

## **Enterprise Optimization at SEMAFO's Mana Gold Mining Operations, Burkina Faso**

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### *Abstract*

Enterprise optimization is a relatively new optimization approach to mine planning used to jointly consider all aspects of a mining operation affecting the mine planning process and related valuation. In this paper, it is applied at SEMAFO's Mana operations in Burkina Faso, consisting of several open pits and a proposed underground mine. The surface-minable ore is relatively shallow, and the pits are long and linear. The underground operations, as currently envisioned, will consist of a stoping operation accessed by two ramps from the surface. Power is a concern at this property due to local power being produced largely by diesel generators, and it has become one of the key optimization constraints. Other important parameters are the mining and processing rates, underground configuration and cutover elevation. Enterprise optimization was found to improve net present value for the Mana Operations property by simultaneously optimizing multiple parameters and constraints to arrive at an optimal pit and mining phase design, optimal cut-off grades over time, and optimal ore feed based on ore hardness, power constraints, and head grades. Reserves were expanded several times over the course of the study to improve the valuation of the mining operation and put SEMAFO in its present enviable position of ongoing reserve increases.

## Introduction

Enterprise optimization (EO) may be seen as a framework used to analyze a mining operation(s) as a chain of value-creating activities, and has been developed to extend and support the long-term mine planning decision-making process. This framework was introduced in the late 2000's as an optimization process that incorporates the entire value chain of a mining project, from the resource in the ground to the metal commodity market (Whittle, 2009a, Whittle, 2010, Whittle, 2010). That is, the optimization includes the entire mining enterprise. Studies such as the one presented herein demonstrate improved net present value of a mining enterprise by simultaneously optimizing multiple parameters and constraints to arrive at an optimal pit and mining phase design, optimal cut-off grades over time, and optimal ore feed based on ore hardness, power constraints, head grades, ore reserves and so on.

This paper outlines the application of enterprise optimization at SEMAFO's Mana operations in Burkina Faso, West Africa. In the following section, the steps involved in EO are outlined; then, pertinent aspects of the Mana operations are described. Next, the assumptions and business model are outlined, and are followed by the presentation of results. Conclusions follow.

## Enterprise Optimization – A Recall

### Key elements

EO is based on maximizing the net present value (NPV) of the cash flows of a mining operation, based on the technical ability to focus on the interactions amongst the different stages in the mine to market value chain. These interactions then have major effects on decisions taken for all stages in the chain. Ten elements are involved in EO and are as follows:

1. *Pit optimization*: Uses the Lerchs-Grossman algorithm to determine a series of nested pit shells based on anticipated plant feed requirements and cut-off and cut-over grades between the various mine products.
2. *Pit phasing*: Considers staging based on the nested pits, minimum mining width, bench turnover rate, and high level planning assumptions to maximize NPV within the bounds of practical constraints. For an underground operation, the size and special relationships of stopes are the relevant parameters.
3. *Mine scheduling*: Considers the timing of mined material from multiple pit phases, multiple benches, and multiple stopes, while considering the mining constraints, the stope timing and development costs, and the value of the material accessible. The Whittle Software scheduler Milawa is applied and generates a different bench lead of each phase for each period.
4. *Cut-off grade optimization*: Use of dynamic cut-off and cut-over grades between the various destinations (waste, stockpile, processing) to optimize the value of material mined and processed. Dynamic cut-offs are based on continuous decisions of whether to send to the processor the extracted material or not.
5. *Stockpile*: Use of stockpiles based on grade, value, material, or combinations of these, to defer lower grade/value material until later in the life of the operation.
6. *Simultaneous optimization*: Given that each decision depends on previous decisions, mine planning is formulated as a simultaneous decision making problem rather than a subsequent decision making problem. The optimizer iterates seamlessly between the previous three steps (schedule, cut-off, and stockpile). Prior to this step, the mechanisms are applied sequentially. It is understandable that changing

the cut-off grade substantially renders the original mine schedule no longer optimal. An iterative approach can sometimes improve the result but cannot match a proper simultaneous optimization. From this step forward all mechanisms are simultaneous. Prober is capable of performing simultaneously from a set of nested shells produced by Lerchs-Grossmann (Whittle, 2009b).

7. *Processing*: Alternative grind sizes, thicker cuts, residence time, or other processing parameters relating to throughput are considered for each period, leading to dynamic combinations of throughput versus recovery over the life of the operation. Changes in the ore feed, the pressure on bottlenecks, and the time value of money lead to different outcomes in each period.

8. *Product*: Changing the concentrate grade affects the metal recovery, the commercial value of the product, and the rate at which product can pass through downstream bottlenecks. Changes in the ore feed, the pressure on bottlenecks, and the time value of money lead to different outcomes in each period.

9. *Logistics*: Consideration of alternative and potentially more expensive transport routes for mined material or products can improve results.

10. *Capital*: Alternative mining fleet, plant, or materials handling facilities sizing can be considered and optimized simultaneously with the mechanisms mentioned above. Project sizing by component can have a material effect on project value.

For a gold operation such as Mana, steps 8 and 9 are rarely applicable, as the product is dore which is sold directly to a refiner, and logistics are usually not as complicated as in, say, a copper operation with concentrate pipeline or trucking.

### **Theory of constraints**

The manufacturing industry learned about the theory of constraints in the 80s, when the economic climate and competition made managers realize that minimizing unit cost was not necessarily the way to make money (Goldratt, 1997). In all businesses that produce something, there is a constraint or bottleneck, or usually several, which dictate the rate at which cash can be produced. Whatever this bottleneck is, it needs to be well-maintained, and a great deal of attention should be paid to it to make sure that it has the best possible utilization. Minimizing unit cost for the bottleneck is likely a detriment to this objective, and usually it is better to spend a bit more on capital and maintenance of this equipment because the entire enterprise depends on it. Analogies in mining are shovels, which carry a disproportionate share of the mining capacity compared to trucks or drills, which are usually (but not always) more plentiful. In a process environment, a ball mill is expensive and all of the material to be processed must pass through it, so it may well be the bottleneck.

In any business, there is a differentiation between variable costs, those directly related to producing one unit of product, and fixed costs, which are overhead and other costs that occur regardless of production. It is important to separate these costs, and there is always a great deal of discussion about how to differentiate these costs. Most costs are semi-variable and have semi-fixed characteristics. Managers generally have a good handle on what the breakdown is for these and how to separate them. For optimizing a mining enterprise, one of the techniques employed by Whittle Consulting is to take the period costs, those which occur every period regardless of production, and apply those to the bottle neck in the system. This extra cost burden forces the optimizer to consider not only the benefit of the value of the material but also the cost of putting an increment of material through the bottleneck. Rock hardness is a good example of how this is applied in practical terms. If an ore is high grade, but also hard, there is a

breakover point where the additional cost of grinding the hard ore overtakes the value of the material. This can be optimized.

### **Cut-off grade optimization**

Ken Lane's seminal book *The Economic Definition of Ore* (1988) and more recently Jean-Michel Rendu's book *An Introduction to Cut-off Grade Estimation* (2008) demonstrate the importance of cut-off grade optimization. In the simplest terms, the concept is to run the highest grade most cost-effective material through the plant. The cut-off grade to achieve this is a dynamic one, and often it is difficult to know exactly what it is. Many operations do this intuitively, by stockpiling material and then running the highest available grade. With a powerful multi-parameter optimizer running on today's microcomputers, it is possible to quantify what this cutoff grade should be and to plan the mine around getting the best material to the plant.

### **Mana Gold Mining Operations, Burkina Faso**

The Mana gold deposits and mines are located in the southwest of Burkina Faso, in the provinces of Balé and Mouhoun, approximately 200 km by road from the capital of Ouagadougou. The Mana gold deposits are located within the limits of ten exploration permits and one mining permit, totaling 1,995 km<sup>2</sup>, including the addition of the Saoura Permit (April 15, 2010) and the Bombouela Nord Permit (December 30, 2010). The mining permit covers the current open pit operations of Wona to the north and Nyafé to the south. All permits are in good standing. Three separate deposits are under mining process and new zones have been introduced in the Fofina- Fobiri area on the Mana property. To the north and next to the processing plant is the Wona (including Kona) deposit. About 10 km south of Wona is the Nyafé deposit. Next to Nyafé and about 300 m to the southeast is the so-called Filon 67 deposit.

### **Geology of the Deposits**

The Mana property is mostly covered by sedimentary, volcano-sedimentary and volcanic rocks of Birrimian age (paleo-proterozoic) from the so-called NNE-SSW Houndé belt (or syncline) within the West African craton, which occupies most of Burkina Faso. Throughout the country, several of those greenstone belts dissect the craton and they play host to recognized gold deposits. Sedimentary, volcano-sedimentary and volcanic rocks in the belts are metamorphosed in the greenschist facies, and they have been subject to at least two deformation phases (a syn - and a post-schistous). Limits of belts with contiguous plutonic rocks correspond to shears in a generally NE-SW direction associated with those phases.

The Wona deposit is hosted in a series of highly deformed sedimentary (black pelites), volcano-sedimentary and meta-volcanic rocks. The gold mineralization has developed along a major NE-SW sub-vertical fault zone of regional extension. The thickness of that zone is about 200 m in the Wona pit sector. The mineralization is associated with a posterior lateral movement along faulting` with hydrothermal fluid circulation and intense silicification. The Nyafé deposit is hosted in a purely volcanic sequence with basalt and mafic to intermediate tuffs. From the observed morphology of pillows, the original stratigraphic sequence is subhorizontal but upside-down with pillow lava at the bottom, then pillow breccias, and finally massive lava at the top. The Filon 67 deposit next to Nyafé is composed of typical quartz veins associated with shear zones with dextral motion within a package of greenschist rocks. Those composite veins show textures of several successive fillings.

### **Mining**

Mining in the Wona pit is done on 3.3 m benches, with 6m<sup>3</sup>- class excavators and 40t trucks. The fleet is to be upgraded next year to achieve a mining capacity of 20M tonnes per annum. Mining at Nyafe (a separate pit) requires a haul of 14 km to the processing plant at Wona. Costs for this additional haul have been modeled.

## **Processing**

Mill start-up took place on February 15, 2008 with a 2,000 tpd ball mill, and the first doré bar was poured on March 31, 2008. The 4,000 tpd ball mill started operation on July 29, 2008. In June 2010, a semi-autogenous grinding (SAG) mill was added to increase the mill throughput at 6,000 tpd. In December 2010, another plant expansion was completed to add two additional carbon-in-leach tanks (CIL) to optimize gold recovery. In February 2011, a fourth phase of plant expansion to attain up to 7,200 tonnes per day (“tpd”) in bedrock and up to 8,000 tpd in blended ore was launched. The primary changes to the processing plant include addition of a pebble crusher, utilization of the third ball mill previously used as back-up, addition of two CIL tanks, and addition of a thickener, additional gensets, critical spares and some equipment capacity upgrades. Work index for all material types has been modeled, and costs for processing have been based on kWh/t. This was calibrated to be in the appropriate range of 7200 tpd in bedrock and 8000 tpd for blended material.

## **Business Model and Assumptions**

The optimization work is based on a business model using mining, processing, and market data and costs. The business model is created in an Excel spreadsheet, and can be readily manipulated for many different types of situations. The data for the Mana operations was acquired from managers, and the latest update to the optimization was based on data from the recently completed Feasibility Study. The Feasibility Study contained a new underground mine plan for the Wona Deep project and preliminary pit and phases for Wona based on different gold prices.

Base case assumptions include:

- All costs and underground capital are from the March 2011 Feasibility Study by Met-Chem.
- The block model and starting surfaces are the December 2010 versions.
- Open pit mining rate is 20 million tons per annum.
- Processing rate is based on power, and has been calibrated from work index information in the December 2010 block model and the designed power capacity and throughput.
- A bench drop rate of 10 benches per annum was used.
- Geotechnical data from Semafo was used for pit design.
- Stockpile inventories from the end of year 2010, plus tonnage and grade to account for balance of Nyafe and Filon 67 reserves were used.

## **Optimization Outcomes**

During the course of the optimization process, SEMAFO increased reserves and modified mining and processing plans as well as operational limits. As a result, there were essentially three optimization phases, and each had similar results. The latest optimization is outlined here.

The first step in an optimization process is to establish a base case, which is a business model and an optimizer run that matches a current plan. This helps establish a foundation that can be agreed on and helps the validation of future work. For the latest optimization work, there were two base cases, with varying gold prices. To assess the benefit of stockpiling, a run was completed that did not allow

stockpiling. The ability to stockpile material for later processing added 0.5% to the NPV. The next step was to assess the effect of cut-off grade optimization. Using a dynamic cut-off grade improved NPV by over 7.6%. Whittle Consulting then designed pits and phases for the Wona pits. The geotechnical parameters from Semafo were honored, and unsmoothed pit shells were generated. The best of the push backs were chosen to maximize NPV based on the cost and revenue data from the business model and the Prober optimized mod file. The outcome of the pit and phase design was an increase of an additional 15.9% in NPV. In total, the pits and phases combined with simultaneous optimization of cut-off grade with stockpiles increased NPV over the base case by 24.0%. These improvements are indicated in Figure 1.

Throughput versus recovery data is still being generated, and it is likely that there will be some value identified by increasing throughput in the near term to get more tonnage through the system and generate more cash. It is typical to see this reverse itself as time passes and the resource is depleted, so that by the end of the mine life the optimizer is running the mill at a lower throughput to gain the maximum recovery, as there is no longer any opportunity cost.

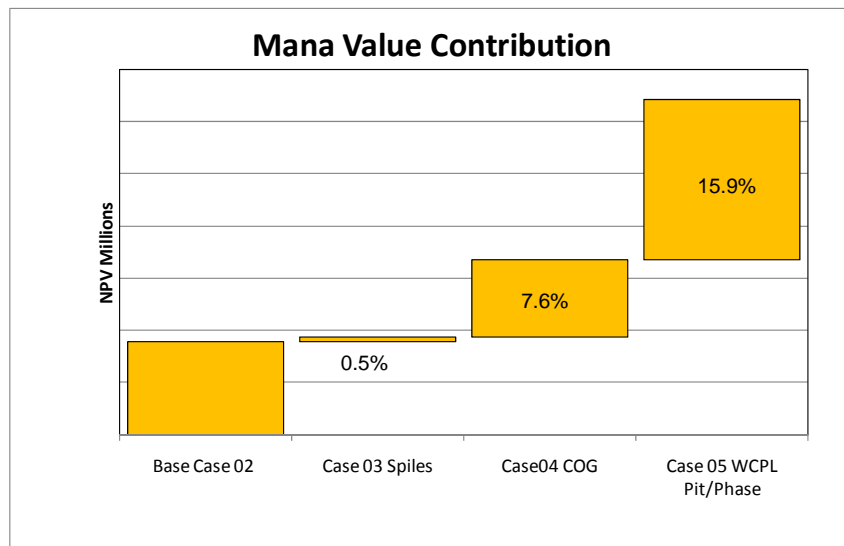
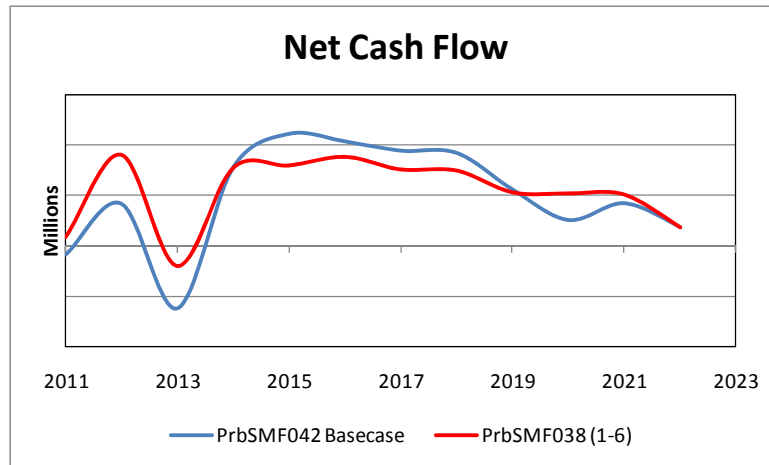


Figure . Mana Value Contribution



**Figure . Improvement in Net Cash Flow**

## Conclusions

The Mana Operations were a challenge to optimize due to the fast pace of development and the enviable position Semafo has with rapidly expanding resources. By utilizing a combination of costing methodology and sophisticated software tools, a gain of over 20% in project NPV has been identified. This manifests itself as an improvement in cash flow, as can be seen in Figure 2. The improvements came from the ability to stockpile material for processing at a later time, utilizing and optimizing a variable cut-off grade, and designing the pit and phases with a costing methodology that penalizes material that moves more slowly through the bottleneck in the system, in this case the processing plant, and more specifically, the mill circuit. EO is a significant tool that may assist mining ventures to make decisions regarding investment analysis, feasibility studies, due diligence, evaluation of emerging technologies, and changing financial valuations.

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