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Simultaneous mining and mineral processing enterprise optimization for the platinum industry

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Optimization techniques can be used to significantly increase the value of mining businesses by enabling better long-term planning decisions. Recent developments enable the combined consideration of open pit and underground mine design, mine scheduling, cut-off grade and blending and most recently the linking of these to the flexibilities in the concentrator, smelter and refinery unit processes. Regional logistics of intermediate products and the peculiarities of the ultimate metal markets are also considered. Experience shows that net present value can be increased by 5–35% or more, often even before the expenditure of significant amounts of capital. This paper outlines these techniques and how they can apply to a typical platinum business.

Introduction

Many tools exist, either distributed by mining software vendors or developed internally by mining companies, to optimize various parts of a mining business in isolation. However, it is still rare for companies to attempt to optimize all parts of their operation simultaneously. This is particularly the case for companies with multiple mines and processes producing several commodities and possibly operating at several locations in more than one country.

In the past ten years, Whittle Consulting has focused on expanding the boundaries of integrated optimization, concentrating on the issues faced by large and complex mining and processing operations. By using advanced business modelling and analytical techniques, an integrated geological, mining, processing, transport and product market model can be constructed. This is then manipulated mathematically to optimize the values of those variables that are considered negotiable. Utilizing this procedure, it is possible to develop long-term plans that maximize the value of large geological and technical plant asset portfolios. Improvements in net present value (NPV) of the business in the range 5–35% have been demonstrated in many cases. As such the approach is a powerful business tool which can be used as a platform to support strategic decision making at many levels.

This methodology is eminently suitable to be applied to the PGM (platinum group metal) and related sectors of the mining industry. In Southern Africa, PGM processing and recovery exhibits a number of complex and sometimes unique features, for example multiple reefs, variable PGM and base metal mineralogy, several co and by-products, open pit and underground mines operating close by and also at great distances from each other, difficult mining conditions, ventilation and other constraints on mining flexibility, power and transport infrastructure limitations, complex and inconsistent metallurgical performance, many competing producers, limited markets for certain products, constraints in total smelting and refining capacity, and strict environmental legislation. This sector has similarities with the nickel industry in several other regions where enterprise optimization has already been applied successfully.

In this paper, the authors outline a variety of modelling techniques applied during recent projects with similar complexities, and discuss the typical characteristics of a globally optimized business plan. The paper also contains some suggestions concerning the specific application of these techniques to the PGM industry.

What is enterprise optimization?

Enterprise optimization addresses the issues raised in mining and processing operations with multiple pits, mining faces and underground mines, multiple metal or mineral products, stockpiling and blending opportunities, and alternative processing options. The combination of these features creates significant long-term planning and analytical challenges that often exceed the capabilities of commercially available mining optimization software. The techniques described in this paper represent the culmination of 25 years of optimization developments by Jeff Whittle and others. These are promoted by Whittle Consulting as a simultaneous optimization package aiming to release value for mining companies either in operation already or in the process of developing new prospects, by enabling them to make better planning decisions and unlock an increase in net present value of their business.

Simultaneous optimization aims to address all steps in the value chain and all assets in the enterprise portfolio together, and does this while also considering all time periods of the planned operation. This is a crucial additional complexity differentiating mining from other businesses such as manufacturing. An orebody being mined is a depleting resource; when we decide what to mine and process in one period, we determine the starting point for the next period and therefore limit the options for all future periods.

Figure 1 illustrates the point. There is little or nothing that any enterprise can do to improve the resource in the ground or the international market for the products, but all the other

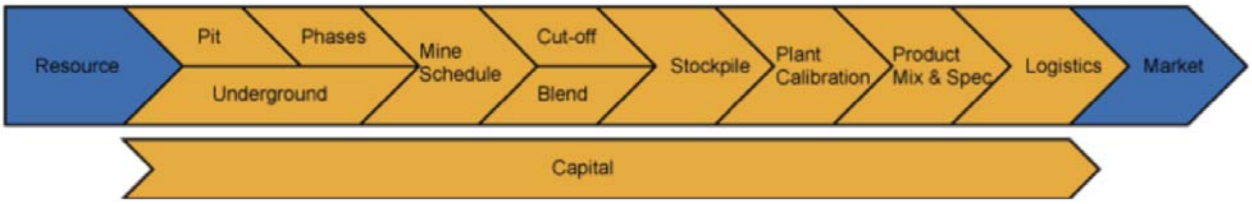

Figure 1. The generic mining enterprise value chain

steps illustrated in the figure can potentially be optimized.

The techniques described in this paper are analytical and utilize the latest available software. However, simultaneous optimization is also a desirable process to prevent sub-optimization for example by different departments of an operation working in discrete silos without knowledge of the divergent objectives of other departments, or of production divisions competing for capital and other scarce corporate resources. An inevitable result of such sub-optimal planning approaches is that many decisions which should be dynamic are fixed or are made far too early, to simplify the planning process. The analytical approach described in this paper enables companies to overcome this, but the organizational challenges to be overcome in order to realise the benefits should not be overlooked.

Enterprise optimization concentrates on optimizing the net present value (NPV) of businesses. NPV is the sum of discounted cash flows, normally calculated or forecast annually. It reflects the time value of money and is considered by the authors to be the best available metric for planning and measuring the performance of any business in a form that will be understood and appreciated by executive management, shareholders and other investors, and all stakeholders.

Philosophically, many mining businesses struggle to identify clear and consistent objectives. For example, maximizing metal production, maximising life of mine, minimizing costs, maximizing resource recovery from the ground, maximizing metal recovery from ore mined, and maximizing utilization of equipment are all often cited as being key objectives for operations. However, it is difficult to rank these against each other, and some of them conflict. The authors therefore focus on a single objective, of maximizing the economic value of the business.

Implications for the platinum mining industry

In order to apply this technique in the platinum industry, all material that could be mined needs to be ranked. Typically this is done by considering the Pt or PGM grade, but in fact a much more logical parameter is the net value per tonne. Net value in this case is determined by adding the products of price and recovery of each individual metal or mineral in every parcel to be sold less the cost of mining and processing each parcel from each distinct location. The higher the net value, the more attractive any specific parcel should be to the operator.

To put this in perspective for this paper, the implication is that enterprise optimization considers each operation to be, not a platinum mining business, but a money mine.

Modelling methodology

Generally as many as ten different mechanisms are employed in the enterprise optimization process and these are described briefly below, with particular reference to operations with several deposits, several processing options and multiple products as well as logistics challenges. Whittle Consulting's approach uses a proprietary search algorithm combined with powerful linear programming techniques to achieve simultaneous optimization. This paper concentrates on the principles and does not discuss the mathematics further.

Pit shell optimization

For open pits, conventional techniques are used to determine pit shells for each deposit using commercially available software such as the Gemcom Whittle Four-X package. In this initial process an isolated view is taken on the definition of ore and how it will be treated. Assumptions will be made about how material will be blended and processed. Pit shell optimization is a static analysis process in that no attempt is made to determine when a block of material will be mined, so it is not possible to consider the likely effect of changes in prices, costs, capacities and recoveries. These factors are only considered during schedule optimization. The initial approach is therefore to develop nested pit shells that have efficient stripping ratios and that prioritise ore based on its value given its most likely processing path. This is by no means a perfect procedure, but in this context is a good starting point for the remainder of the enterprise optimization process. Once a round of schedule optimization has been performed, another iteration of pit shell optimizations is usually warranted. Figure 2 shows the typical outcome of this technique. The optimized pit is slightly smaller than the original manual pit, and is also a slightly different shape due to exclusion or inclusion of ore blocks that were not in the original pit.

Phases

It is implicit in a pit that phases can be mined consecutively or concurrently, subject to the rule that an outer phase cannot overtake an inner phase in descending at any point in time. Details of any required minimum/maximum lead/lags, earliest start dates, start-after rules, alternative mining methods, tonnage rate limits, vertical rate limits, costs, dilutions and so on must also be considered. Figure 3 illustrates pit phasing for the pit shells shown in the previous paragraph. As can be seen, the phases are far more different in this particular case than can be deduced simply be looking at the overall pit shells. Generally, the selection of the early phases has the most influence on NPV, and the quantum is often very significant.

Underground mine design

Enterprise optimization is a strategic planning tool and does not attempt to control specific mining activities within an underground mining area or block. Each block is just one component of the overall system, and existing local

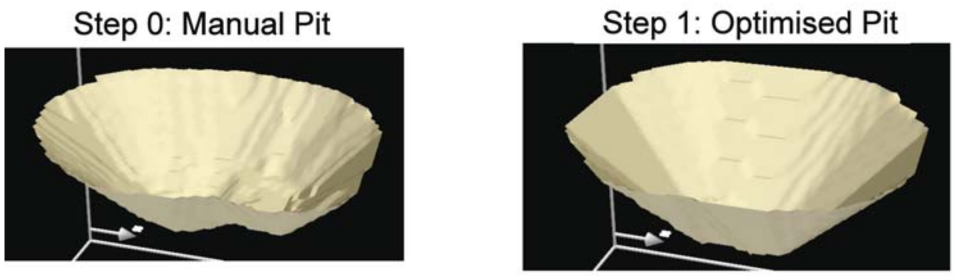

Figure 2. Pit optimization process

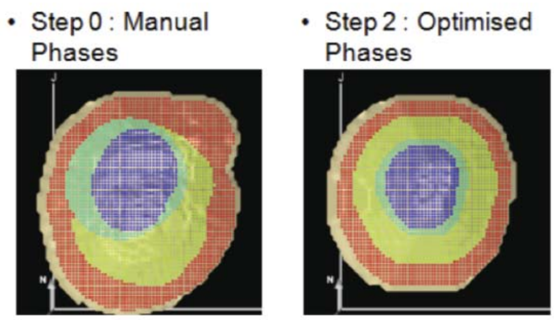

Figure 3. Comparison between manual and optimized pit phases

schedules and plans are utilized to identify and quantify development cost and time, stoping and haulage costs and rates, tonnage/grade profile, dilution, backfilling, maintenance requirements and similar activities. The overall optimization plan will then determine how and when a particular underground mining block will relate to all other sources of material in the total system. As with pit shells, some revision of the initial plans may be needed after the first round of schedule optimization. Figure 4 illustrates the complexity of a typical underground platinum mine, with multiple reefs, several shafts and alternative haulage and loading strategies all featured.

A number of underground mine planning and optimization packages have been developed in recent years which are in some ways analogous to the Gemcom Whittle software for pit optimization. Enterprise optimization is not intended to replace or compete with these tools but should be complementary. It is possible to use the data generated by such packages as inputs to the overall strategic optimization process.

Pit and mine geology

Geological blocks are consolidated into 'grade bands'. In pits, the bands fall within a bench of a phase or pushback. In underground mines, precedence diagrams are assigned to ensure that grade bands can be accessed in a logical sequence as the mine development proceeds away from a shaft or other haulage point. Grade banding techniques are designed to summarize ore data, while maintaining a relevant segregation of mineralogy and either a matrix of relevant ore grades and attributes or a ranking of ore based on net value calculations. It is typical to work with between eight and twenty grade bands, depending on what is relevant for cut-off grade, stockpiling or blending, and the actual operational grade control capability that exists. A geological model with many millions of block records can therefore be reduced to a grade banded database of several thousand records.

It is likely that a particular band of mined material will report to different destinations in different periods as the decision will be influenced by other aspects of the optimization process at the time when a parcel is mined. Figures 5 and 6 illustrate the application of grade banding in open pits and underground operations respectively.

Grade banding is the key to significant value in the schedule optimization, by facilitating appropriate decisions on cut-off grade, stockpiling, processing path selection, blending and product mix. It is important for the scheduling of pits in a system but is more difficult to apply in

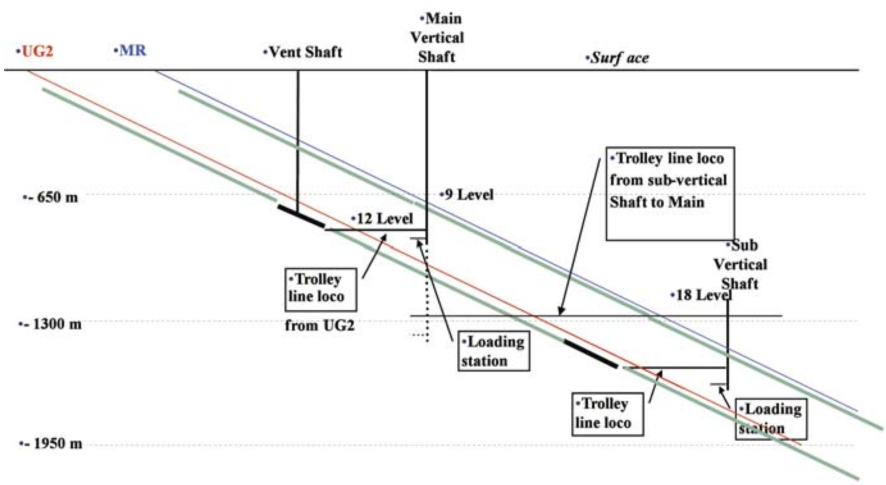

Figure 4. Typical platinum mine extraction strategy

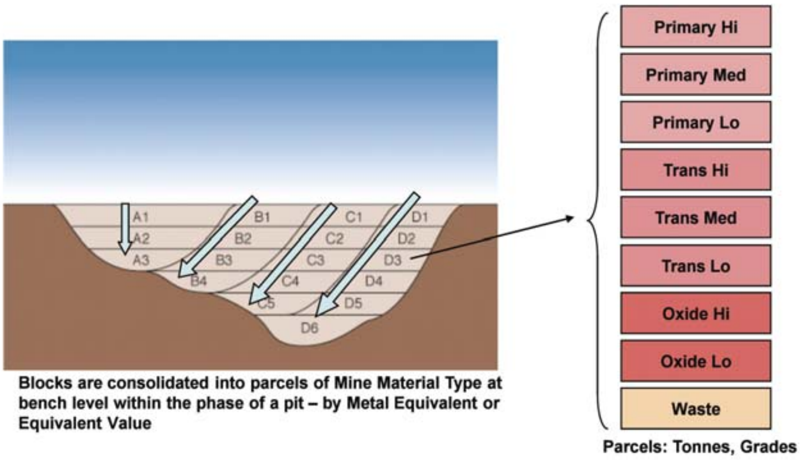

Figure 5. Grade banding for maximum throughput in multi-element systems

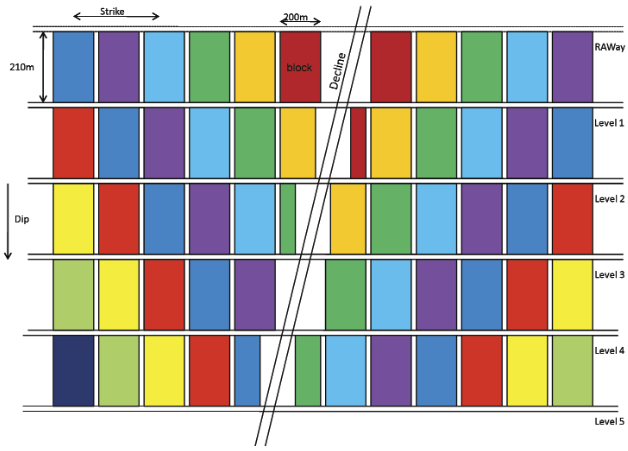

Figure 6. Grade banding applied to underground operations

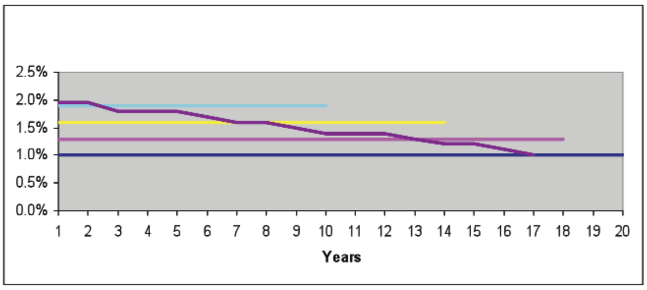

Figure 7. Decreasing cut-off grade through the life of the mine

underground mines as these focus by nature on premium high grade ore of one type within a single reef and do not generate the wide range of grades and ore types typical in pits. Nevertheless, haulage distances, depth and other factors do influence the net value of ore even in underground operations and the technique can therefore be applied to mines as well as pits, subordinate to application of logical sequencing.

Scheduling

When scheduling a pit with phases generated through pit optimization, higher grade is usually a component driving the optimization since this ore's net value is also higher. The average grade of ore mined is therefore usually higher in early years than later. Ore is defined here as material that has a positive net value after mining and processing and is therefore above the 'marginal cut-off grade'. By mining in multiple optimal phases, the early average grade is therefore usually increased and mining focuses on high grade areas in these early periods. However, there is usually also a focus on minimizing stripping ratios or dilution in the early years in order to reduce total mining and processing costs (including waste) per tonne of ore recovered.

Cut-off grades

Provided that the project is constrained by the capacity of the process plant, it can be demonstrated that the NPV can be increased by discarding some low value material (which is nevertheless above the marginal cut-off grade) in the early years of production. Total life of mine cash flow will decrease but early cash flow will rise resulting in an increase in NPV.

This can be explained by mentally dividing the material to be mined into two increments. Increment A is what we would have mined and processed in the first year if we had used a marginal cut-off, and increment B is the material to be mined and processed in subsequent years. If we raise the cut-off slightly for increment A but not for B, the NPV will be affected in two ways. First, the cash-flow from A will be reduced and A will be mined in less than one year. If A is mined in only eleven months then the mining and processing of B will be brought forward by one month. If the discount rate is 1% per month, the NPV of increment B will be increased by 1%. Thus we have a reduction in NPV due to reduced cash-flow from A and an increase in NPV due to B being mined earlier. Since increment B is usually large compared to A, the latter effect will dominate and the best cut-off grade for A will be significantly higher than the marginal cut-off.

The same approach can be applied in each subsequent year. Since the amount of material remaining decreases with each year of mining, the optimum cut-off grade for each successive year becomes closer and closer to the marginal cut-off. This logic applies to both open pit and underground ore bodies. Figure 7 illustrates the methodology and also specifically shows that simply increasing the cut-off grade above the marginal value and operating at a constant cut-off grade through the life of the mine will also not yield an optimum solution.

Stockpiling

There is often reluctance to permanently discard material that is above the marginal cut-off grade. This can be addressed if it is feasible to stockpile this material and process it later. The balance point is shifted in favour of even higher cut-off grade in the early years combined with a higher mining rate. The life of mine is not necessarily reduced in this case, since all of the material over the marginal cut-off grade will eventually be processed. The cost of rehandling and any reduction in recovery due to oxidation of stockpiled material must be taken into account in the calculations. Figure 8 shows a particularly flexible example of stockpiling applied as a normal operating strategy at a lateritic nickel operation.

Ore processing

A processing summary model is developed which captures the cost, throughput and recovery relationships for each type of ore and each of its potential processing paths. This summary will contain as many as fifty channels enabling the metallurgical sensitivities to be captured in great detail. There will be separate channels for each plant and for different groups of ore types if they have different costs, throughput or recovery in each plant. Different channels can also be created for the same plant operating in different modes.

In the case of PGM processing, it is anticipated that processing models for crushing and screening, preconcentration (sorting, DMS or gravity separation), multi stage milling including HPGR circuits, flotation, chromite recovery, smelters of various types, acid leaching, sulphur capture, base metal refineries and precious metal refineries will be required, particularly if this methodology is applied by the larger and more complex operations. Figure 9 schematically represents some of the processing possibilities inherent in the operations of any large and integrated PGM producing company.

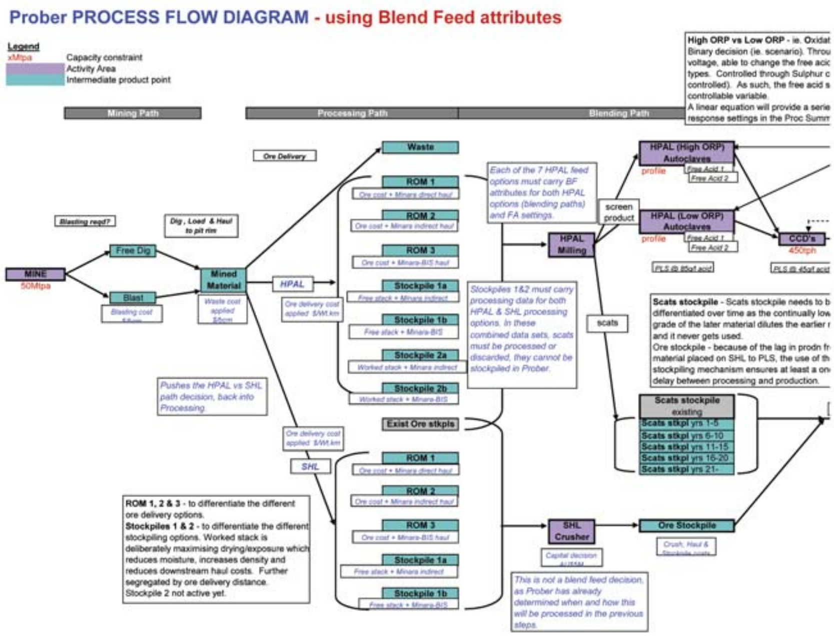

Figure 8. Stockpiling applied as an operational optimization strategy

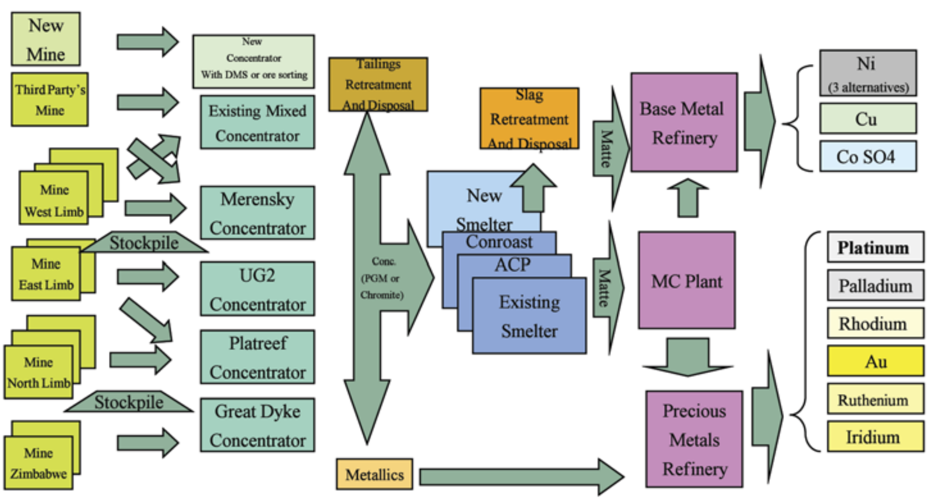

Figure 9. Alternative processing routes to be optimized in the PGM sector

None of the unit processes mentioned above are unique to the platinum industry and processing models have already been developed on other enterprise optimization projects to deal with all of them. The models consider mineralogy, grades, blending limits, synergy from blending, hardness, sizing, specific gravity, density, viscosity, rejects, by-products, intermediate stockpiles, reagents, consumables, maintenance, sustaining capital, purchase and sale of intermediates, availability and shutdowns, and variable performance over time. Capacity of each plant is considered to be dynamic. Plant conveying and pumping systems are almost always designed to be able to handle more than the nominal design capacity and it may make sense to make use of this feature from time to time although it will temporarily reduce residence time and recovery in the main process vessels.

This is illustrated conceptually in Figure 10. Although PGM and nickel recovery would decline significantly in this theoretical example if the processing plants were to be operated at the right hand end of the horizontal axis (i.e. at 13 Mt per year of ore processed), the amount of metal produced in concentrate for sale would be much greater than if the concentrator were to be operated at 9 Mt per year throughput achieving higher recoveries. This may be an optimum solution in some years of operation, due to other constraints elsewhere in the system, but it is unlikely to be the optimum solution all the time. This is an important point. It is rare for the optimizer to propose constant operating conditions throughout the life of the mine, and in order to achieve an optimum financial solution it may be necessary to alter the processing parameters of the plant quite frequently, every few weeks for example.

In the example shown, the concentrator tailings produced in a period of high production rates will contain more recoverable metal than in a period of low ore feedrates. These higher grade tailings could be stockpiled separately for future retreatment or could be routed immediately to a tailings retreatment plant if one exists, in preference to reclaiming existing lower grade tailings from the mine's tailings dams.

It is typical for some ore types, or ore from different mines, to be eligible for more than one processing route or process plant location. Methods of processing may experience changing availability, capacity and performance over time, all of which can be captured in the model. Rules are formulated to define which categories of mined material can go through each processing path, and what will happen in each case.

Products

Blending of feed material from different sources may be important to some of the processing units in order to enable processing or to achieve the desired product specification, and equally so it may be necessary to blend some products in order to achieve marketable product grades. Blending can be a powerful mechanism representing a significant opportunity for optimization but also a challenge to achieve in practice.

In most cases it has been found that constant product specifications are unlikely to be optimal. The optimizer will usually propose a dynamic product specification in order to maximize the economic benefits. Figure 11 shows how a smelter or refinery capacity constraint could influence the grade and quantity of PGM concentrate produced for any given mining rate. The base metal sulphide content of the concentrate will increase roughly proportionally to any increase in PGM grade, but even the highest grade concentrate shown in Figure 11 will have a low inherent calorific value and will require substantial amounts of external fuel or heat in the smelting process. Since most PGM smelting operations use electric furnaces they are constrained by the power ratings of the furnaces, and it may therefore sometimes be beneficial to feed smaller amounts of higher grade concentrate to a smelter in order to produce more marketable PGM and associated base metals in converter matte even though this will result in more metal being discarded to concentrator tailings.

Similar logic can be applied throughout the smelter, base metal refinery and precious metal refinery processes.

Logistics

It may be possible to sell the various products to a number of different buyers, locally or at diverse export locations. The products may be shipped in bulk, by rail or road, in bulk solid, powder or liquid form, or in the form of metal sheets, ingots or sponge, or as salts. It may be possible to transport the feed, intermediate and product materials by conveyor, hoist, rail, road, sea or air. There will be limits on the carrying capacity of some of the available transport routes, and on the size of some of the purchase contracts. There will also be different prices for each contract, with varying degrees of competitiveness.

All of these parameters can be incorporated into the mathematical model to enable the optimizer to calculate which forms of transport and which purchase contracts provide the best financial solution for the operation. Figure

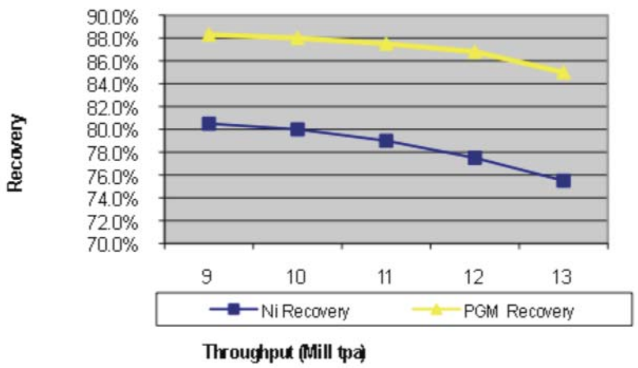

Figure 10. Potential to optimize plant by varying throughput and recovery

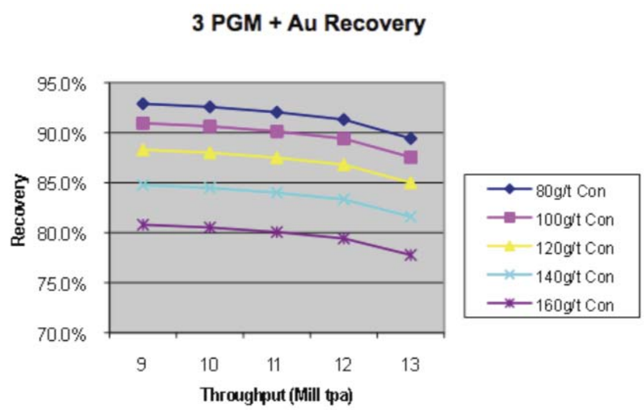

Figure 11. Effect of downstream processing constraints on concentrate grade

12 shows the typical net smelter returns for copper concentrates of different grades at different copper prices. As can be seen, at a copper price of US$2.50/lb, it makes sense to produce larger quantities of lower grade copper concentrate and incur higher transport prices, in order to increase copper recovery from ore and get more copper to market. At lower copper prices, on the other hand, it makes more sense to run the concentrator at a lower mass pull, lose more copper to tailings and produce smaller amounts of copper concentrate containing 28% Cu instead of 24%. The cost for the concentrate to be transported (sometimes to be exported) to the toll smelter will be reduced significantly, more than compensating for the reduced revenue in this case.

The same principles apply in the PGM industry, even for the larger operations with their own smelting and refining operations, particularly in cases where they are buying and processing recycled secondary materials or are treating concentrate on behalf of other companies. Smaller companies producing and selling flotation concentrate have to consider net smelter and refinery returns as illustrated below for a copper concentrate. The main difference is that there are several marketable metals contained in a PGM concentrate all of which require different downstream processing routes and which have different product specifications, markets and pricing dynamics.

The next figure (Figure 13) illustrates a different logistics issue which is certainly applicable to the PGM industry. It could apply either to feed material or any intermediate product needing to be transported between different plants. It is also possible that it could apply to waste streams for disposal such as waste rock, tailings or slag.

The example assumes that the material in question is normally moved using one specific form of transport, for example a conveyor, a rail system, or a pipeline. The installed system has a capacity limit. One common option is therefore to limit the production rate to the capacity of the system, but is this the optimum solution? In the case illustrated, the optimizer has determined that in several years it would be more profitable and cash generative to transport additional material by a second mechanism. This could, for example, be road trucks to supplement an installed rail system. The second mechanism will have to be implemented by means of short-term contracts and may require short-term labour hire as well. Consequently, it will be significantly more challenging to operate than the primary transport strategy, and will almost certainly also have higher operating costs. Nevertheless, if this approach yields higher NPV, enterprise optimization will propose that management implements the more complex operational solution.

Capital expenditure

The mechanisms described so far aim to make maximum possible use of existing equipment, and do not require major capital purchases in order to increase cash flow in early years. The enterprise optimization approach deliberately focuses on achieving all possible other benefits before looking at elimination of bottlenecks by installing new or replacement equipment. However, it is possible to quantify and evaluate the economic effect of all potential capital projects. This includes major expansion projects being considered.

Figure 14 illustrates two possible types of capital project that could increase NPV of an operation. In the first chart, it is supposed that the total mining rate (ore plus waste) is limited to 60 million tonnes per year by the available mining equipment. However, if this constraint is released in this example, the optimizer would mine more than this in some years, in order to open up blocks of higher grade ore more quickly than would otherwise be the case. This higher grade material would be processed in the early years of operation to increase cash flow (remembering that cash flow in early years has a significant effect on NPV), with lower grade ore being stockpiled for later treatment, and waste material with net value below the optimized cut-off grade being discarded. The operating cost requirements to achieve the additional mining capacity are built into the optimization model as a cost per tonne mined, and the increase in net present value is compared with the estimated capital cost to purchase more equipment to determine whether the proposed solution is really justified.

The second chart shows a similar constraint, in this case being the capacity of the tailings pipeline. Once again, the optimizer has calculated that in several years of operation, it should be beneficial to upgrade the capacity of the pipeline and run more tonnage through the plant.

This mechanism can be used to confirm and quantify the potential financial benefits of proposed capital projects, during the initial or expansion feasibility study phases of an enterprise and during operation before approving 'debottlenecking' projects.

The input file

Collection of data from existing operations and from

Cu Price /lb =	$2.50	NSR $/T Con
24% Con	24%	18785
26% Con	26%	18753
28% Con	28%	18506
30% Con	30%	18011
32% Con	32%	17369

Cu Price /lb =	$1.50	NSR $/T Con
24% Con	24%	8545
26% Con	26%	8728
28% Con	28%	8772
30% Con	30%	8667
32% Con	32%	8463

Figure 12. Logistics optimization example—copper concentrate for sale

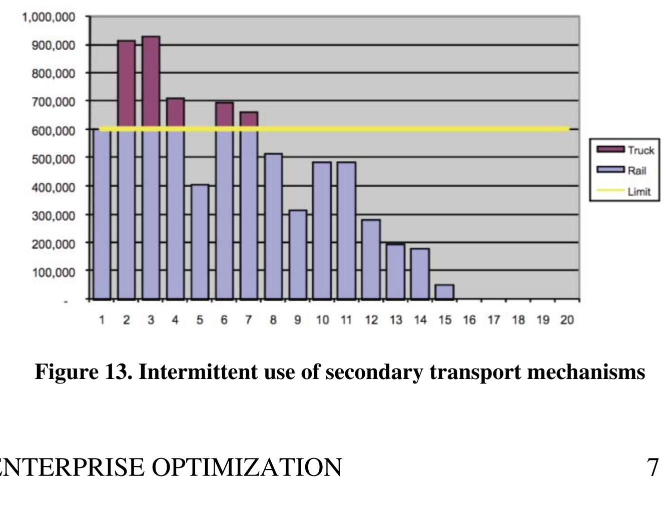

Figure 13. Intermittent use of secondary transport mechanisms

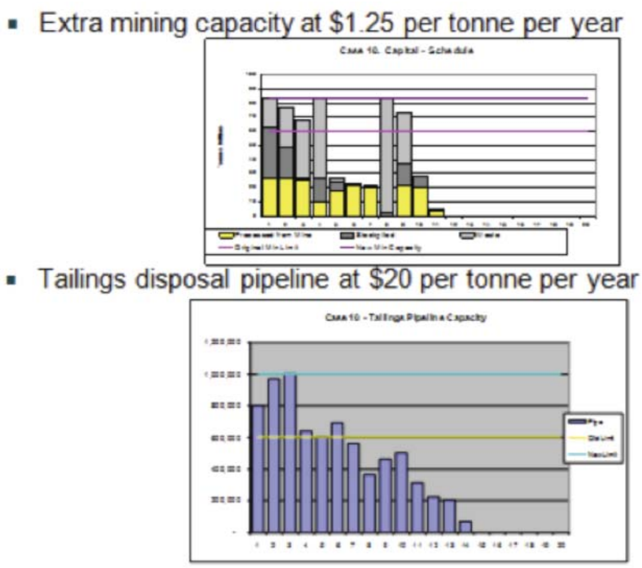

Figure 14. Potential benefits of capital projects

project feasibility study teams is a key element of any enterprise optimization study. The ore body block model is used as a major source of data for the model, whereas the rest of the data are collected using a standard approach but a project specific format, into a data input file or 'project business model'. This file can be quite voluminous and can take between a few days and a few months to compile depending on the availability, completeness and accuracy of the data. Sometimes, additional data collection or test work may need to be carried out by the owner's team before the optimization modelling can commence.

The input data file contains an important section dealing with constraints and limits of each major section of the production route: mining, processing and logistics.

The calculation and allocation of operating costs is also dealt with in the input file. The allocation of fixed or 'period' costs is particularly important in the determination of the optimized solutions for various scenarios. The major bottleneck in the process is identified and period costs are mainly allocated to this section or process unit since this is what constrains overall production or output from the circuit. This is a technique from the manufacturing industry and is an important feature of enterprise optimization.

Capital cost estimates for proposed projects are also provided by the owner's team. Enterprise optimization is not an engineering design or estimation tool but can be used to complement the work done by engineering contractors, feasibility study consultants and owner's teams during the investigation of new capital projects.

Further notes on applicability to the PGM industry

A surprising amount of information has been published in recent years on PGM operations and projects and these notes have been prepared with reference only to information already in the public domain.

Typical open pit operations

There are some small open pits and near surface orebodies on the western limb of the Bushveld complex but the main potential for this type of development is on the northern limb near Polokwane and Mogalakwena, and in some stretches of the Great Dyke in Zimbabwe.

Generally, open pit operations processing the Platreef exhibit some of the following features:

- Significant strip ratios, with waste and ore being recovered by hydraulic shovel and road trucks
- High basket prices due to reasonable grades of PGM but also nickel
- Low operating costs per tonne milled
- Flexibility embedded in the operation—it is relatively easy and cheap to flex production rates from this type of operation
- Good safety records, with less exposure than underground mines to fall of ground and similar accidents
- Relatively small labour complements and high degree of mechanization
- Multiple pits at any single operation, unless the production rate is very low
- Steeply dipping, thick, wide orebodies.
- Good metallurgical performance, particularly when compared to UG2 operations
- Limited availability of power, water and transport infrastructure
- Operations are spread over a wide area, far from smelting and refining facilities.

These features are similar to open pits in other industry and commodity sectors that have proven to be very amenable to enterprise optimization techniques.

Typical underground operations

The western and eastern limbs of the Bushveld igneous complex contain numerous mining operations owned and managed both by large companies with integrated processing facilities and smaller companies generally operating a few mines and concentrators and having their concentrate products processed at a small number of local smelting and refining facilities. Some of the common features of these operations are:

- Shallow ore sources have mainly been worked out in the past fifty years and many operations are now mining between 650 and 1 500 m below surface. Vertical, sub-vertical and incline shafts are all used to access the orebodies.
- The temperature gradient at depth is much greater than in the Witwatersrand goldfields. Cooling and ventilation are key and expensive issues for these mines.
- Reefs are narrow and not always amenable to mechanized mining techniques. Consequently these mines are labour intensive and great attention has to be paid constantly to safety because of the mining conditions in addition to the normal rigorous practices of any high quality operation.
- The UG2 reef consistently underlies the Merensky Reef and can usually be mined and recovered through the same shaft system at any single operation.
- Various mining and stoping techniques are employed.
- Ore is hoisted to surface but thereafter can be moved by rail, road or to some extent by conveyor. Various mines have different levels of established infrastructure which influences their transport strategies.
- Generally, there is little comminution or pre-concentration attempted underground.
- The Merensky Reef contains significant amounts of nickel and copper contained in sulphide minerals, in

close association with the PGM. The UG2 Reef, on the other hand, contains much lower percentages of base metal sulphides, has different Pt/Pd/Rh ratios from Merensky ore, and also contains significant amounts of chromite which can potentially be sold to ferrochromium producers. Because of their very different mineralogy, the Merensky and UG2 reefs require different flowsheets to achieve optimum recovery and grade of concentrate, so should ideally be separated before being processed, even if they are hoisted through the same shaft system. Stockpiling is therefore an obvious consideration in any optimization plan.

- Concentrate from the UG2 reef generally contains significant amounts (1–5%) of Cr_2O_3, which makes it more difficult and expensive to smelt than concentrate from the Merensky Reef. Blending of UG2 and Merensky concentrate is often practised before smelting in order to control the chrome levels in the furnace feed.

Downstream processes

- Several new smelting and related processes have been developed in recent years and have been commercialized by the PGM industry to varying degrees. This opens up a number of opportunities for the processes to be compared quantitatively during any optimization exercise. In principle, a similar exercise could be carried out to compare different refining processes which are already used or have been considered by diverse producers. It may be that the benefits of such investigations could be small by comparison with the pit, mine, concentrator and logistics optimization steps.
- In theory, export of concentrate or matte to other countries (mainly Canada, Russia, China, Australia, Finland or Norway) could be technically feasible. However, the inventory of PGM in transit would be very high, and most nickel smelter and refinery facilities outside South Africa are used to processing much greater quantities of base metals but much less PGM. Optimization techniques could be applied to determine whether such strategies are viable.

Analogies with other commodities and industry sectors

The best analogy is with the nickel sector. The mineralogy of PGM ore is strikingly similar to that of nickel sulphide orebodies, with the predominant minerals being pentlandite, chalcopyrite and pyrrhotite. Consequently, many of the processing and product alternatives open to nickel producers are also relevant to PGM operations, and there are also some similarities between the mining operations. Of most relevance, the larger nickel companies operate a number of open pits and underground mines, with ore being directed to multiple process plants, just as is the case with the large PGM producers.

Nickel laterite operations also have some relevance. Disseminated or massive ore is generally mined from open pits and is stockpiled and blended before being processed either by pyrometallurgical or hydrometallurgical techniques, with limited preconcentration possible. Base metal products are then produced using refining processes very similar to those used in the PGM industry.

The enterprise optimization technique has been applied successfully in study work done for Minara Resources, Goro Nickel, PT Inco and SLN in the laterite sector. BHP Billiton's Nickel West (sulphide) business unit commissioned an optimization exercise covering the entire division, and Vale Inco has recently begun an investigation of its Sudbury operations. Many of the lessons learned in these studies are expected to be fully applicable to any PGM optimization exercise.

Conclusions

Figure 15 illustrates how value is added by each of the ten optimization steps described in this paper. This figure was developed specifically for a case study of a copper/gold open pit and concentrator operation in Australia, and includes verifiable data for that case. The amount or percentage added to NPV by each step varies considerably from case to case, but all of the principles explained and described in this paper are applicable to any PGM operation or project just as they have been applied successfully to other commodities around the world.

To conclude, in a typical open pit optimization, some of the outcomes of an enterprise optimization exercise will include:

- Reduction in the ultimate pit size, eliminating some marginal ore from the reserve
- Increased mining, plant and logistics operating costs in order to generate more revenue
- Lower utilization of mining equipment when it is not required
- Higher cut-off grades, especially in early years of operation
- Lower plant recovery in some years, due to higher throughput and increased concentrate grade
- Increased capital expenditure to remove specific bottlenecks
- Reduced life of mine.

If considered by a single department in isolation, many of these outcomes would be counterintuitive and would contradict the key performance indicators of the departmental managers, whereas when considered together they often result in a significant increase in net present value being demonstrated to be possible.

Similarly, in underground operations, enterprise optimization often recommends a reduction in stope widths

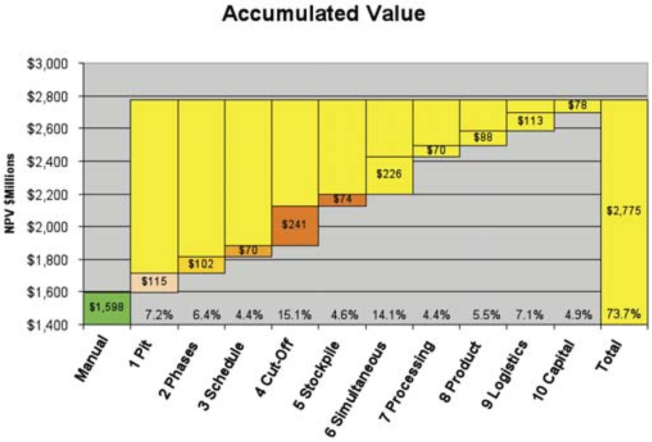

Figure 15. Where does the value come from? Ten components of enterprise optimization

and reserves, higher cut-off grades, reduced plant recovery in some years, shortened life of mine and reduced total cash flow. When the enterprise is considered as a single unit, the optimization process will once again concentrate on discounted cash flow and the time value of money, and will treat the enterprise as a 'money mine' in order to optimize net present value, often demonstrating that improvements in NPV in the range 5–35% can be achieved.

Enterprise optimization appears to be highly relevant to the platinum industry as it is a proven integrated approach to business planning with the ability to dynamically capitalize on the inherent flexibility of all parts of the business, resulting in a harmonized solution for the enterprise as a whole.

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Whittle Consulting specialises in the modelling and optimization of complex mining and mineral processing operations. Combining business planning techniques with advanced mathematics and specialized programming, supported by the application of proprietary optimization software developed by Jeff Whittle, Whittle Consulting is recognized as a leading strategic advisor to resource organizations.

As Group MD, Gerald handles program/project management/co-ordination, optimization strategies and model design, business analysis and management reporting and presentations.

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27 years experience in the environment of extractive metallurgy, all gained working in the mining industry worldwide, both in production and project work. Currently Managing Director of Whittle Consulting (Africa), a consulting company offering Enterprise Optimization services to the mining industry, involving significant interaction with mineral resource management and mine planning professionals throughout the industry. Previously CTO (Chief Technology Officer) of Bateman Engineering NV, responsible for process technology acquisition, partnerships or internal developments aimed at improving and increasing the Company's technology portfolio, and for the implementation of the technology commercialisation strategy of BENV. Prior to that, Managing Director of the Bateman Metals business unit delivering projects globally from offices on three continents.