DE KOCK, P. A back to basics approach to mining strategy formulation. *The 6th International Heavy Minerals Conference 'Back to Basics'*, The Southern African Institute of Mining and Metallurgy, 2007.

A back to basics approach to mining strategy formulation

P. DE KOCK
Richards Bay Minerals

Strategic mine planning is concerned with the decisions that determine the value of the business, while tactical planning deals with the tasks to realize that value. When tasked with formulating a strategic mine plan, the mining engineer often turns to commercially available software. However ,these software packages have limited applicability to the RBM situation. Adopting a simpler, back to basics approach founded on a deep understanding of the economics of the orebody has the advantage of providing a clear logic to guide tactical planning. By creating a coherency between strategic mine planning, and tactical planning the likelihood of successfully executing the plans and attaining the value promised by the strategic plan is increased. This paper describes the reasons why RBM embarked on a strategic mine planning process, the rationale of choosing the process, and the process itself.

Introduction

Mining strategy formulation or strategic mine planning can be viewed as the convergence of the two disciplines of business strategy and mining optimization. Strategic mine planning is concerned with the manner in which orebodies are exploited in order to compete in the marketplace. Specific questions addressed include:

- What technology should be used?
- How should the technology be deployed?
- What scale should the operations be?
- How much of the orebody should be mined?
- In what sequence should the orebody be mined?

Traditionally the mining industry categorizes mine planning by period, for example 'short-term planning' and 'long-term planning' There is, however, a growing trend to adopt the military and business terms of 'strategic planning' and 'tactical planning'. A quote from Camus (2003) explains these terms: 'In summary strategic mine planning is concerned with those decisions that largely determine the value of the business, and tactical mine planning is concerned with the tasks required to actually achieve that value. Both types of planning are necessary; they can be looked at separately, even discussed separately, but they cannot be separated in practice'

Formulation of a strategic mine plan is usually done during the prefeasibility or feasibility stage of a mine and is rarely reviewed unless precipitated by a crisis or significant change in knowledge or the economic environment. A number of factors demanded a review of Richards Bay Minerals (RBM) mining strategy, namely:

- Growth in the global economy has led to a robust demand for commodity products
- Exploration utilizing new technology, and extensive analysis led to a greater understanding of the nature of the mines orebody. This understanding was embodied in a resource model, which in turn led to new forecasting models. These forecasting models led to a step change in the quality of forecasts, particularly the aspects of throughput and mine recovery
- The life of mine production profile showed two characteristics: (1) A long-term decline in product output; (2) Substantial cyclical variations in product output as the various mining plants traversed geological features
- Mining of a second orebody was proposed to counter the declining output. This second orebody required significant capital expenditure. Limitations imposed by the capacity of downstream processing, and the fluctuations of the current mines output negatively affected the proposed operation's ability to attain economies of scale.

In response to these factors a reformulation of RBM's mining strategy was conducted in 2006. Since RBM has been profitably active for over thirty years and has significant investment in productive capacity, the questions of technology and scale have been answered, thus the focusing question for this strategic process was: In what sequence should the orebody be mined?

This paper will set the context by briefly describing RBM's operations, then discuss the selection of the strategy formulation method, followed by a description of the method, and end with conclusions. Due to the competitive nature of the heavy minerals industry figures quoted will be disguised, but without detracting from the 'truth' of the conclusions drawn.

Richards Bay Minerals operations

Richards Bay Minerals (RBM), formed by the component companies Tisand (Pty) Ltd and Richards Bay Iron and Titanium (Pty) Ltd, mines and extracts heavy minerals from sand dunes along the northern KwaZulu-Natal coast on the eastern seaboard of South Africa near the harbour town of Richards Bay. RBM produces titania slag, high purity pig iron, rutile and zircon for local consumption and export.

A dredge mining technique is used to mine the orebody. Dredge mining is an integrated method of ore winning, processing and tails management using fresh water and electricity as the main inputs. The key to the mining method is the dredge pond. The dredge pond is a freshwater dam typically fifteen metres deep, 250 m wide and 400 m in length. A dredge floats in the pond and uses a submerged bucket wheel or scroll cutter to loosen the mineral-bearing sand and slurry it. The slurried sand is pumped through a rubber pipeline placed on floating pontoons to the concentrator. The concentrator floats in the pond and using a multi-stage process separates the ore into three streams of slimes, sand tailings and heavy mineral concentrate. The slimes, which are particles smaller than 45 micron, are deposited in the dredge pond where they settle to form a layer at the bottom. Sand tailings are pumped to tail stackers located behind the dredge pond where a hydro-cyclone recovers water, which is gravitated back to the pond, and places the dewatered tailings into benches similar to the original dune morphology. The dunes are rehabilitated into either indigenous or commercial forests. The heavy mineral concentrate (HMC) containing the economic minerals ilmenite, rutile and zircon as well as gangue minerals are pumped to a stockpile where a hydro cyclone recovers the water.

HMC is trucked some 20 km from the stockpiles to the smelter complex where a number of processes occur to produce saleable products. The first step in the process is the mineral separation plant (MSP) where magnetic and electrostatic methods are used to produce rutile and zircon saleable products. Ilmenite is further processed to produce the saleable products of titania slag and high purity pig iron.

RBM currently mines the Zulti North orebody consisting of loose and semi-consolidated sands. The orebody's main axis is approximately 20 km long and lies in a north—south orientation parallel to the Indian Ocean coastline. The width of the orebody varies between two and four kilometres. Mining is conducted in four separate dredge ponds, which have been phased in over a period of thirty years. The characteristics of the four dredge ponds are summarized in Table I.

Inferred from Table I is that each new dredge pond has incorporated improved technology and thus the throughput capacity, metallurgical recovery of economic minerals and cost behaviour of the dredge ponds differ.

Strategy formulation method selection

A choice between two alternate methods of formulating a strategic mine plan for RBM is apparent; the two options are:

- *Off the shelf*—utilize a commercially available optimization software package, or an existing published methodology
- *Custom solution*—design a process that addresses the unique needs of RBM.

A custom solution was selected. The rationale for this decision can be categorized into two themes of technical and managerial considerations. These considerations are discussed further.

Table I
Dredge pond characteristics

Dredge pond	Approximate age	Relative sand throughput
MPA	30 years	1 unit
MPC	20 years	2 unit
MPD	12 years	2 unit
MPE	7 years	3 unit

Technical considerations

The discipline of mining optimization has a rich body of knowledge in the field of open pit optimization. The field was revolutionized in 1965 when Lerchs and Grossman published an algorithm to determine the final limit of mining for an open pit based on the criterion of undiscounted cash flow, i.e. the time value of money is not considered. Most commercially available optimization software packages incorporate the Lerchs Grossman algorithm. However, according to Bush and Golosinski, optimization is best suited to design of a pit's economic limits rather than the design of the extraction sequence.

A number of techniques have been developed and utilized to solve the problem of designing an extraction sequence while incorporating the time value of money; these techniques include:

- The Milawa algorithm employs linear programming techniques developed by Halatchev (1996). It cannot guarantee an absolute maximum net present value (NPV) but can find a schedule with a high NPV–Whittle quoted in Bush and Golosinski
- Tolwinski and Underwood (1996) 'guided search' algorithm employs stochastic search techniques
- Ramazan, Dagdelen and Johnson (2005) fundamental tree algorithm uses linear programming techniques.

The application of these techniques has a limited relevance to the RBM situation in two ways. Firstly the final limits of mining of the Zulti North orebody is known. The horizontal extents of the orebody are determined either by tenure boundaries or pinching out of the orebody. In the vertical plane, the orebody is at surface and the base of the orebody is characterized by a sharp transition from mineral-bearing sands to barren sands. In contrast, the orebodies usually subject to optimization programmes are overlain by, and/or surrounded by gangue rock, and sometimes have transitional changes from ore to waste. These orebodies therefore require decisions as to the amount of waste rock that must be mined in order to gain the ore, and the definition of ore expressed in terms of a cutoff grade. The Zulti North orebody does not require any waste mining. Most of the available packages rely on Lerch Grossman algorithms defining economic limits to underpin the time optimization algorithms, a condition that is not met in Zulti North.

Secondly, an underlying assumption of open pit optimization techniques is that the mining method has a reasonable degree of flexibility. There are two dimensions to flexibility, namely:

- *Non locality of mining faces*—typically shovels are utilized in open pit mining, which can rapidly and inexpensively be relocated to different mining faces i.e. it exhibits non-locality, the ore mined in any given period need not be contiguous. In comparison, dredge mining is fairly inflexible, a dredge pond cannot be drained, and the dredge, concentrator and floating pontoons dismantled and reconstructed elsewhere without incurring considerable expense and production delays. Once constructed a dredge pond can only advance; the ore mined by a dredge pond over its life can be conceived as one long contiguous 'sausage' of sand. Any 'off the shelf' solution would require extensive customization to address this issue
- *Independence of tails placement from ore winning*—Typically in open pit mines waste rock and ore are differentiated in pit, the waste rock is hauled directly to placement outside of the pit. The only constraint on

mining sequence is the cost of transporting the waste rock, which changes over distance. There is a disconnection between the availability of waste placement space and the availability of mining faces. In RBM's dredge mining there is no differentiation between ore and waste; the entire volume mined is treated in the process plant. The tails from the process plant must be placed in the voids created by mining. As the angle of repose of tails is less than undisturbed ore, the volume of tails that can be placed in a single dredge path is less than the ore contained in that path. In order for mining and tails stacking to be in equilibrium there must be at least two dredge ponds' width worth of tail stacking space available. Dredge mining thus has a strong connection between ore winning and tails placement. The history of a dredge pond strongly determines the current performance and future options. The complexity of planning the inextricably entwined activities of ore winning and tails placement has prevented reduction to simple algorithms. The experiential knowledge of personnel, and the widely consultative planning process at RBM is key to managing this complexity.

Managerial considerations

A concern with 'off the shelf' solutions is the problem of causal ambiguity. The output of the 'off the shelf' method is a sequence of mining, not an explanation of why that particular sequence is optimal, i.e. there is causal ambiguity. To understand the impact of causal ambiguity one can consider mining to consist of the following three steps:

1. *Strategy formulation*—determine the technology, scale and sequence of mining.
2. *Tactical planning*—convert the strategic plan into a practical implementation plan. Addresses such issues as infrastructure and tails management.
3. *Execution*—physically execute the plan.

These three steps require different skill sets and are performed by different people. At the strategy formulation step it is vital that an understanding of the economics of the situation is developed. Without simple goals and an understanding of the economics there will be no dominant logic to guide the people responsible for tactical planning. The needs of tactical planning may require modifications to the plan; without understanding the reasons for superior value, tactical planners may make practical decisions that destroy value. Strategic and tactical mine planning is based on imperfect information. For example, during the execution step unforeseen events can occur, which forces change. In the presence of causal ambiguity there is no guidance on how to deal with unforeseen events; the most likely outcome is value destruction.

The problem of causal ambiguity is not new; the discipline of business strategy deals with this issue. Grant (2005) defines four characteristics of a strategy that are conducive to success, they are:

1. Goals that are simple, consistent and long term.
2. A deep and insightful understanding of the competitive environment.
3. An objective appraisal of resources. Successful strategies generally exploit internal strengths and protect weak areas.
4. Effective implementation. A strategy that is not implemented is meaningless and a strategy that cannot be implemented is by definition a poor strategy.

An 'off the shelf' solution does not by itself exhibit these characteristics necessary for success. A custom strategy formulation process can be more easily designed that meets Grant's (2005) four characteristics of successful strategies.

Back to basics strategy formulation method

To overcome the implementation problems inherent in 'off the shelf' tools, RBM adopted a simpler approach to strategy formulation. The process consisted of the following two phases:

1. Fundamental analysis of the orebody in terms of economic performance, which led to a 'value rule' defining those few things that must be done to achieve superior value
2. Develop and evaluate mine plan options based on the value rule.

This section of the paper will describe these two phases.

Orebody economic analysis

Analysis is the search for leverage. The principle of leverage is that by effecting a small change in a critical area, a large outcome can be produced. Leverage is often expressed as the Parieto principle, which states that 20% of factors produce 80% of results. In order to structure the search for leverage Porter's Value chain is a useful framework. Shown in Figure 1 is a simplified value chain for RBM.

From Figure 1 there are five variables that affect value (value drivers); four of the value drivers are independent variables in relation to the orebody. The four orebody value drivers are:

- *Throughput*—the orebody is not homogenous; the nature of the stratigraphy and sand thickness has a large impact on the rate of mining. As each dredge pond incurs fixed overhead operating costs, the rate of mining affects unit costs per ton of product. Since the throughput is directly related to the orebody, location is important, and therefore when considering the time value of money the sequence of mining is important.
- *Grade*—there are variations in the grade in both the horizontal plane and the vertical plane. The impact on value is simple: the higher the grade, the more product is produced for the same operating costs and therefore higher profits are earned. Location and sequence of mining affects value by similar reasoning as that used for throughput.
- *Metallurgical recovery*—the recovery of economic heavy minerals (EHM) in the concentrator is strongly related to a ratio of certain minerals in the orebody.

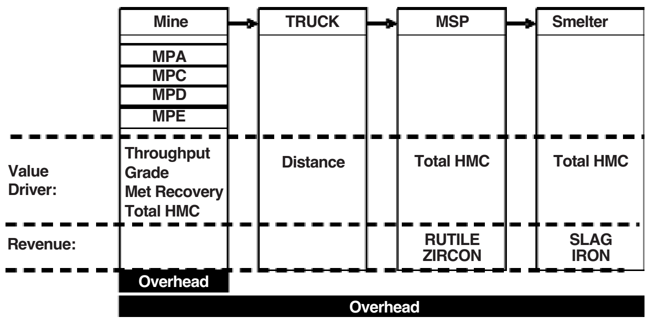

Figure 1. RBM value chain

This ratio varies in the orebody.

- *Distance*—since the smelter complex is located to the south of the orebody, the cost to truck HMC to the smelter increases in the northward direction.

The fifth value driver is total HMC produced, since both the mine and the smelter complex incur fixed overhead operating costs, the total production of the four dredge ponds affects the unit costs and therefore profitability. Total HMC produced per pond per unit of time is the product of throughput, grade and met recovery.

To asses the orebody value drivers, a 50 metre wide grid was overlain on the orebody. For each grid cell the throughput, grade, metallurgical recovery and HMC contained were estimated from the perspective of each of the four dredge ponds. To determine which value driver has the most potential, a leverage factor was used. The leverage factor is defined as the maximum value observed divided by the minimum value observed. Shown in Table II are the leverage factors for throughput, grade and met recovery.

From Table II it can be seen that metallurgical recovery is a weak lever and grade and throughput the strongest levers. Thus metallurgical recovery was not subject to further analysis. Distance was also excluded from further analysis as the transport cost component is relatively insignificant, less than 3.7% of total costs.

Since both throughput and grade are dependent on the orebody, they are not truly independent of each other, implying a trade-off between the two value drivers. To aide tactical planning and execution of the strategic plan simplifying the throughput—grade trade-off can be achieved through categorization. Shown in Figure 2 is a categorization of the orebody; the vertical axis is throughput and the horizontal axis is grade.

Tactical planning and management of the ponds will differ among the categories, for example capital expenditure on increasing dredging capacity will be contemplated in the Low TPH/High Grade category but not the Max TPH/Low Grade category.

The time value of money concept implies that the orebody should be mined in descending order of cash flow. Shown in Table III is the contribution margin of the orebody categories by dredge pond as a percentage of the lowest value. The contribution margin is equal to revenue less dredge pond operating costs.

From Table III the following two trends are apparent:

1. In all the orebody categories dredge pond MPE delivers the highest contribution margin followed by MPC, MPD and MPA with the lowest contribution margin.
2. There is a substantial difference in the contribution margin between the orebody categories, in descending order: Max TPH/High Grade, Med TPH/High Grade, Max TPH/Good Grade, Max TPH/Low Grade, Med TPH/Low Grade, Low TPH/High Grade, Low TPH/Low Grade.

These two trends can be stated in the value rule used to guide the mine plan: first design MPE dredge path assigning it the best orebody, then design MPD and MPC, and finally design MPA.

The value rule is reinforced by examination of the fifth value driver total HMC. Figure 3 shows how the unit cost of fixed overheads per product ton changes with a change in total HMC produced; the horizontal axis is scaled to the maximum production that the smelter complex can treat in a year.

From Figure 3 it can be seen that if the mine were producing at half the required capacity, the unit cost per product ton would be 49% higher than at full capacity. Therefore the mine should produce at full capacity, since MPE is capable of treating 50% more sand than MPC and MPD (see Table I), it has the highest potential to determine the mine's total output. Therefore MPE should be given preference in mining the better parts of the orebody.

Develop and evaluate mine plan options

The development and evaluation of mine plan options was a sequential process. Firstly a software tool was developed by a consultant, who specializes in strategic mine planning, to evaluate mine plan options. The consultant advised and assisted the RBM team throughout the process. The

Table II
Leverage factors

		Value driver		
		Throughput	Grade	Met recovery
Dredge pond	MPA	11.19	3.62	1.12
	MPC	6.70	3.62	1.07
	MPD	7.73	3.62	1.07
	MPE	8.40	3.62	1.04

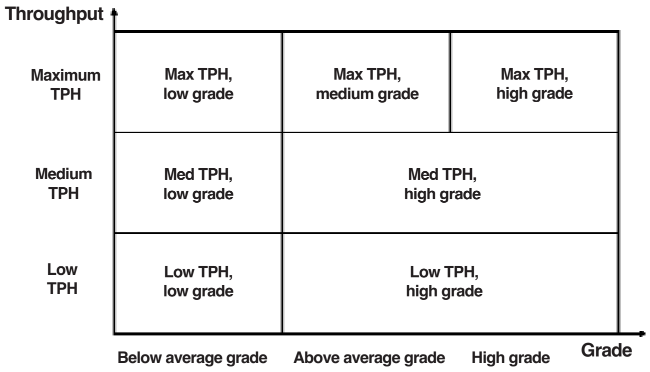

Figure 2. Orebody categorization

Table III
Relative contribution margin lper orebody category and dredge pond

	Max TPH, low grade	Med TPH, low grade	Low TPH, low grade	Low TPH, high grade	Med TPH, high grade	Max TPH, good grade	Max TPH, high grade
MPA	430%	363%	100%	434%	681%	713%	1121%
MPC	967%	867%	326%	1078%	1550%	1590%	2405%
MPD	966%	848%	298%	1019%	1494%	1566%	2383%
MPE	1592%	1480%	477%	1479%	2893%	2595%	3755%

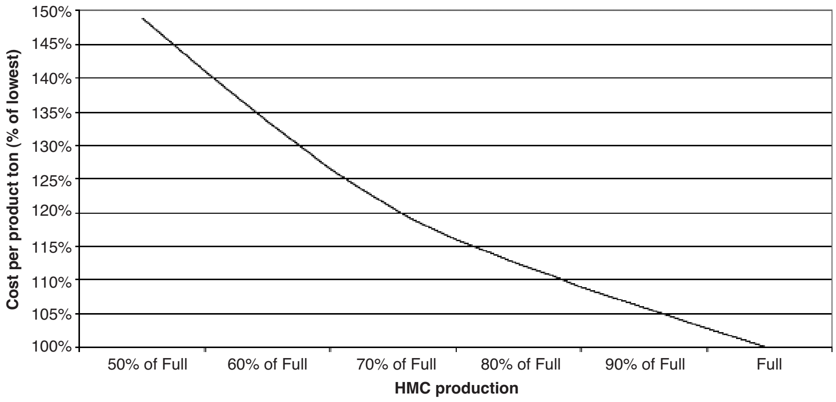

Figure 3. Change in unit costs

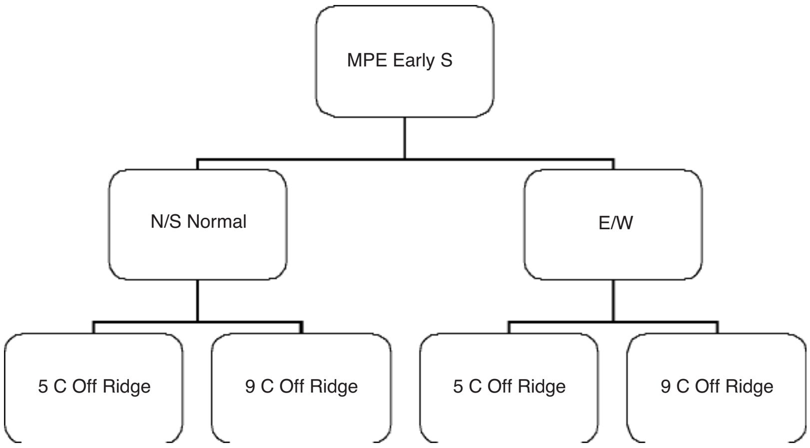

Figure 4. Sample of decision tree

software tool works by: allowing the user to lay-out the dredge paths; calculating the production schedule using the layout and reserve block model; estimating the operating costs and revenue to give a cash flow; and calculating the net present value (NPV). To minimize programming requirements and enable rapid evaluation, a number of simplifying assumptions were made. To test the validity of the software tool, the existing life of mine plan was replicated and compared against RBM's evaluation, and was found to be valid for a high level evaluation. The existing life of mine plan became the base case against which options can be compared. After some practice a user was able to evaluate an entire mine plan option in two hours, a process that would normally take over three days.

The second step of the process was to identify mine plan options. A team of RBM's mining engineers brainstormed options that exploited the value rule, drawing on the experiential knowledge of the team. A plan colour coding the orebody by category (described in Figure 2) served as a stimulant. The options were given meaningful names and organized into a decision tree representing series of mutually exclusive decisions; a portion of a decision tree is shown in Figure 4.

The third step was to systematically evaluate the options on the decision tree using the software tool. The final step was to select the best mine plan option, at each node of the decision tree the option with the highest NPV was selected.

The process described cannot guarantee that the selected mine plan is optimal in terms of NPV. However, inference can be made by examining all the results if the selected option is near optimal, or if significant opportunity for further value is likely. In addition to the options identified, a counter case was developed which purposefully broke the value rule. Shown in Figure 5 are the indexed NPVs for all the options evaluated, ordered by NPV.

A number of phenomena can be observed in Figure 5. Firstly the counter case has the lowest NPV, some seventeen percentage points less than the next option to exploit the value rule, providing validation for the value rule. Secondly of the 29% improvement in NPV between the base case and the best option, half is due to a single decision, as shown by the option immediately to the right of the base case. Finally, there is little improvement in NPV among the four options on the right of Figure 5, indicating diminishing opportunity to increase the NPV.

In conclusion, there is evidence to suggest that the selected mine plan is near optimal.

Conclusion

Use of a commercially available software package for strategic mine planning is inappropriate for RBM due to the nature of the orebody and the inflexibility of dredge mining. A simpler approach to strategic planning, based on a sound knowledge of the orebody economics, has the advantage of providing a clear rationale for tactical planning and execution of the plan. While this process cannot determine

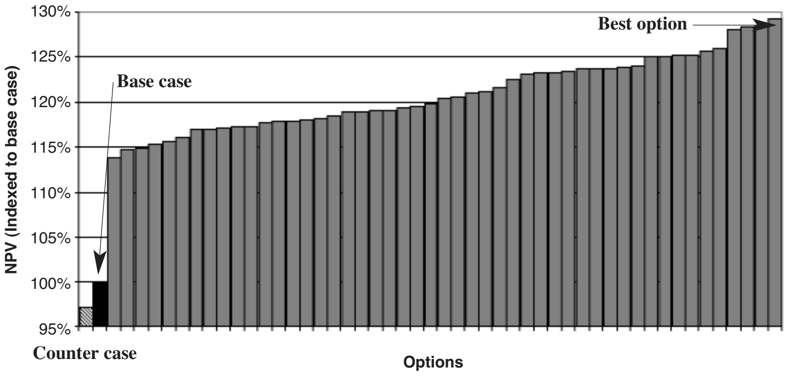

Figure 5. Indexed net present value

if the selected plan is optimal in terms of NPV, it can highlight the critical decisions, and demonstrate diminishing returns, inferring that the plan is near optimal.

Acknowledgements

Robin Kear provided sage advice and wrote the software tool. Stephan Esterhuysen and Navesh Ragoonanthun had most of the bright ideas for the mine plan options, and did the hard work evaluating them. Andre Redgarde assisted in understanding the economics of RBM. RBM management gave the author the intellectual freedom to develop the process.

References

WHITTLE, D. Strategic Mine Planning and a Decision-Making Behavior Model. Coal International/Mining and Quarry World. March/April 2002.

RAMAZAN, S., DAGDELEN, K., and JOHNSON, T. Fundamental tree algorithm in optimising production scheduling for open pit mine design. *Mining Technology,* vol. 114, March 2005.

BARBER, J. and MOORE, B. Strategy and Tactics in Mine Planning, www.gemcomsoftware.com

CAMUS, J. Management of Mineral Resources Creating Value in the Mining Business. SME 2003.

BUSH, T. and GOLOSINSKI, T. A comparison of Open Pit Design and Scheduling Techniques

TOLWINSKI, B. and UNDERWOOD, R. A Scheduling Algorithm for Open Pit Mines. *IMA Journal of Mathematics Applied in Business and Industr*, vol. 7, no. 3, 1996. pp. 247–270.

HALATCHEV, R. and MOUSTAKEROV, I. Optimum Scheduling of Waste and Ore Production. *Mining Technology*, vol. 78, no. 894, 1996. pp. 61–64.

GRANT, R.M. *Contempory Strategy Analysis*, 5th edition. Blackwell Publishing. 2005.