauling and loading cycles, coal excavation equipment and respective haul fleets are commonly oversized to actual production requirements to ensure sufficient support is available to recover coal production lost by stripping delays [14].

Depending on the geology of a pit, different loading, and hence, truck fleets, would be required. For example, narrow open cuts comprising of coal seams generally require loaders with a large operating reach and dumping height to load the coal hauling trucks. In this situation, loading generally starts with haul trucks sitting on the top of coal being loaded, by the loader, from the bottom of the pit. As mining progresses, both units end up on the pit bottom. In some cases, where conditions at the bottom of the pit are not suitable for loader and/or truck operations, all mining may be undertaken from the top of coal. Figure 5 shows both the loading from bottom of pit to top of coal, as well as from bottom of pit to bottom of pit.

During normal operating conditions, loaders can be replaced by cable or hydraulic excavators, as more room is available for these larger machines. If the bottom of pit conditions is unsuitable for this equipment, backhoes can even be implemented for loading from top of coal.

Technology has also been playing its part in coal removal excavation equipment, with new machines being developed which can slew, dig and travel at speeds exceeding traditional excavation equipment. They can be controlled to selectively mine layers of thicknesses ranging from 10cm up to approximately 1m.

As mentioned at the beginning of this section, similar to overburden removal, a number of parameters affect the selection of coal loading and hauling equipment. These include: thickness and stability of coal seams, presence of removable partings, and stability of bench or pit bottom, production rate required.

The equipment chosen for implementation would have specified mechanical parameters such as operating radius and dumping height, relevant to the specific conditions. Detailed planning and simulation is required, utilizing varying mechanical and operational parameters, in order to develop a mine design compatible to both overburden and coal removal operations.

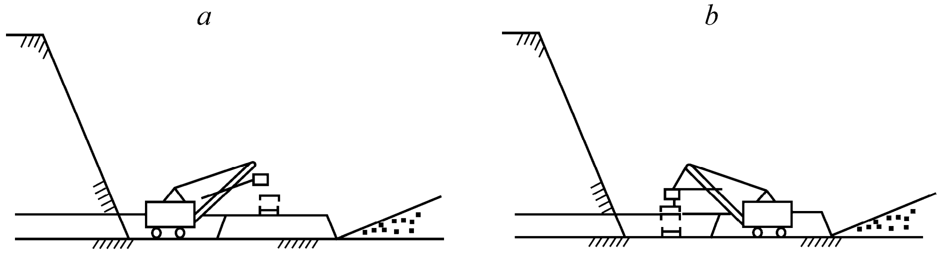

Fig. 5. Loading: (*a*) from bottom of pit to top of coal and (*b*) from bottom of pit to bottom of pit [14]

CONCLUSIONS

This paper has outlined the issues, considerations, advantages and disadvantages regarding the various opencast mining methods available in Australia for overburden removal as well as exploitation of coal. It also provides an overview of the various opencast mining methods available so that a general comparison can be made.

Draglines have low operating costs as well as higher production, productivity as compared to other mining methods but at the same time it is very expensive. It can be used only in bigger mines where high volume of coal reserves is present as well as high operator skill is required.

Truck and Shovel is less capital intensive as well as can cope with irregularities present in mine geology. It gives less production, productivity as well as has high operating costs.

Bucket Wheel Excavator also gives higher production rate with higher productivity as well as has low operating costs compared to truck and shovel, but it has higher maintenance costs as well as can be used only in limited geological and geotechnical conditions. Also, it can be used only where high volume of reserves is present due to its high costs.

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