CORE
Metadata, citation and similar papers at core.ac.uk
Provided by University of Johannesburg Institutional Repository

Using Programming to Optimize Mineral Processing

Xiaowei Pan

ABSTRACT— Ore beneficiation at a mine could be described as complex and expensive, involving many balancing processes where material flow rates, size, density and other factors must all be in balance, if any degree of plant optimization is to be achieved. To determine the optimum setup for maximizing throughput at the final step in the beneficiation process, such as the dense media separation units, a mine optimizer is developed to maximize the production throughput as objective function, using constraint-based global optimization.

The mine optimizer uses a search engine to find a set of operational conditions, that will help achieve the maximum production within all constraints, such as the availability of plant, the capacity of all press units; the change in material size and property (between crushers) and other operational conditions at the mineral process plant. The result is that improving cheaper upstream processes, such as blasting, can significantly increase the throughput of expensive downstream processes, like crushing, through improved fragmentation of the ROM ore. For instance, if the ROM ore is not in the required range, the plant production is unbalanced and consequently the mine could loss production by 10-20%, even up to 50% of production loss in the worst case. On one hand, a finer ROM ore may result in lower production of both crushing and coarse separation by 50%, while other process units are running at 100% capacity, such as slimes and tailing dumping. In addition, a finer ROM ore may destroy the mineral value as well, such as in the cases of mining coal, iron ore, and diamond ore, where a higher price is paid for the products of larger size.

Keywords—Process optimization, mineral processing, process modelling, process simulation

Xiaowei Pan is with Department of Metallurgy, University of Johannesburg, phone: +27 83 456 3514; fax: +27 559 6513; e-mail: xpan@uj.ac.za.

I. INTRODUCTION

A typical mine includes two parts of operation, namely mining and mineral processing. The mining operation usually consists of planning; drilling; explosion; loading; and hauling. A mining operation of an iron ore mine is shown in **Figure 1**, with visible mining equipment and facility. A mineral processing operation normally has a combination of different processes.

Figure 1. A mining operation of an iron ore mine, including drilling; explosion; loading; and hauling

The main processes include crushing; screening; milling; separation; storage; stockpile; conveying; water treatment; tailing dump; slimes dam, etc. **Figure 2** depicts a mineral processing flowsheet of a diamond mine with the following process units **[1]**:

- Primary crushing
- Primary scrubber and screen
- Secondary crushing
- Secondary scrubber and screen
- Re-crushing
- Coarse module of dense media separation
- Fines module of dense media separation
- Stockpiles
- Water treatment

- Tailing dump
- Slimes dam

A balanced production plays an important role at any mines, involving mining and mineral processing. An unbalanced operation may destroy the value of minerals being processed and may result in lower productivity. It is well-known that the ROM ore size has a profound impact on the production of mineral processing plants. A suitable ROM ore size helps the downstream processes to achieve a balanced production. While, on the other hand, if the ROM size is not in the required range, the entire processing production will not be balanced. For instance, a large size ore from mining will require more work to crush it to smaller size. The coarser the ore is, the harder the crushers must work. When the crushers reach their limits, the production throughput will be lower. In such case, the mining operation will end with more capacities and those extra capacities may be wasted, including drilling; loading and hauling.

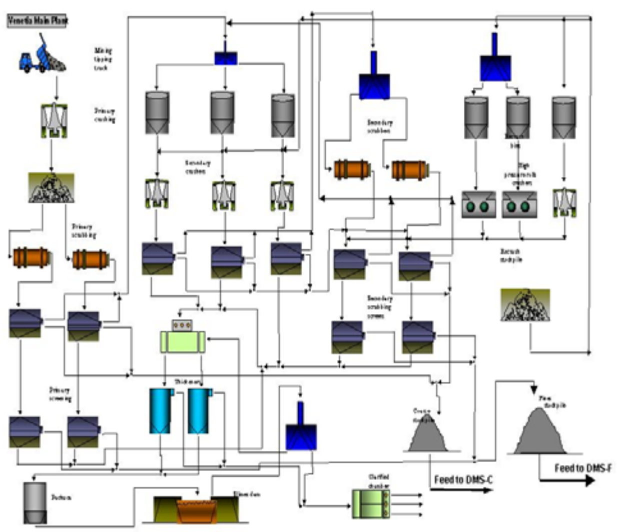

Figure 2. A typical mineral processing operation consisting of primary crusher plant; main treatment plant; recovery plant and water treatment plant. The main treatment plant includes scrubbing, screening, crushing, dense media separation

In spite of the advancement of technologies **[1-7]**, it is still very popular that the ROM ore size is not included as an important key performance indicator (KPI) at many mines. Instead, "meters" of drilling and "tonnages" of processed ore are used to measure the production at the mining and processing operations respectively. This article is attended to bridge some operational gaps between the mining and mineral processing plant with a focus on the size of the ROM ore.

II. DEVELOPMENT OF MINE OPTIMIZER

A software solution is developed in MS Excel to optimise a mineral processing plant shown in **Figure 3**, based on the previous work done on Mine Optimizer **[1]**. It consists of the following functions:

- Objective function
- System transfer function
- Global search engine
- System identification

The total feed rates of coarse module and the fines module of dense media separation (DMS-C and DMS-F), as shown in **Figure 3,** are used as the objective and the objective function (F) is defined as:

F = Max f(x) (1)

f(x) = DMS-C-Feedrate + DMS-F-Feedrate (ton per hour) (2)

Subject to:
System Transfer Function (STF) (3)

The system transfer function includes all forms of constraints that exist in a concerned mine operations, such as plant design capacities, operational conditions, safety requirements.

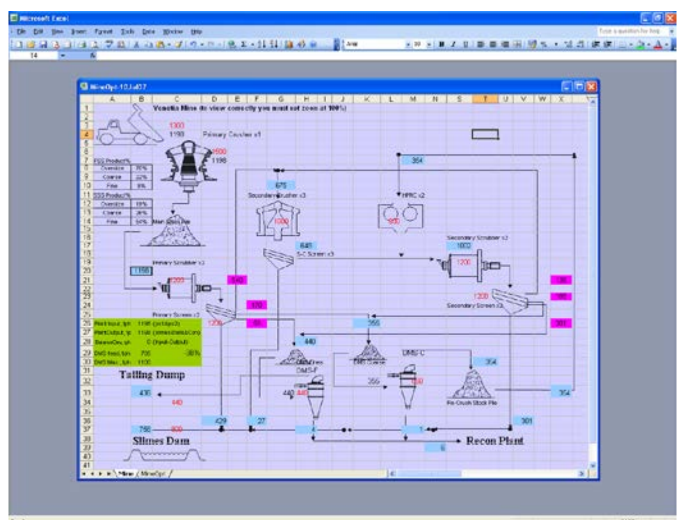

Figure 3. A diagram of mineral processing plant with products of coarse concentrate and fine concentrate. The processes include primary crushing (PC); primary screen (PS); secondary crushing (SC); secondary screen (SS), re-crushing (RC); fines dense medium separation(DMS-F) and coarse dense medium separation(DMS-C)

Global search engine is developed using generalized reduced gradient non-linear programming. System identification is used to determine what process variables should be selected and included for the optimization. Those selected variables are called independent variables. After the optimization, those independent variables will be used to present the optimal solutions. The following six variables are elected as independent variables, see in **Figure 3**:

- feedrate of oversize ore after primary crushing and scrubber/screen
- feedrate of coarse ore after primary crushing and scrubber/screen
- feedrate of fines ore after primary crushing and scrubber/screen
- feedrate of oversize ore after secondary/re-crushing and scrubber/screen
- feedrate of coarse ore after secondary/re-crushing and scrubber/screen
- feedrate of fines ore after secondary/re-crushing and scrubber/screen

The design capacities of the main process units are listed in **Table 1**. They include primary crushing (PS), primary screen (PS), secondary crushing (SC), re-crushing (RC), secondary screen (SS), water treatment (WT), coarse dense medium separation (DMS-C), fines dense medium separation (DMS-F).

TABLE 1. DESIGN CAPACITIES OF THE MAJOR PROCESS UNITS OF MINERAL PROCESSING PLANT IN TONE PER HOUR

No	Major Process Units	Design Capacity, ton/hour
1	primary crushing (PS)	1500
2	primary screen (PS)	1200
3	secondary crushing (SC)	1000
4	re-crushing (RC)	800
5	secondary screen (SS)	1200
6	water treatment (WT)	760
7	tailing handling (TH)	436
7	coarse dense medium separation (DMS-C)	660
8	fines dense medium separation (DMS-F)	440

The first three independent variables are used to indicate the optimal size distribution of ROM ore, produced by mining operation with processes like drilling, explosion, and even primary crushing at some mines. The other three independent variables are used to indicate the optimal size distribution, required to be produced by the secondary crushing, re-crushing units.

There two levels of optimisation in the mine optimiser, namely production optimisation of a mine and the production optimisation of processing plant, as indicated in **Figure 4** by buttons of “Start MineOpt” and “Start PlantOpt” respectively. When the mine optimization is executed, the search engine will try to find an optimal solution in terms of the six independent variables, as mentioned above. When the plant optimization is used, the ore size before secondary crushing will not be included. Therefore the search engine will try to find an optimal solution for the following three independent variables:

- feedrate of oversize ore after secondary/re-crushing and scrubber/screen
- feedrate of coarse ore after secondary/re-crushing and scrubber/screen
- feedrate of fines ore after secondary/re-crushing and scrubber/screen

Other unselected process variables become dependent variables and can be calculated using the independent variables. Many dependent variables are used to monitor and control the plant production, such as slimes rate at primary screen (PS-Slimes), slimes rate at secondary screen (SS-Slimes), feed rate at primary scrubber (PS), feed rate at secondary crushing (SC), feed rate at re-crushing/HPRC (RS), and etc, see in **Figure 4**.

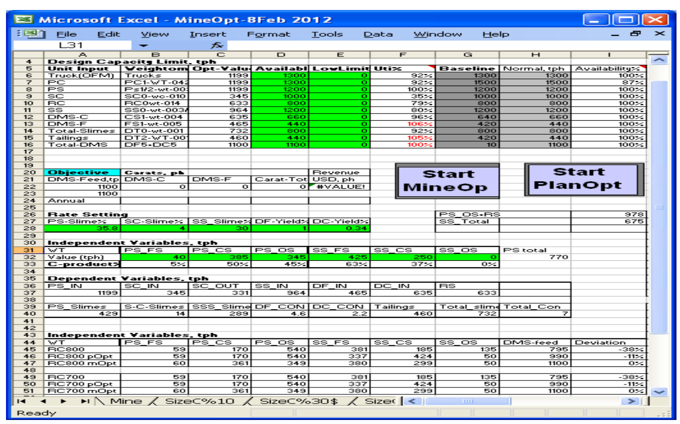

Figure 4. Mine Optimiser developed in MS Excel, including an objective function, a system transfer function, a global search engine and a system identification function

III. RESULT AND DISCUSSION

After primary screening unit, the ROM ore consists of 3 streams, namely fines, coarse and oversize. The effect of ROM ore size on production is shown in **Figure 5** with the coarse ore percentage measured at the output of the primary screen at 10% (C10%), 30% (C30%), 50% (C50%) and 70% (C70%). The total feed rate of both fines and coarse of dense media separation units is used to measure the mine production.

When the ROM ore consists of 70% coarse, the plant production can achieve its maximum of 100% production capacity with percentage of fines ranged up to 30%, indicated by C10% in **Figure 5**. It means that when the plant is fed with the ore containing of 70% of coarse, there are enough capacities of crushing at the plant to produce enough fines ore from the coarse ore to meet the maximum capacity of fines module of dense medium separation. At the same time, the coarse ore is reduced to the level that is just enough to meet the maximum capacity of the coarse module of the dense medium separation. Without reduction of coarse ore, the coarse module of dense medium separation may not have enough capacity to process all coarse ore, it will build up and fulfil the coarse stockpile, consequently the plant has to stop the feed of ore until there is enough space left at the coarse stockpile.

When the ROM ore consists of 50% coarse, the plant production can achieve its maximum of 100% production capacity with percentage of fines ranged up to 50%, indicated by C50% in **Figure 5**. The same explanation may apply from the case of ore with 70% coarse, as mentioned above.

With the feedrate of coarse stream at 50% or 70%, the processing plant can produce enough fines ore and reduce coarse ore to meet the max feed rates of both coarse and fines modules of dense media separation. Consequently the plant production can reach its 100 percent throughput.

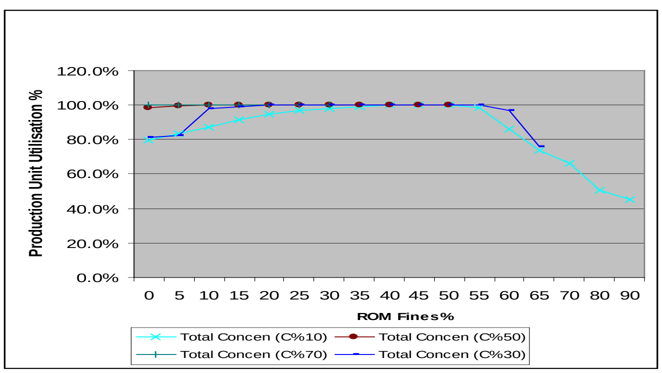

Figure 5. Effect of ROM ore size on the production of a mine with 10-20% production loss, even 50% in the worst case, if the ROM ore is not in the required range

When the processing plant is fed with less coarse ore with coarse stream of 30%, the plant can reach its maximum production only when the fines in the ROM is in the range of 10%-55%, indicated by C30% in **Figure 5**. The mineral processing plant will not be able to reach its maximum production if the plant is fed with ore containing of either less than 10% of fines or more than 55% of fines, due to too much fines (more than 55%) or too much oversize (more than 60%) in the ROM ore.

When the processing plant is fed with less coarse ore with coarse stream of 10%, the plant can reach its maximum production only when the fines in the ROM is in the range of 40%-50%, indicated by C50% in **Figure 5, 6**. The plant will not able to achieve it maximum production, if the fines in the ROM ore is either less than 40% or more than 50%, corresponding to the percentage of oversize in the ROM is more than 50% or less than 40% respectively. With such very small range of fines in the ROM ore, it is very difficult to achieve and maintain the maximum production in practice. Furthermore, when the plant is fed with the ore arbitrarily containing of as little as 5% of fines or as much as 90%, the plant could only achieve the production at 80% and 50% of its design capacity, respectively.

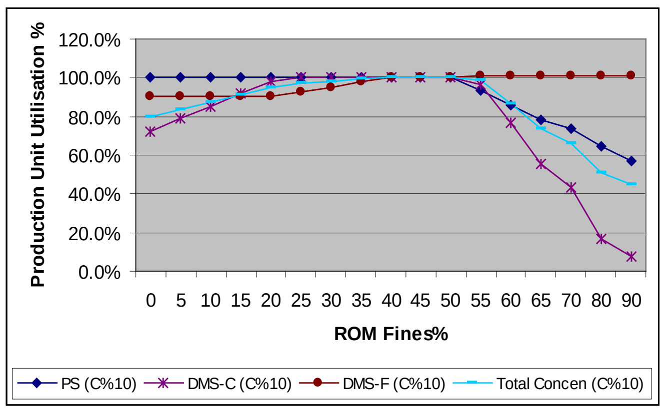

Figure 6. Effect of ROM ore size on the production of coarse module and fines module of dense media separation with 10-20% production loss, even up to 50% in the worst case, if the ROM ore is not in the required range

When the over size is too high in the ROM ore, the plant crushing capability is not big enough to produce enough fine/coarse ore to feed the fine/coarse dense media separation. On the other hand, when the fine size is too high in the ROM ore, the plant will not have enough capacity at the fines dense medium separation unit to process all fines ore, which will result in the full up of the fines stockpile, and consequently the plant has to stop feeding ore until there is enough space left at the fines stockpile of dense medium separation unit. At the same time the plant will not able to have enough coarse ore to feed the coarse dense media separation.

When the plant is fed with a ore of 10% coarse, the feed to coarse dense medium separation could be as low as 10% of its capacity if the fines ore is arbitrarily as high as 90%, resulting the plant production as low as 50%. Another factor is the capacity of tailing handling at the plant. When the content of fines in the ore is in the range of 40%-50%, the maximum capacity is reached at the process units of both primary screening (PS) and tailing, see **Figure 7**. When the content of fines in the ore is more than 50%, less oversize ore keeps crushers running at lower capacity, and produce lass slimes. As a result, a lower utilization occurs at primary screening (PS); total slimes, and dense medium separation. Only tailing unit is running at the full capacity of 100%, which may indicate that the tailing capacity becomes the bottom neck of the plant production. An increase of the tailing capacity should be considered if the plant wants to increase its production further in the future.

It is worthy noticing that a finer ROM ore may destroy the mineral value as well, where a higher price can be achieved when we sell the products with larger size, such as coal, iron ore, and diamonds in particular.

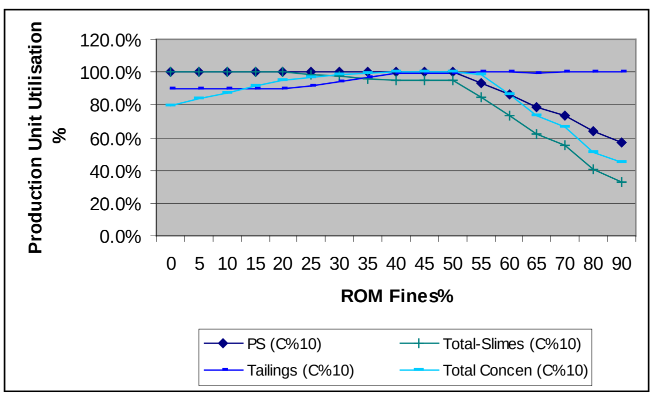

Figure 7. Effect of ROM ore size on the utilization of production units, showing 100% utilisation at tailing and primary crushing and screen with 60% to 20% utilisation of secondary crushing, if the ROM ore is 10% coarse

IV. CONCLUSION

The ore beneficiation at a mine could be described as complex and expensive, involving many balancing processes where material flow rates, size, density and other factors must all be in perfect balance, if any degree of plant optimization and efficiency is to be achieved. To determine the optimum set-up for maximizing throughput at the final step in the beneficiation process, such as the dense media separation units, a Mine Optimizer is developed using constraint-based global optimization.

The Mine Optimizer uses plant unit availability, capacity in tons per hour (t/h), change in material size (between crushers) and other constraints, such as the capacity of the main bottleneck. The result is that improving cheaper upstream processes, such as blasting, can significantly increase the throughput of expensive downstream processes, like crushing, through improved fragmentation of the raw material.

It is well-known that the ROM ore size has a profound impact on the production of mineral processing plants. A suitable ROM ore size helps the down stream processes to achieve a balanced production. While, on the other hand, if the ROM size is not in the required range, the entire processing production will not be balanced. For instance, if the ROM ore is not in the required range, the plant production is unbalanced and consequently the mine could loss product by 10-20%, even 50% in the worst case. On the other hand, a finer ROM ore may result in a situation of lower utilisation of both crushing and coarse separation by 50%, when other process units are running at 100% capacity, such as slimes, tailing dumping, even primary crushing and screening. At the same, a finer ROM ore may destroy the mineral value as well, in the cases of mining coal; iron ore; and diamond ore, where a higher price is for larger size of products.

REFERENCE

1. X. W. Pan, Constraint-Based Mine Production Optimization for a Diamond Mine, Proceedings of the 33rd International Conference on Application of Computers and Operations Research in the Mineral Industry, Santiago, Chile, 2007, pp477-pp483
2. A. B. Beleguudu**,** Optimization Concept and Application in Engineering, Prentice Hall 1999
3. E. Tsang, Foundations of Constraint Satisfaction, Academic Press Limited, 1993
4. T. C. Eisele; S. K. Kawatra; Simulation of a Novel Grinding Flowsheet to Prevent Overgrinding, Proceedings of the 33rd International Conference on Application of Computers and Operations Research in the Mineral Industry, Santiago, Chile, 2007, pp484-pp483
5. A. Dance, etc, Higher Productivity Through Cooperative Effort: A Method of Revealing and Correcting Hidden Operating Inefficiency, Proceedings of SAG 2006, Sep 23-27, Vancouver, Canada
6. J. W. Valery; Mine to Mill Optimization and Case Studies, Presentation on the VI Southern Hemisphere Conference on Mineral Technology, May 27-30, Rio de Janeiro, Brazil
7. W. Valery; A. Jankovic; D Larosa, etc, Mining and Milling Process Integration and Optimization, http://www.metso.com/in/india_articles.nsf/Webwid