THE SYSTEMIC INTERDEPENDENCY OF CLOSURE DECISIONS AT SHAFT LEVEL

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Abstract
In an environment of constant to declining real metal price, working costs that are escalating at a rate greater than inflation and declining grades, decisions are being made to rationalise production through the closure of working sections and/or shafts. This rationalization tends to be guised as an optimisation process aimed at enhancing overall value and/or short-term profitability. The closure of working sections however ultimately impacts both variable and fixed working cost structures across the section, shaft, mining complex and in large corporations, the Group. Should a shaft be closed when it can no longer carry its direct and overhead costs or are direct costs the only factor?

This paper identifies and investigates the systemic links that exist between shaft, mine complex and mining group cost structures which impact on the financial modelling of value optimisation of mining operations. Evaluation of the impact of a shaft closure on the mine's NPV offers some interesting insights into the decision making process involved. It is concluded and demonstrated that it is crucial to understand the systemic interaction of cost structures across the mining enterprise to execute effective, tactical and strategic, value optimisation.

1. INTRODUCTION

The decision to close a working section, shaft or mining complex requires, amongst other aspects, a good understanding of the interdependency of mining infrastructure and associated costs. Initial efforts are usually directed at optimisation of the production entity at logical levels such as a mining section or shaft with the optimisation process leading to life extension or early closure. This optimisation process should indicate the potential timing of shaft closures, if necessary, to create value. The validity of this timing is however dependent on the optimisation modelling correctly reflecting the interdependency of infrastructure and associated costs.

2. OPTIMISATION AND THE "HILL OF VALUE"

Optimisation is about trade-offs in order to achieve a desired outcome whether it be profit maximisation, value maximisation, capacity utilization or a host of other objectives. The process entails the allocation or configuration of independent and interdependent resources in order to maximise (or minimise) the specifically desired objective (Ballington *et al*, 2004).

In many respects an underground mine is similar to a factory in that a specific process is repeated over a cycle. A core difference however is that there is generally only one entry and exit for all men, materials, service requirements and product – the shaft. This shaft infrastructure has a large fixed cost component which, regardless of throughput, has to be distributed across the production areas in that shaft. Similarly the infrastructure that connects individual shafts in a complex has a fixed cost component which must be distributed between the individual shafts for reallocation to the working areas below the collar. This interdependency has major implications regarding optimisation and cost reduction.

The authors view the "Hill of Value" concept as described by Hall (2003), Ballington *et al* (2004) and Smith and Ballington (2005) as the starting point for any optimisation study, bearing in mind that this "Hill of Value" is a roadmap to optimal extraction configurations and not the sole solution to value enhancement.

The 'Hill of Value' (Figure 1), a 3D surface, is generated from multiple scenarios that are evaluated using an economic model where only two chosen variables are adjusted and plotted on the 3D surface to measure an objective function. The surface is valuable as it will highlight local maxima/minima that may not otherwise be identifiable in a conventional 2D chart with only two variables plotted

The optimal point on the "Hill of Value" is an indication of where a maximum/minimum of the objective function (value, unit cost, capital investment, or another chosen variable) may lie. The exact nature of this theoretical point must still be characterised through detailed planning and feasibility studies as, for pragmatic reasons, a lower point may only be feasible. Additionally the optimal point may have very steep drop-offs on either side making this a riskier choice than choosing a point that is flat on either side allowing for variability in the underlying variables without major sensitivity to the objective function.

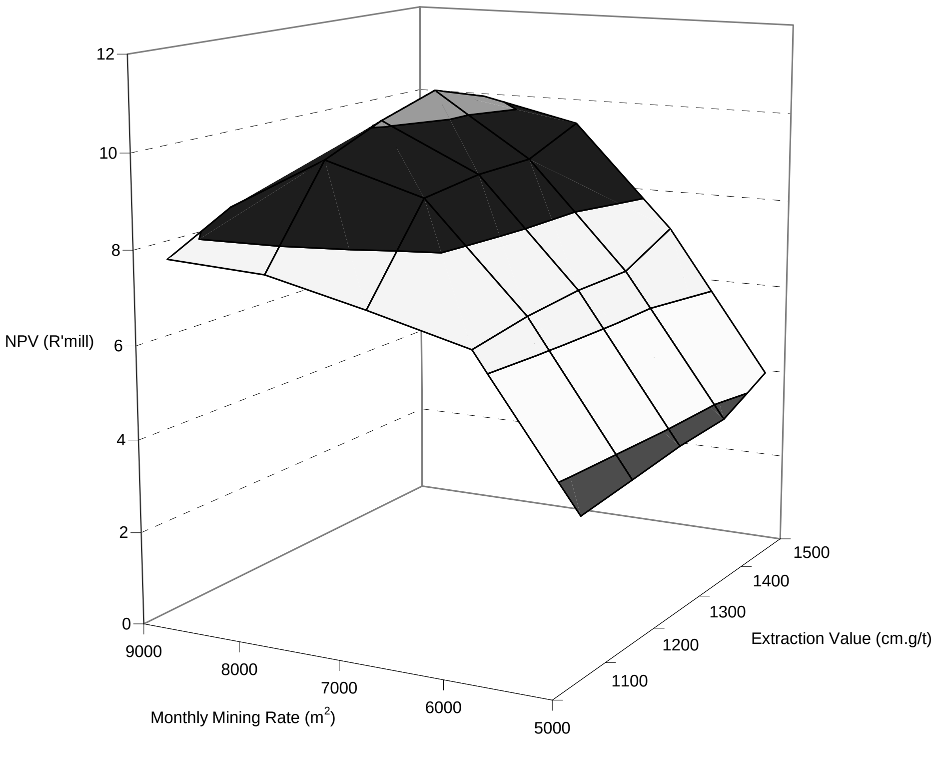

Figure 1. Hill of Value indicating an optimal value position.

A 'Hill of Value' optimisation process, at shaft level, needs to take into consideration the interdependency between mining areas. No mining area, whether it is a mining level, shaft, or mining complex, is independent of other mining areas. With the substantial infrastructure required for deep level mines there is, inevitably, sharing of utilities (pumping, ventilation, refrigeration, hoisting etc).

The optimisation of a shaft may yield a different optimal point, on the value surface, where individual levels are not actually mined at their individual points of optimality. Here the constraints around shaft capacity, total ventilation availability and ore transfer capacities limit the number of and mining rate of levels. The same applies to the optimisation of an operation containing a number of shafts where surface logistics and treatment capacities may again dictate a different optimal point. In essence the sum of the parts does not equal the value of the whole.

The interrelationship of surface infrastructure can result in situations where production decisions at one shaft directly impact another. For example increasing the mining rate from a shaft may increase its value but reduces overall life of mine. This reduction in life implies that in the future when production is terminated, and therefore not contributing to surface infrastructure cost, that there will be an increase in cost to the remaining shafts if the total fixed cost is not proportionally reduced. This proportional reduction in fixed costs is often difficult to achieve as step reductions in installed refrigeration capacity, for example, may not be synchronised with the shaft closure. This results in a net increase in cost to the remaining shafts, which for a marginal operation, may in turn become uneconomic.

In this circumstance, a short term decision, possibly influenced by short term moves in commodity prices, has a long term impact that is often not understood or inadequately captured in value optimisation simulations. Invariably there is a need to harmonise extraction rates in mining complexes where there is shared infrastructure. As optimisation moves from the individual production area to a mining complex level the number of permutations within a scenario increases exponentially.

For example, the optimal configuration of a mining complex should result in every shaft having a unique volume and pay limit which may differ from the individual shaft production areas optimal points. An approach could be to keep all the high value shafts at their optimal points and sacrifice volume and paylimit (ultimately value) on the lower value shafts. This would need to be tested by running permutations with each permutation being a point on the ‘Hill of Value’.

It is important to note that the optimisation of an individual shaft may thus be to the detriment of another and therefore careful notice has to be taken of the interdependency between the component parts of a mining complex.

3. INTERDEPENDENCY

As mines age, there is a continual drive towards real cost reductions. This is often achieved through reducing the surface footprint whilst maintaining access to the mineral resource. As the footprint reduces, fridge plants, pumping facilities and metallurgical facilities are closed in an attempt to utilise full capacity of the remaining infrastructure whilst not hindering the production process and thereby reduce costs.

It is imperative that a full understanding of infrastructural interdependency is obtained prior to the implementation of footprint rationalisation. For example shafts tend to be interconnected within a mining complex therefore making it possible to move men, materials, rock etc. between shafts. A decision to close a shaft hoisting facility where production is declining and cross tram this production material to adjacent shafts may be the wrong decision if the shaft is still required for pumping or other logistical purposes.

In order to accrue full economic benefit from infrastructure reduction it is necessary that there is no residual dependency on the infrastructure – from a logistics or flexibility perspective.

4. ALLOCATED COSTS AND INTERACTIONS WITH SHAFT CLOSURES

The decision to close a mining level, shaft or even a mining complex may be based on valuations that have inappropriate direct and allocated cost assumptions owing to a lack of understanding of interdependencies. The inappropriate use of these cost metrics can be ascribed to there being a number of varied definitions in existence describing similar concepts. To prevent misunderstanding the following definitions have been applied in this paper.

Direct costs are those costs directly related to the production process. These costs effectively disappear once production ceases. This metric includes the variable costs which are associated with the shaft infrastructure, logistics, processing function and some of the overhead costs that are variable.

The non production related fixed costs incurred at a mining operation are referred to as the *overhead costs* and these costs tend to be incurred irrespective of the level of production. Further, for accounting purposes, these overhead costs need to be carried by a production entity (shaft, level, workplace etc) and are therefore also referred to as *allocated costs* once reassigned to the production entity. There may be a relatively small portion of these costs which are actually variable but treated as fixed for planning purposes.

The *contribution* metric is defined as revenue derived from metals, less the direct costs, representing the quantum of money that is available to cover the overhead fixed costs.

A misconception that often arises is that certain overhead costs disappear when a mining entity is closed or in the extreme case where an entity is closed based on a full allocated cost assessment (which assumes all the allocated costs will disappear). There is also a view that shaft closures should be made on the basis of the direct underground costs only. This argument is based on the belief that the processing facilities at a mine would need to operate anyway whether that shaft is supplying material or not, as long as other shafts at the mine remain operational.

A full understanding of cost behaviour and what constitutes fixed and variable costs through the complete mining value chain is required to accurately model and make decisions on shaft closure. The misconception that a direct cost is all cost items directly related to mining and surface costs being allocated costs can lead to the incorrect decision to close a shaft. When a shaft is closed, all shaft variable and fixed costs should go away, unless that shaft is on care and maintenance or is required to service other shafts for pumping etc. Those surface costs that are directly related to that shaft whether variable or fixed are expected to disappear although increased production from other shafts to supplement the shaft closure may result in an increase in the variable component of costs which need to be allocated back to the remaining shafts.

The truly fixed cost component of a shaft should never disappear if production occurs, irrespective of the quantum of this production. There may however be step functions to this fixed cost metric at different production levels. So the decision to shut a shaft should be based on that shafts contribution which takes direct costs and direct capital investment into account.

From an accounting perspective all surface fixed costs are allocated back to the production shafts. This is acceptable for cost accounting purposes but can be misleading when conducting valuations for closure decisions. Therefore in an economic model it is recommended that either surface fixed costs are <u>not</u> allocated back to shafts or that two levels of contribution reporting are catered for where decisions around shaft closure can be made based on the relevant contribution level.

If it is assumed that real metal prices will decline over time, the natural reaction is to seek cost reductions through closure of loss making shafts. In some instances this is only considered from a short-term perspective and on an individual shaft basis. Mining is however a long term business and often the potential long-term repercussions are generally not understood or acknowledged. Not withstanding the option price potential of the shaft that is not covered in this paper, the short term gain may in fact destroy long term value by making mineral resources towards the end of the life of mine, on the remaining shafts, uneconomic to mine. In fact all decisions relating to closures or even mining of the shaft pillar must be assessed from the perspective of the full life of mine plan. Often profitable reserves that could have been mined now are left, never to be mined at the end of the life of mine due to insufficient volumes to cover surface fixed costs.

The same argument can be used for decisions relating to configuration and closure of levels within a shaft. The scheduling and sequencing of levels within a shaft is critical to optimising the shaft value and extraction over life of the shaft to prevent valuable reserves being left in the ground towards the end of life. Basically it comes down to actively managing the tail of the shaft (diminishing tonnes profile as reserves deplete) from the day mining starts.

5. PATH TO CLOSING A PRODUCTION ENTITY

To make the appropriate decisions on mining level or shaft closures it is essential that a sophisticated economic model be developed. This model needs to take cognizance of the inter-relationships that exist within the economic system. A model entailing these requirements has been discussed in Ballington, *et al* (2004) and the same concepts have now been applied to models developed for other mining clients. Two types of optimisation are described below, the first dealing with half level closures and the second with shaft closures.

5.1. Half Level Optimisation

A half level is the smallest economic entity than can realistically have all direct costs and direct capital investment attributed to it. A half level is the smallest self contained production unit that encompasses development, ledging, equipping, stoping, vamping, reclamation and logistics. It comprises the area East or West (North or South) of the station cross cut extending from stope crosscut intersection updip to the upper level stope crosscut intersection viz an area of one back length extending East or West of the station cross cut. A level therefore consists of either two or more half levels depending on whether there is more than one reef plane and the distance between them.

Shaft A, where half level optimisation has been undertaken, consists of both a vertical shaft and a subsurface decline shaft. There are two economic reefs present with the one being predominantly mined in the past. Stoping is done on a conventional, scattered breast basis. As the decline extends, additional levels (therefore half levels) have been added so that more and more levels (half levels) are being mined but at a lower rate. Owing to ventilation constraints, less area is being mined per half level as additional levels are added. In addition development on some half levels has not kept pace resulting in insufficient face to meet the planned mining schedule. This results in a spiralling effect on costs as volume and productivity reduces year on year.

The strategic objective of optimisation for this shaft was to find the optimal number of half levels required to maximise value without compromising extraction rates. It was further required that costs be reduced substantially within the current confines of the shaft infrastructure (ventilation, hoisting, decline capacity, tramming etc). The hypothesis being that a half level has a certain amount of fixed cost associated with it irrespective of mining rate. In addition some half levels had significant investment in development far ahead of that immediately required while others had none.

Critical optimisation questions are:

- What is the optimal development ratio?
- How much development is required to achieve this ratio?
- What is the optimal number of half levels to mine to meet production targets?
- What is the optimal mix between the two reefs, even though the one has limited mineral reserves, so as to maximise life of mine whilst ensuring short term viability?

A detailed Economic Optimisation Model (EOM) was developed to simulate all the relationships and interdependencies within the shaft. These relationships and interdependencies where all modelled at half level resolution. Further, the relationship between development and stoping was simulated so that “available for stoping”’ centares could be determined. This was important as in the short to medium term, a key driver was the additional development required to open up face to mine and get each half level into an equilibrium extraction state. This model allowed the testing of various tactical responses that would yield the optimal solution.

The following issues were identified as being critical when making tactical decisions on half level closure in this circumstance:

- The ventilation design for scattered breast mining means that a certain face shape between levels must be maintained to support the ventilation design. Therefore, a half level cannot just be closed without impacting ventilation on other levels.
- A detailed and accurate understanding of direct costs is required (as per the discussion earlier in the paper) so that a decision to shut a half level completely can be made based on the correct assessment of cost. On a direct cost basis, a half level that is making a profit is contributing to shaft and overhead fixed costs. Assessment on a fully allocated cost basis will be detrimental to the overall shaft viability.
- Understanding the constraints associated with the vertical and decline shafts and their interdependency is important. The decline belt capacity versus the vertical shaft hoisting capacity plays an important role in optimally planning out all the half levels over the life of mine; especially if the decline shaft belt has a lower capacity. The

ventilation constraint on the decline versus the vertical shaft has a similar impact on the life of mine schedule.

- The optimal mix between reefs (low grade and high grade ore respectively) plays an important role over life of mine, especially with regards the constraints on the vertical and decline shaft hoisting capacities.

Using hypothetical numbers and names, figure 2 below indicates how on a direct contribution basis (present value of half level revenue less direct costs and direct capital) the overall shaft value over life of mine is eroded by half levels that are not adding value due to production rate, direct costs or capital requirements into the future (half levels 12, 9, 8 and 11). The optimisation process would look at increasing value from each half level which may in turn make these negative half levels positive through increased production rates, reduced costs and reassessment of capital requirements. Also note the impact that shaft and surface fixed costs have on overall shaft value.

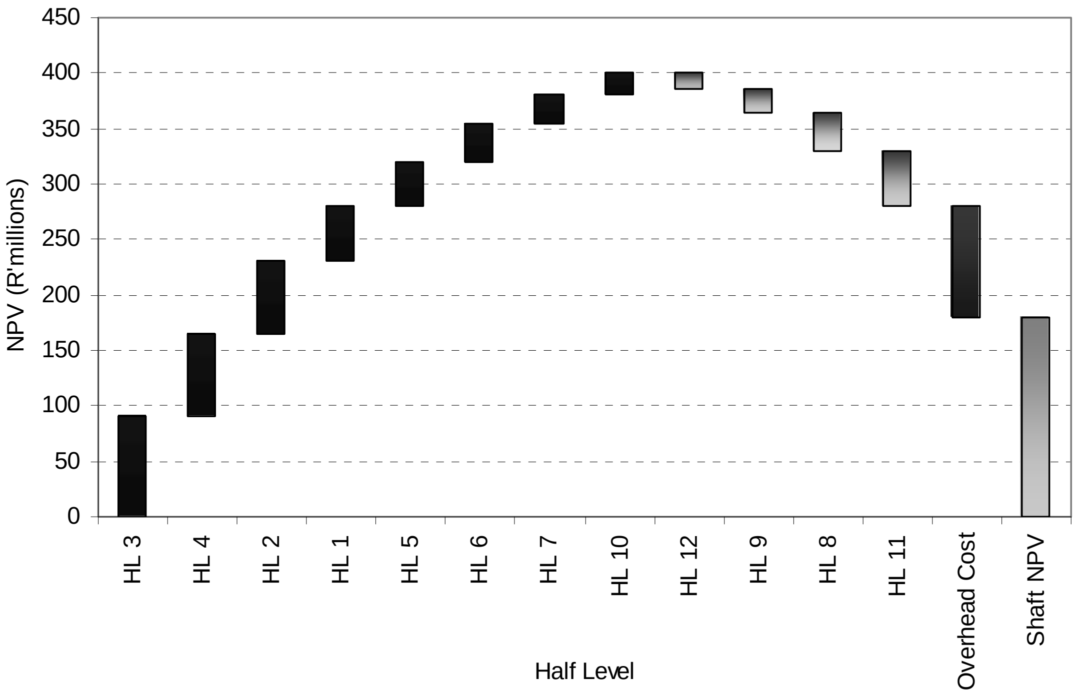

Figure 2. Half Level Contribution to Shaft Value

What is interesting to note is that from a pure profit perspective (half level revenue less direct costs only) all the half levels were actually making contribution. This is due to the fact that the shaft management were being measured on production volume, costs and profit metrics. The impact that direct capital had on half level value was not being assessed resulting in some half levels being over capitalised.

Figure 3 below highlights a hypothetical case to demonstrate the difference between profit and value, all in present value terms.

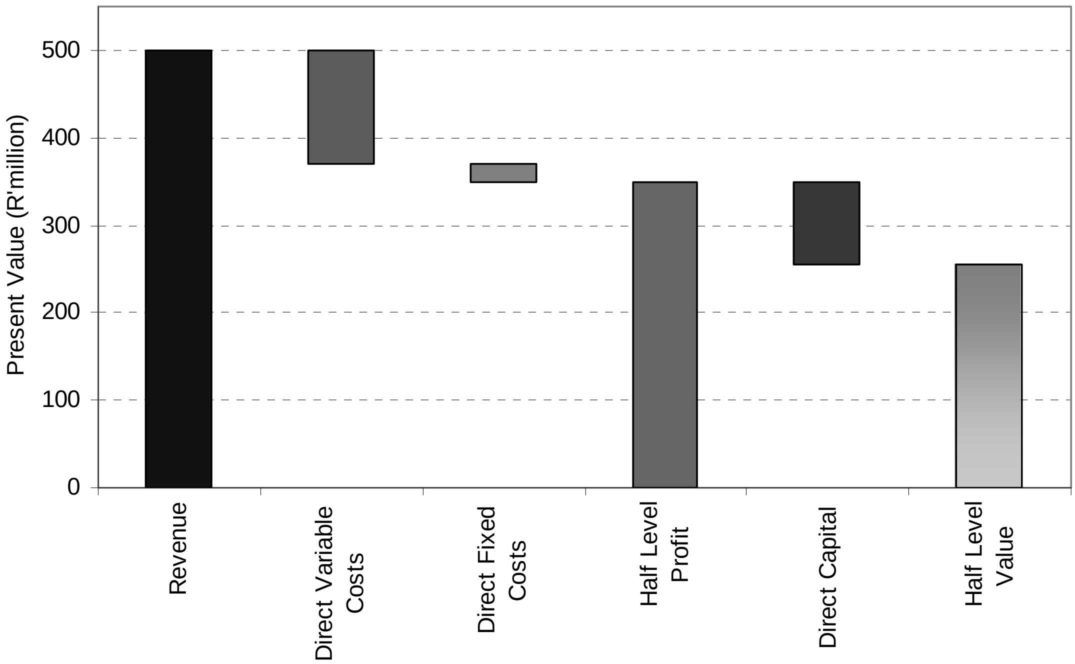

Figure 3. Half Level profit and value in present value terms

Upon completion of the optimisation process the following insights were noted:

- Most half levels were generating a positive return on a contribution basis (taking direct capital into account). Therefore it was not a case of simply closing half levels but rather how to schedule and sequence production from each area.
- Insufficient stoping was found to be taking place on some half levels, resulting in suboptimal contribution due to the fixed cost component of a half level.
- Development, like at most mines, tended to be sacrificed in order to reduce costs. However this effectively strangles the half level over a period of time which may result in early closure and loss of economic resource due to face availability and lack of flexibility.
- Optimisation suggested increased mining rates where sufficient mineable face was available. Those half levels with limited flexibility could then be scheduled for extraction at a later stage once development had caught up.
- A short-term increase in unit costs was required on some half levels due to additional development requirements to increase face availability and therefore be able to increase mining rates.
- To ensure full shaft utilisation and associated unit cost reduction some half levels must be extracted at suboptimal rates until face availability increases to the point where the lowest contributing half levels can be closed.
- Short-term decisions to shut-down half levels may have a significant impact on unit costs and short-term profitability but a long term perspective is essential as the remaining half levels at the end of the life of mine may be insufficient to carry shaft and overhead fixed costs so destroying value.
- Capital investment decisions pertaining to infrastructure upgrades that impact all future half levels should be assessed in the context of the full life of mine and not

allocated in a way that negatively impacts current operational half levels.

5.2. Shaft Level Optimisation

At a deep level mine consisting of a number of surface and subsurface shafts, the decision to close shafts was taken based on various levels of contribution. The impact on the mining complex value, as measured by NPV, was assessed, with the actual values derived from the exercise being adjusted for the use in this paper.

Shafts X and Y are both reasonably long life shafts, with current life of mine planning indicating that Shaft X should close at the same time as Shaft Y. On a profitability basis however, the final 2 years of mining at Shaft X can be deemed as being sub-economic on the basis of total costs. Using this approach, the shaft was closed 2 years earlier than originally planned. From the EOM it was noted that the reallocation of fixed costs resulted in Shaft Y having to carry an increased proportion of the allocated costs.

The quantum of allocated costs at Shaft Y increased by 85% for the first year that Shaft X was closed (Figure 4). Approximately 30% of this increase being attributable to employment termination costs.

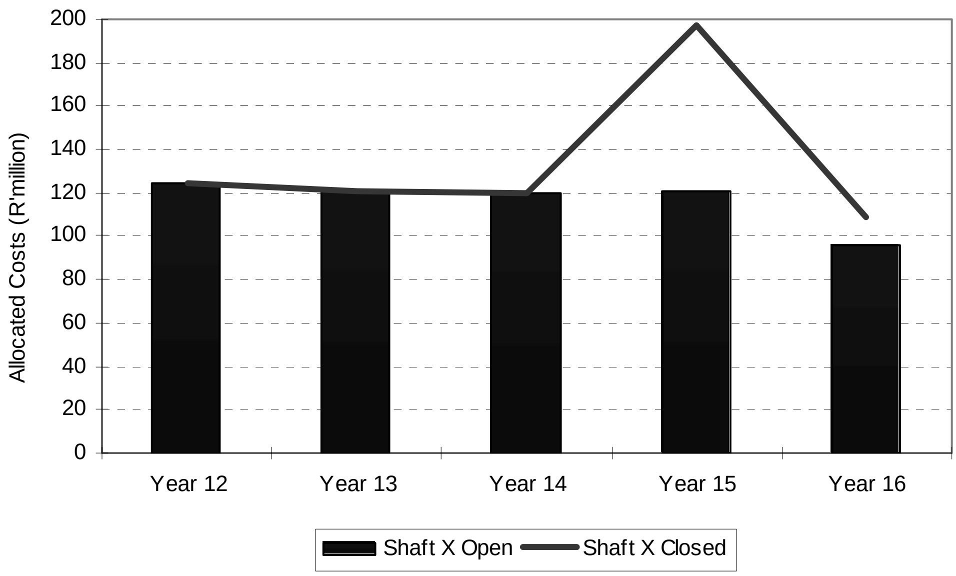

Figure 4. Impact of the Closure of Shaft X on Allocated Costs at Shaft Y

Due to the expected closure of the shaft taking place more than 10 years into the future, only a 3% decline in NPV for Shaft Y was observed. If the closure of Shaft X was based on the direct costs metric, as defined earlier, then Shaft X would have been kept open for an extra year, however, one year of mining would still be lost. In this instance, Shaft Y's allocated costs are not affected and the NPV of the shaft and the mine increases.

This would suggest that closure of shafts should be undertaken using direct costs only.

However, what if the shaft is the last shaft left producing at the mining complex? If this is the case, somebody has to carry the onsite overhead costs. If the shaft cannot, then the mine must be closed.

On a similar basis that a shaft contributes to surface overheads, a mining complex contributes to a corporate overhead and therefore decisions to close a mining complex should take cognizance of the impact on other mining complexes in the group.

6. CONCLUSION

The decision to terminate operations at a shaft is complex and needs to meet both short term viability and long term optimisation requirements. Central to the decision is the ability to adequately model/simulate operations to assess options and sensitivities. A clear understanding of the interdependencies of activities and costs is crucial for valuation modelling. Interpretation of options and sensitivities can be aided through the use of techniques such as the “Hill of Value” to find the optimal value potential of a mining level, shaft or mining complex.

Should a mining level or shaft not have a positive NPV at direct cost level then it should be a clear cut decision to close the mining entity. An entity showing a positive contribution at the direct cost level is contributing to the fixed surface costs thus assisting to make the whole mining complex profitable. The decision to close this type of economic entity should be based on its overall impact on the viability of the mining complex. It is illogical to cease mining at a shaft when that shaft is delivering a negative contribution after allocated costs if the shaft is essential for logistical purposes, i.e. Pumping, rock hoisting, refrigeration etc.

The remaining life of mine is a critical factor in decision making. In the case of a short life shaft where longer life shafts exist within the same mining complex, closure should be based on whether the shaft can carry its own direct costs. Long life shafts however need to be able to carry all costs to ensure profitability of the whole mining complex. This argument can be extended further in that, a loss making mine (including allocation of offsite overheads) may still add value to the group through its contribution to the fixed cost structure and ensure profitability of the whole group.

Before taking the decision to close a mining level or shaft it is essential that a clear understanding of the infrastructural interrelationships is obtained. With the increased complexity of ageing mines it has become imperative that proper, accurate economic modelling, that reflects the complexity of the interdependencies, is undertaken to ascertain the implications of infrastructural closures.

It is also critical to understand that short-term decisions around profitability may have a major impact on life of mine and shaft value as the remaining half levels at the end of the mine life may be insufficient to carry shaft and overhead fixed costs.

A point to take into consideration regarding infrastructural closure, is that ultimately flexibility is decreased. If the NPV of the mine improves by running both or either of these scenarios with an EOM then shaft closure should be considered. Bear in mind that the flexibility to be able to put a shaft on care and maintenance provides management with flexibility to reopen the shaft should the commodity price improve. It is important to acknowledge this additional potential option value that should be added to the NPV of the scenario. This additional value can be calculated through real options analyses methods which are not part of this paper but can be referred to from the following references: Trigeorgis (1990), McCarthy & Monkhouse (2003) and Hudson (2005).

It is important to note that optimisation is not a simple once-off exercise. As commodity prices change, the optimal configuration may have to be adjusted owing to changes in cut-off grades and half level profitability. The viability of options should therefore also be assessed on a scenario basis.

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