Crushing & Conveying - A new mining technique for the Hunter

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Abstract

Open cut mining in the Hunter Valley currently faces a number of challenges. A decline in productivity over the past decade is at least in part due to maturing operations. This gives increased production at higher marginal costs and higher strip ratios. Mining operations are also getting deeper. A number of open cuts are mining to depths greater than 200 metres, with some planned to greater than 400 metres deep. Marginal cost for waste removal at these depths becomes very high.

Environmental impacts due to noise, dust, visibility and aquifer interference are a major community concern. In particular, the cumulative impact of numerous high production operations in close proximity is heavily scrutinised. Studies into the principal sources of emissions show haul trucks, the currently favoured haulage technology, in a poor light. These impacts are further exacerbated by the pressures from competing land use. A review of the strategic regional land use plan indicates that most of the potential open cut areas, not contained in current mining leases or exploration licenses, fall within strategic agricultural land.

Crushing and conveying of waste may provide one solution to these issues. The concept is not new, with many applications in metalliferrous mines, as well as some Australian coal mines. The system components are well developed, with a number of equipment suppliers having proven expertise and products.

Limitations of waste conveying systems centre on lack of flexibility. Mine designs need to adapt to the system requirements and cannot be easily altered. The advantages, however, include reduced costs and reduced noise, dust and visibility impacts. The key innovation required is in developing a suitable mine plan to take advantage of the capabilities of this mining technology.

Challenges for Open Cut Mining

Open cut mining in the Hunter Valley currently faces a number of challenges. These include cost pressures due to reducing productivity from mature operations that are mining deeper resources. They also include community concern over environmental impacts such as noise, dust, visibility and aquifer interference. These impacts are further exacerbated by pressures from competing land use.

Over the past decade open cut mines in the Hunter showed a dramatic decrease in productivity (**Hartcher C., 2010, and Obeid E., 2002**). ***Table 1 – Recent Changes in Productivity from Hunter Valley Mines*** shows a decline in productivity over eight years, expressed in ROM tonnes per man year, of greater than 25% for shovel & truck operations and 45% for dragline operations. This compares with no change in longwall productivity and only a slight decline in pillar mining productivity. In fact, productivities are now very similar for dragline and shovel & truck operations.

Table 1 - Recent Changes in Productivity from Hunter Valley Mines

Working Method	2000-01		2008-09		Change	
Classification	Mines	OME	Mines	OME	Mines	OME
Dragline	6	24,315	6	13,198	0	-46%
Shovel	12	17,500	17	12,932	5	-26%
Longwall	10	8,663	7	8,762	-3	1%
Pillar	8	4,989	6	4,461	-2	-11%
Dragline & Longwall	2	15,210	1	8,060	-1	-47%
Shovel & Longwall	-	-	3	7,423	3	0%

(OME – Output per man employed as tonnes/man-year)

Potential causes include the maturing of mining operations combined with the impacts of pressure to increase production due to continued high coal prices. The result of these factors is increased:

- prestrip in dragline operations;
- strip ratios and waste removal requirements;
- production at a higher marginal cost; and
- overheads.

Unfortunately, the impact of marginal costs is often poorly understood in the mine planning process. This can lead to inappropriate mine planning decisions. Marginal cost is the cost of the next increment of production, depth, etc. To evaluate marginal costs effectively one must consider the additional costs associated with incremental production or depth of cover. These marginal costs determine whether the increment is economic. Use of pit optimisation, block ranking or other tools does not sufficiently evaluate the economic decision.

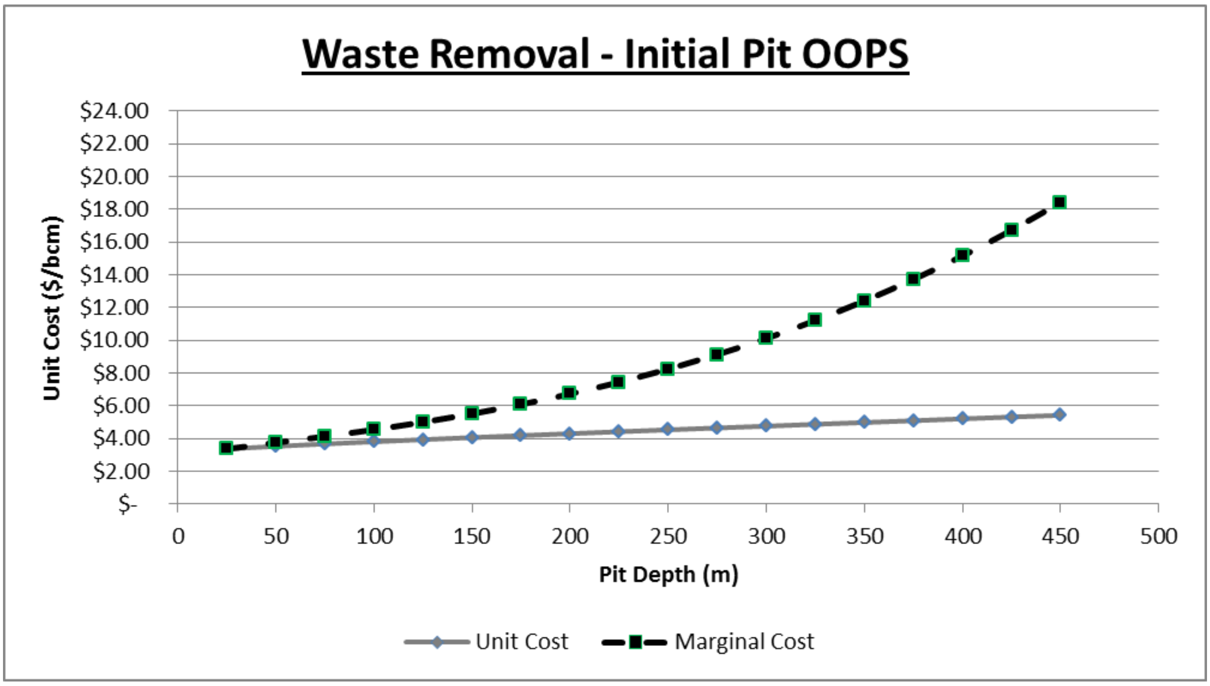
Deeper Operations

A feature of the Hunter coalfield is the large number of economic coal seams. These exist in three thick coal measures: the Greta coal measures are generally 100 metres thick, but can be up to 400 metres thick; the Singleton supergroup is up to 1,450 metres thick; and the Wollombi or Newcastle coal measures are up to 400 metres thick (**Knight et.al., 1975**). All open cut mines extract coal from multiple seams. Strip ratios often do not vary greatly as the mine progresses deeper, due to the introduction of additional coal seams.

The competence of coal measures rocks commonly favours deep open cut mining. Recent investigations of deep open cut stability have indicated that open cut excavations of 300 to 400 metres are possible with wall angles exceeding 45 degrees (**Holt and Coulthard, pers. comm.**). Because of favourable geological and geotechnical conditions a number of open cut operations are currently mining to depths greater than 200 metres. Some open cut mines are planning ultimate depths in excess of 400 metres.

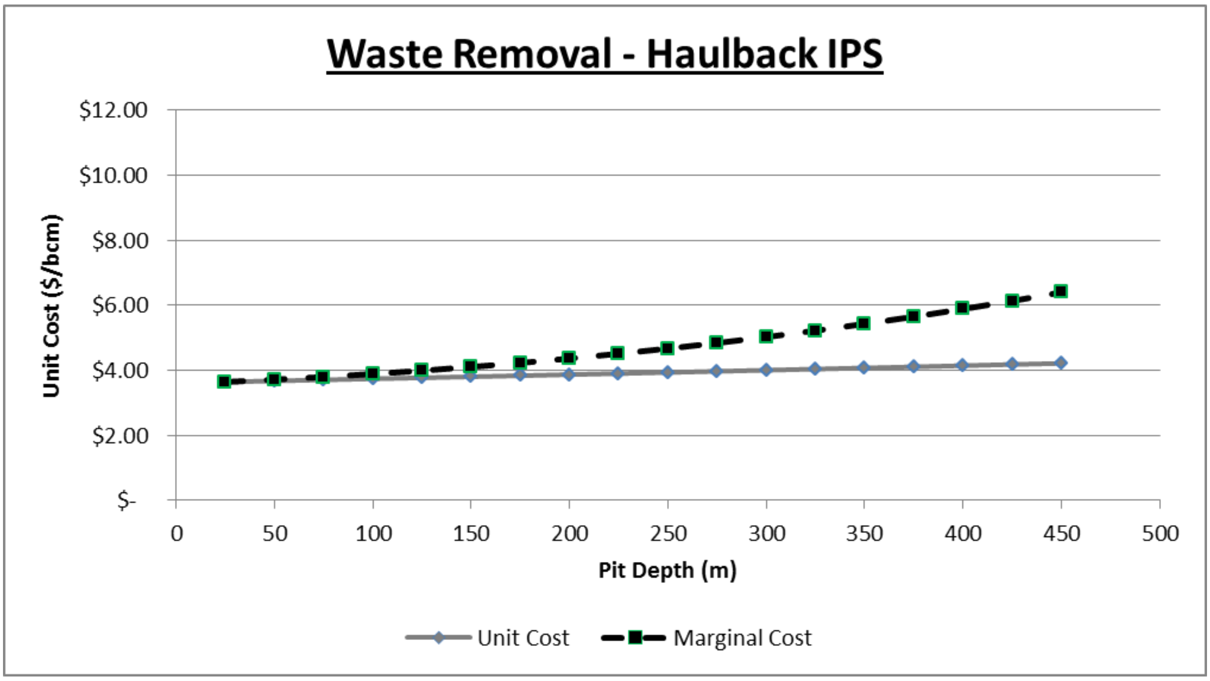
Mining to greater depths carries significant marginal costs for shovel & truck operations. Marginal costs will, of course, vary with the details of the mine design. Two indicative models demonstrate the change in marginal cost with increasing mining depth. The first is a model that simulates the increasing unit cost of waste removal from a pit with a 300 x 300 metre base as the pit becomes deeper. Waste is dumped in an out of pit pile adjacent one edge of the void. This gives an indication of the ever increasing cost of creating a deeper void ***Figure 1 - Marginal Cost of Waste Removal for an Initial Pit***. Marginal costs of mining deeper increase at a significantly greater rate than average costs.

Figure 1 - Marginal Cost of Waste Removal for an Initial Pit



The second model simulates the increasing cost of waste removal from a haulback operation as the base of pit becomes deeper. Waste is hauled around the pit ends to minimise the change in elevation between dig and dump. Marginal costs of mining deeper do not increase as rapidly ***Figure 2 - Marginal Cost of Waste Removal for a Haulback Operation*** as in the previous model, but are significantly above average costs at depth. Marginal cost variation with depth will be between these two extremes for most operations.

Figure 2 - Marginal Cost of Waste Removal for a Haulback Operation



Environmental Impacts

Community concern over the cumulative environmental impacts of mining in the Hunter has led to tighter controls on mining operations. This trend is likely to continue. Dust, noise, visibility and aquifer interference are the principal impacts that can be controlled, to some degree, during mine planning.

The NSW Office of Environment and Heritage commissioned a benchmarking study into dust minimisation in the NSW coal industry (**Katestone Environmental, 2011**). This confirmed coal mining as the largest emitter of particulate matter (as PM_{10}) in the greater Sydney metropolitan area. The largest source of PM_{10} from coal mining activities is haul trucks travelling on unpaved roads (40%), followed by wind erosion of overburden (27%), bulldozers (8%), blasting (6%) and trucks dumping overburden (4%).

Katestone indicated that dust emissions could be reduced by over 50% by measures such as:

- application of suppressants to haul roads (21%);
- conversion of 50% of haul roads to conveyors (20%);
- replacement of current fleet with larger capacity vehicles (10%);
- rehabilitation of 80% of overburden emplacements (20%);
- full rehabilitation of other exposed areas (3%); and
- reduction of other smaller contributors.

The Australian Department of the Environment published a best practice guide for noise, vibration and airblast control (**Needham and Brooks, 1998**). It outlined nine principal measures for controlling noise and six means of reducing vibration and airblast. The control measures that pertain to mine planning are to:

- select low noise plant;
- provide additional silencing of fixed and mobile plant;

- provide acoustic enclosures around process plant;
- optimise mine layout to shield noise generating plant and haul roads; and
- provide bund walls for acoustic screening.

Visibility is coming to the fore as a key concern for some stakeholders. Far from being an irritant, clearly visible mining operations detract from the clean, green image valued by the customers of some Hunter businesses. Being able to hide, or mask, the most obtrusive aspects of mining will become an ever increasing objective of mine planning.

Aquifer interference is a major concern in any rural community dependent on groundwater. In the Hunter, most water is sourced from runoff or near surface alluvial aquifers. Open cut mines are restricted from mining alluvial lands. The connectivity between the deep aquifers that are affected by mining and the shallow alluvials is the main concern.

Clearly, dust and noise from open cut mines are minimised by operating as few trucks as possible on short hauls within the mining pit below ground level. High productivity can then be best achieved by use of the largest equipment sizes available, with additional benefits in dust and noise reduction due to fewer operating units. These measures require minimising exposed areas, which can have added benefits in reducing operation visibility.

Competing Land Use

Competition for land use comes from the Hunter's key industries of mining and agriculture as well as national parks, urban areas, electricity production and industrial areas. The main mining interests include coal mining and coal seam gas as well as other mining. Agriculture includes dairy, beef cattle, pasture production, associated service industries, horse breeding, viticulture and wine making.

The Strategic Regional Land Use Plan, prepared by the NSW government, (**O'Farrell, 2012**) indicates that 39% of the Upper Hunter, not tied up in National Parks (19%), is amenable to coal mining. The same area is also of interest for coal seam gas. Strategic agricultural land is defined as those areas having a high biophysical value (8.8%), largely river flats and high fertility areas, and critical industry clusters. The two critical industry clusters defined for the Upper Hunter are equine (9.7%) and viticulture (4.4%).

Most of the strategic agricultural land is situated in areas with potential for coal resources (13.9% of the Upper Hunter). Of these areas 4.4% has potential for open cut mining and 9.5% for underground mining. Almost no land, with high prospectivity for open cut mining, that is not conflicted with strategic agricultural land exists outside of current mining and exploration tenements. The exception is the Ulan – Wollar – Bylong corridor.

If open cut production is to increase, it must come from existing tenements. This will necessarily entail making use of deeper resources as well as resources with higher strip ratios. Current open cut mining technologies are not up to the task. A new open cut technology is required to allow lower cost mining from greater depths. The alternative is for open cut mining to decline and be replaced by larger and more extensive underground operations.

The Underground Alternative

There can be little doubt that technological advances made in underground mining will continue. With some restraint on overheads this should translate into increased productivities and reduced cost of mining. It should also translate into a larger proportion of total coal production from underground mining. The selection of underground mining, however, is essentially a strategic decision and is not a panacea.

Underground mining does have significant environmental benefits compared with open cut mining. It has reduced dust and noise emissions as well as reduced visibility. For a given output, underground mines generally require a larger areal extent and may not improve aquifer interference. Subsidence can also be a significant issue.

Longwall mining is particularly inflexible, requiring very specific conditions for successful application. The result is poor overall resource recovery, especially compared with open cut mining that recovers most coal seams. Since underground mining generally recovers coal from only one seam at a time, marketing and blending requirements may also make underground mining of a deposit undesirable. In many deposits geological and geotechnical conditions are unsuited to high productivity longwall operation. Due to the factors limiting underground mining, the quantity of underground reserves may be insufficient to justify establishment of a mine in many areas.

Crushing and Conveying of Waste

Crushing and conveying of coal and waste is one technology that offers the potential to meet the challenges facing open cut mining in the Hunter. It offers the potential to significantly reduce dust and noise emissions and, with careful mine design, can improve visual acuity.This technology also offers the potential to mine from greater depths at significantly lower marginal unit costs than existing mining methods.

This mining technology is not a new concept. The components are similar to the fixed crushing and conveying systems for ROM coal at most mining operations. A fully mobile coal crushing and conveying system commenced operation at Ulan in 1982. Changing market conditions eventually led to the crusher being used in a semi-mobile configuration and fed by trucks, rather than directly by a rope shovel. Fully mobile waste crushing and conveying systems were installed at Goonyella in 1991 and at Clermont in 2010. The Clermont crusher is initially being used as a semi-mobile crusher fed by trucks. It will transform to a fully mobile system fed by a rope shovel once the box cut is complete (**Küng, 2009**). The first large scale semi-mobile waste crushing and conveying system commenced in 1984 at Mae Moh, an open cut coal mine in Thailand (**Schröder, 2003**).

System Components

All crushing and conveying systems are composed of discrete components connected in series. Many of these components come from bucketwheel excavator systems used in brown coal mining in throughout the world. The key system components are:

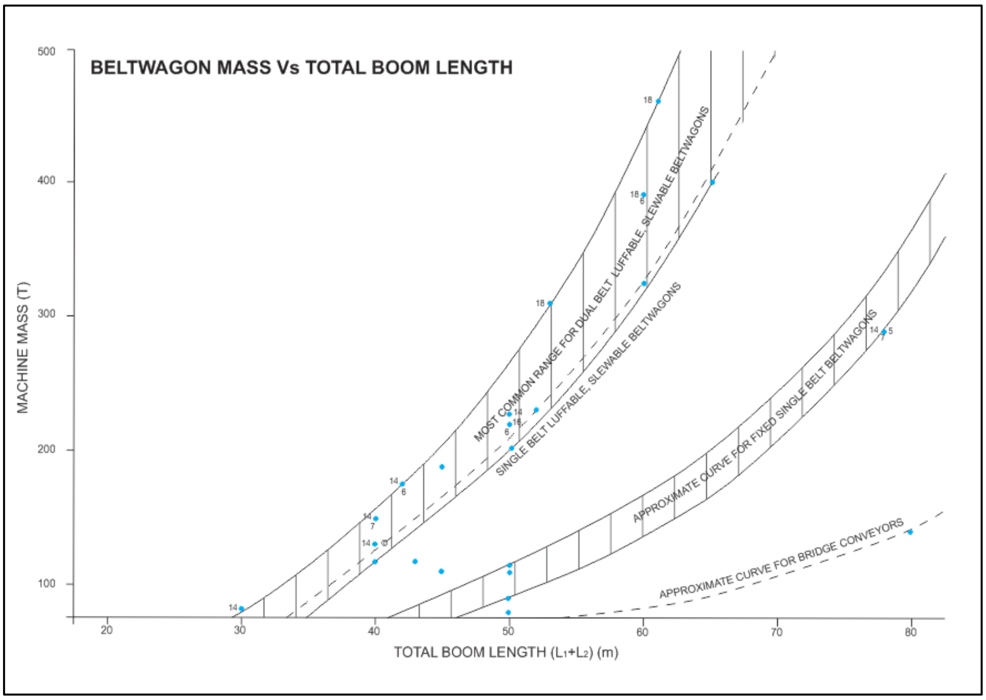
- **Crusher –** Crushers may be fixed, semi-mobile or fully mobile. Fixed crusher installations have little application within the pit since they cannot follow the mining face. Semi-mobile crushers are loaded by trucks and generally require a dump pocket to be developed. Relocation is generally in sections using a crawler transporter. To minimise the cost of earthworks construction and maximise productive time, the interval between relocations should be as large as possible. Mobile crushers are generally mounted on crawlers and can relocate rapidly enough to be fed directly by the loading unit, thereby negating the need for trucks.

Mobile crushers were originally developed for quarries, where the product required crushing. Throughputs were generally lower than 1,000 tph and the crushers employed were hammer, impact, or occasionally double rolls. The propulsion mechanisms were rubber tyres, crawlers, or hydraulic walking feet for larger crushers. For larger crushers in harder rock, gyratory or jaw crushers were required. High capacity mobile crushers (up to 12,000 tph) are now possible due to the development of high capacity sizers, double roll crushers and hybrid crushers (**Tutton and Streck, 2009**). These have lower vibration and are amenable to use in a mobile crusher mounted on crawlers.

- **Beltwagons and Bridge Conveyors –** These are used to provide a flexible connection between the crusher and the moveable components of the conveyor system. They can allow a greater block width, increased separation between blasting and the conveyor line, and additional benches extracted from the one moveable conveyor location.

These come in varying designs depending on the application. Beltwagons may be dual or single belt, luffable and slewable for maximum flexibility in negotiating bench changes. Longer boom lengths are required for greater elevation changes. Fixed single belt beltwagons are less flexible and allow an increased block width. Conveyor bridges are less mobile than beltwagons, having two sets of crawlers. They do, however, come at a significant cost reduction **Figure 3 – Variations in Beltwagon / Conveyor Bridge Weight with Boom Length and Capacity**. A bridge conveyor able to negotiate a given bench height can be a quarter the cost of an equivalent beltwagon.

Figure 3 – Variations in Beltwagon / Conveyor Bridge Weight with Boom Length and Capacity



- **Relocatable Conveyors –** Relocatable conveyors are less flexible and less costly than bridge conveyors. They may be crawler, rubber tyre or skid mounted, with a number of units being required in series to negotiate the distance from the beltwagon to the main conveyor. Relocation and system delays, due to the number of conveyor transfers, are a key drawback to this equipment (**Tutton and Streck, 2009**). Piggyback conveyors are more common in smaller capacity systems.

- **Shiftable Conveyors –** Conveyor segments mounted on sleepers connected by rail can be readily shifted using bulldozers with a track shifting head. The drivehead is most commonly mounted on pontoons and relocated with the assistance of a transporter. Shiftable conveyors are used for long, straight dig or dump faces, relocated at regular intervals.

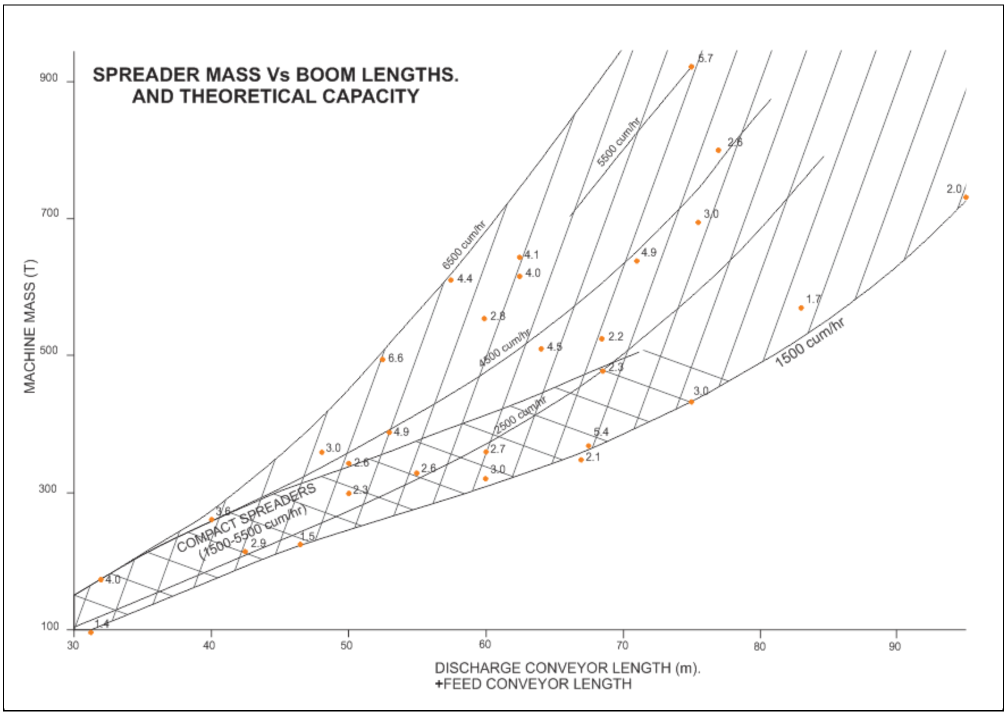
- **Hopper Car and Cable Reeler –** Is necessary in a fully mobile crushing system to allow feed to be placed on the shiftable conveyor at any point along its length. This unit commonly comes with a cable reel car to handle power cable and other systems.

- **Overland Conveyor –** Significant advances have been made in overland conveyor design in the areas of optimisation, implementation of curved conveyors, noise reduction and dust reduction. Conveyors represent the heart of the system and give major improvements over truck transportation necessary for the future of deep open cut mining in the Hunter.

- **Tripper –** A tripper is necessary to remove the overburden at any point from a shiftable dump conveyor.   It may be rail or crawler mounted and can incorporate a discharge conveyor to allow more flexibility for the spreader. The tripper can also incorporate a belt take-up and dump conveyor drive.

Spreader – Spreaders come in a wide variety of designs depending on the nature of the overburden handled, geotechnical requirements, throughput rate and the desired block width between moves. ***Figure 4 – Variations in Spreader Weight with Discharge Boom Length and Capacity*** gives an indication of the variation of spreader weights with boom length, capacity and design.

Figure 4 – Variations in Spreader Weight with Discharge Boom Length and Capacity



Limitations of Crushing and Conveying Systems

The two main limitations of these systems are high initial capital and reduced flexibility compared with truck and shovel techniques. For long life mines, however, the capital requirements are generally neutral when truck replacements are taken into account (**Oberrisser, 2009**).

The flexibility of fully mobile in-pit crushing and conveying systems (IPCC) is much lower than semi-mobile systems. Fully mobile IPCC systems generally require a shiftable face conveyor. This limits the layout to straight faces that are generally 1.5 to 2.5 km long as a compromise between frequency of face moves and conveyor capital. Benches need to be approximately horizontal with little flexibility to accommodate coal horizons.

Blasting is always in close proximity to the face conveyor, with most blasts needing to be buffered (or choke) blasts to minimise flyrock damage. The Goonyella IPCC system removed a 25m high overconsolidated horizon that did not require blasting, or only required light blasting. The Clermont IPCC system is designed to remove three benches, with the assistance of a beltwagon, for a maximum waste thickness of 55m. This requires a very significant amount of shot ground inventory, as the bottom two benches are blasted before the conveyor is relocated to the new dig location (**Atchison and Morrison, 2011**).

A fully mobile IPCC is also constrained to annual productivities of between 15 and 25Mbcm, depending on the loading shovel employed. This, combined with the limitation in face heights, blasting constraints and difficulty in accommodating coal seams, makes a fully mobile IPCC system difficult to employ in a deep multi-seam mine. The use of piggyback conveyors may improve flexibility at the expense of complexity and technical risk.

The use of fully mobile IPCC in deep open pits is somewhat contested. **Tutton and Streck (2009)** dismiss them as unviable due to inflexibility leading to sub-optimal mine development. **Morrison (2009)** believes that the use of piggyback conveyors and extendable bench conveyors may be feasible. Regardless of the feasibility, the technical and production risks associated with application of fully mobile IPCC systems in deep open cut mines makes them an unlikely prospect for early adoption.

Relocation of semi-mobile crushers is the key inflexibility inherent in these systems. The relatively rapid advance rate of mining faces in open cut coal mines, combined with the need to advance multiple benches, lead to frequent crusher moves. Each move requires up to one week for completion and may cost up to $1.5M in civil construction. Metalliferrous operations using semi-mobile IPCC systems attempt to limit crusher moves to every 6 months to 10 years (**Chadwick, 2010 and Tutton and Streck, 2009**).

Advantages of Crushing and Conveying Systems

For deeper open cut mines IPCC systems offer the potential to: reduce costs; reduce dust and noise emissions; and improve visual acuity. A fully mobile IPCC system has lower costs than a semi-mobile system. Based on Hunter Valley conditions, a fully mobile IPCC system will give a lower net present cost (NPC) than a shovel supported by four to six trucks, depending on the configuration of the IPCC system. A semi-mobile IPCC system has a lower NPC than a shovel supported by seven trucks. Longer hauls are more cost effective using an IPCC.

Both dust and noise emissions are more controllable with conveyors than with mobile equipment. Dust suppression can be by water sprays, covers / enclosures, efficient belt cleaners, suction / filters or by electrostatic dust suppression. Noise can be reduced by more than 25dBA/m by conveyor optimisation, improved idlers, variable speeds, preventing harmonics and specially designed soundproof enclosures.

Equipment controls, however, are not the whole story; careful mine design is essential. The supplementary EIS for Clermont coal mine (**Rio Tinto, 2005**) indicated that the IPCC system, with no noise or dust suppression, gave no detectable improvement in dust or noise emissions over the original truck and shovel mine plan. On the other hand, a proposed mine plan involving an IPCC at a Hunter Valley mine, with suitable emissions controls, gave significantly reduced levels of PM_{10} dust. It was the only mine plan that could maintain emissions within departmental guidelines at nearby residences.

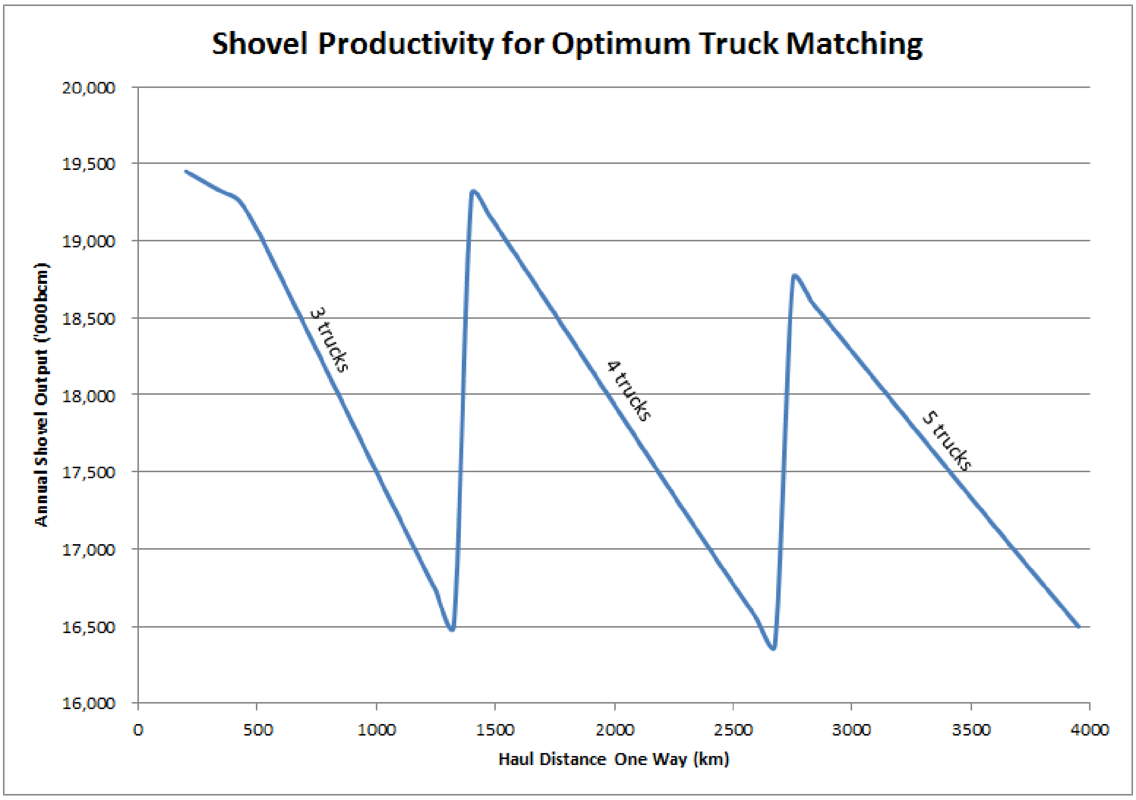
The reduced cost of haulage using conveyors allows out of pit spoil to be transported further to be placed in less visibly intrusive areas. The ability of conveyors to create a full height dump, rather than building from the base up as with trucks, can assist with more rapid rehabilitation. This also applies to surcharging in-pit dumps created using other equipment.

Innovation in the Mine Plan

IPCC equipment and systems are not new, with successful operations dating back 30 years. The main innovation required to successfully apply this mining method to deep Hunter operations is in mine planning. The mine plan needs to be developed to suit the equipment; not the other way round. Key drivers in devising the mine plan are:

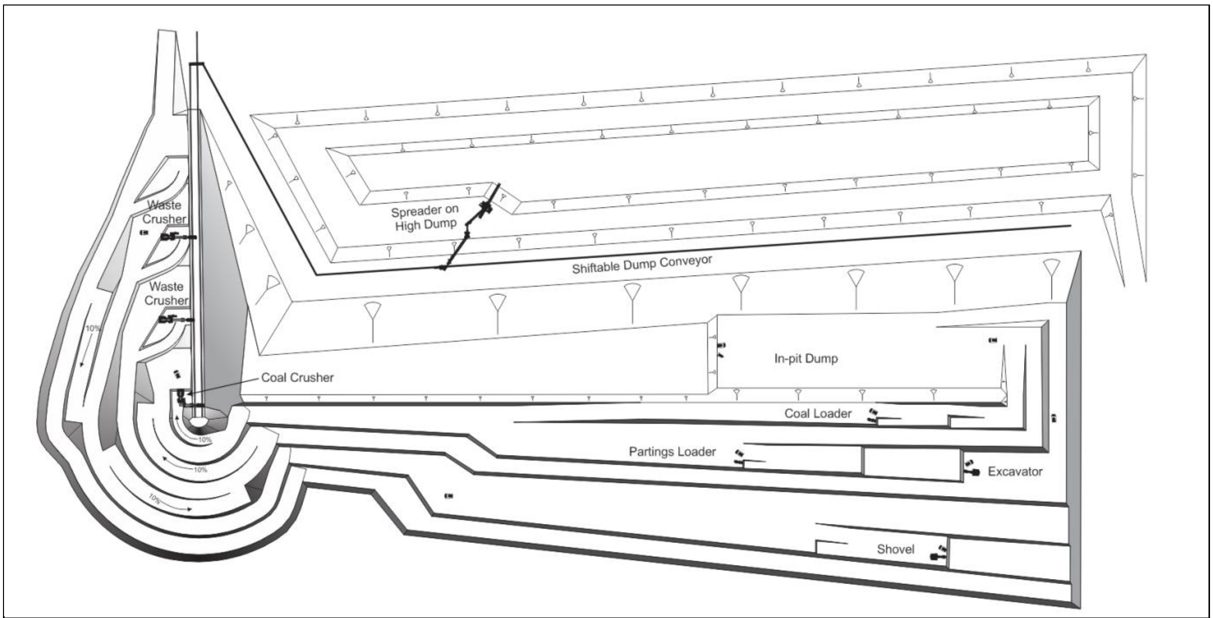
- The maximum haul distance should be around 1.5km, with the minimum change of level on the haul possible. As haul distance increases the optimum number of haul trucks increases. To minimise costs, truck numbers should be minimised. ***Figure 5 – Optimum Trucking with Increasing Haul Length*** shows that a three truck fleet is optimum to a haul length of about 1.3km.
- Dump pockets should be relocated as infrequently as possible. This requires a fixed conveyor ramp for an extended period. A conveyor ramp relocation interval of between 10 and 20 years is feasible with careful mine design.
- Waste from all upper benches should be conveyed, since these are the benches with the longest haul distances and greatest elevation. Lower waste benches should be able to be hauled to in-pit dumps with minimal elevation change. In-pit hauls should be available for times when the IPCC system is unavailable.
- Trucks and shovels should operate below topography at all times to maximise visual, dust and noise screening.
- Surface conveyors and equipment should, as far as possible, be shielded from neighbours to reduce noise and improve visual amenity.
- Dumps should be created to allow rehabilitation as close as possible to the working face to reduce dust emissions.
- Working faces should be maintained as steep as possible, commensurate with maintaining adequate inventories and working room. This minimises exposed areas and assists with reduction of dust.

Figure 5 – Optimum Trucking with Increasing Haul Length



An example of a mine design to suit a semi-mobile IPCC system for a deep open cut operation in the Hunter Valley is shown in ***Figure 6 – Typical Pit Layout for A Deep Open Cut Operation in the Hunter Valley***. The figure shows steady-state pit operations after commencement of in-pit dumping. The fixed conveyor ramp has four dump pockets located at 30m vertical intervals. Semi-mobile waste and coal crushers are relocated between these levels as required. The conveyor ramp can be at grades up to 25%, although a reasonable compromise between minimising ramp excavation and conveyor maintenance would be around 15%.

Figure 6 – Typical Pit Layout for A Deep Open Cut Operation in the Hunter Valley.



Lower benches are short hauled to in-pit truck dumps. This can use either a rehandle bridge or endwall roads. Upper benches can also use high level endwall roads (not shown) to access short truck dumps and bypass the conveyor system. Elevation of waste to surcharge the in-pit spoil is done using conveyor haulage to minimise cost.

Rather than a parallel advance, the mining and dump faces progress radially around the ramp conveyor. The mine design makes maximum use of the IPCC where it can provide reduced costs, while allowing direct dumping by trucks where this is the most efficient. The plan shown is for a 200m deep operation, but is suitable for pits as deep as 400m with only slight increases in marginal costs.

Conclusions

Changing conditions in the Hunter Valley are forcing open cut mining of deeper resources. A new mining technology is required to ensure continued economic operations that address community concerns of environmental impact. Underground mining is one option, but leads to poor resource recovery and is not universally applicable.

Using a semi-mobile IPCC system teamed with conventional truck and shovel operations promises to provide suitably low costs in deep open cut mines. It can also allow better management of environmental issues. The mining technology is not novel and carries little technological risk. Numerous examples of successful operations using IPCC exist throughout the world. The main innovation is in adapting the mine plan to suit the less flexible conveyor haulage systems.

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