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OPTIMIZATION OF MINERAL PROCESSING PLANT THROUGH ROM ORE SIZE

1. 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.

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

A mineral processing operation normally has a combination of different processes. The main processes include crushing, grinding screening, separation, storage, conveying, water treatment, tailing dump, slimes dam, etc.

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Figure 2 depicts a mineral processing flowsheet of a diamond mine with the following process units:

— 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.

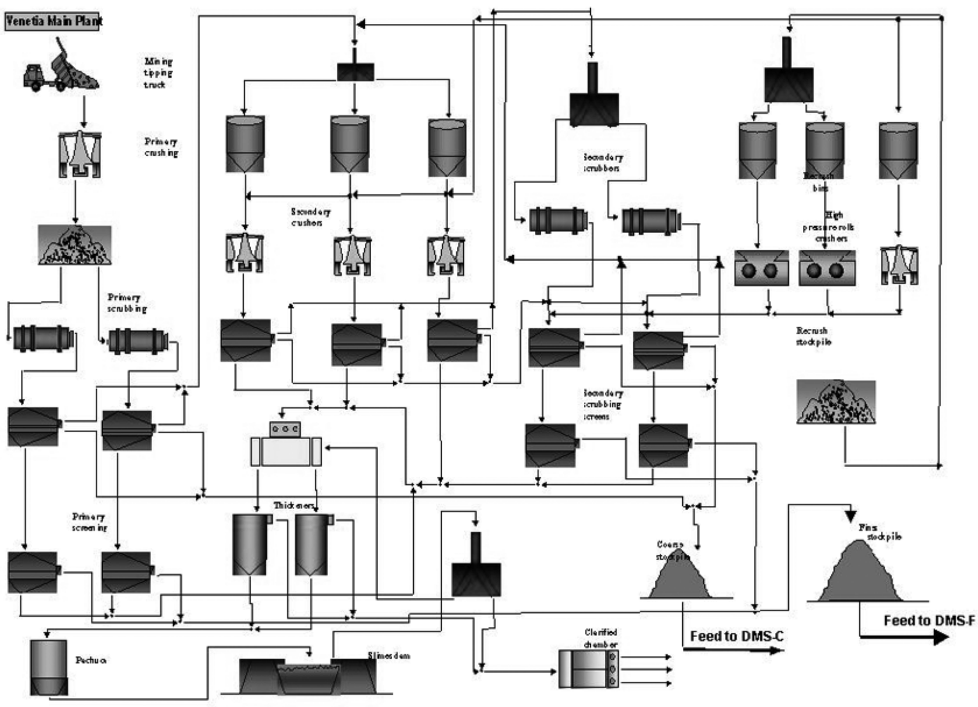


Fig. 2. A mineral processing operation of a diamond mine with primary crusher plant, main treatment plant, recovery plant and water treatment plant. The main treatment plant includes scrubbing, screening, crushing, dense media separation

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 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, 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. Due to the higher pressure imposed on the mineral processing operation, some capital expenditure may be required to add more crushers. A lower production or more capital expenditure occurs merely because the ROM ore is coarser. On the other hand, a finer ROM ore may result in a situation of lower utilisation of both crushing and coarse separation, see in Figure 3.

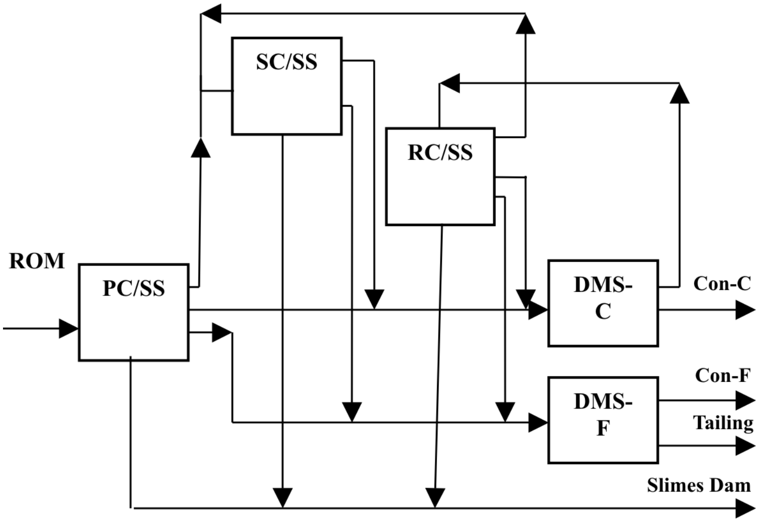


Fig. 3. A diagram of mineral processing plant with products of coarse concentrate and fine concentrate

In spite of the advancement of technologies, 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.

2. Optimization of mineral processing plant

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].

The processes include primary crushing and scrubber/screen (PC/SS), secondary crushing and scrubber/screen (SC/SS), re-crushing and scrubber/screen (CR/SS), dense media separation for fines (DMS-F) and dense media separation for coarse (DMS-C).

The mine optimizer consists of the following functions:

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

2.1. Mine Optimizer

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

$$F = Max\, f(x) \quad (1)$$

$$f(x) = DMS\text{-}C\text{-}Feedrate + DMS\text{-}F\text{-}Feedrate \text{ (ton per hour)} \quad (2)$$

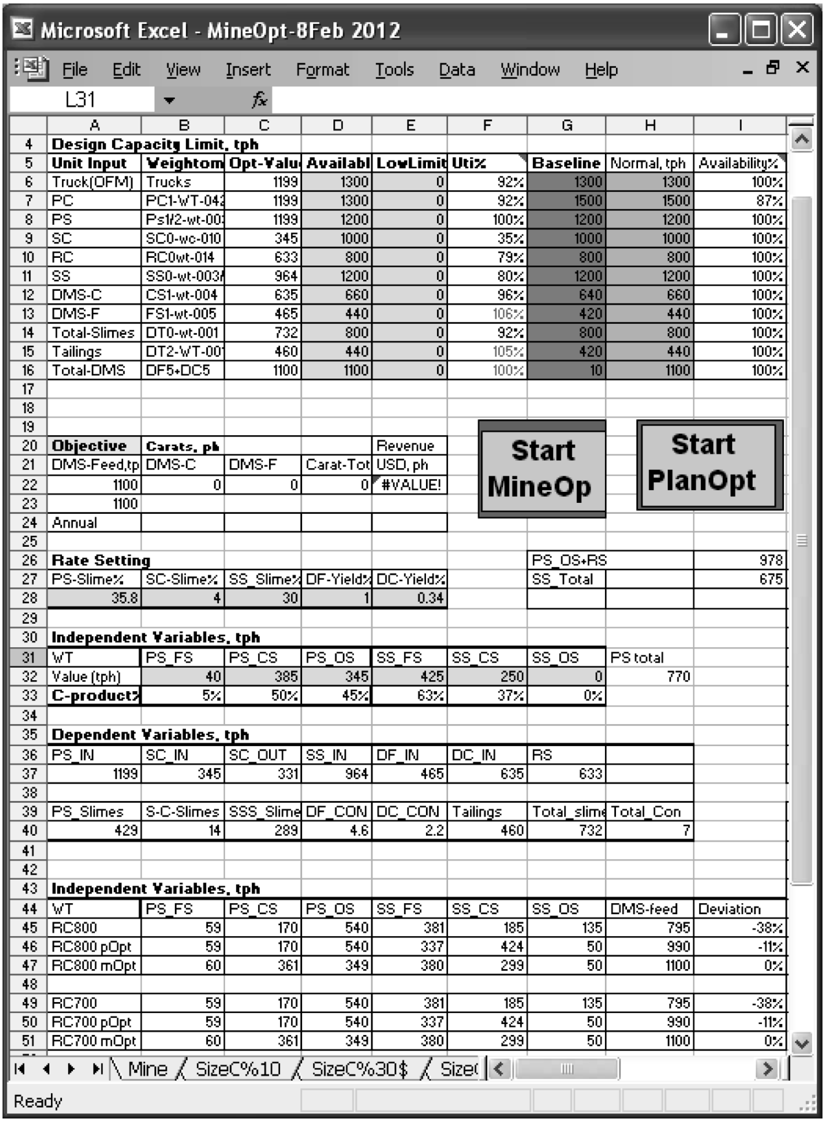
subject to:

$$System\ Transfer\ Function\ (STF) \quad (3)$$

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

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

- 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.



Microsoft Excel - MineOpt-8Feb 2012

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	A	B	C	D	E	F	G	H	I
4	**Design Capacity Limit, tph**								
5	**Unit Input**	**Weightom**	**Opt-Valu**	**Availabl**	**LowLimit**	**Uti%**	**Baseline**	Normal, tph	Availability%
6	Truck(OFM)	Trucks	1199	1300	0	92%	1300	1300	100%
7	PC	PC1-WT-04	1199	1300	0	92%	1500	1500	87%
8	PS	Ps1/2-wt-00	1199	1200	0	100%	1200	1200	100%
9	SC	SC0-wc-010	345	1000	0	35%	1000	1000	100%
10	RC	RC0wt-014	633	800	0	79%	800	800	100%
11	SS	SS0-wt-003	964	1200	0	80%	1200	1200	100%
12	DMS-C	CS1-wt-004	635	660	0	96%	640	660	100%
13	DMS-F	FS1-wt-005	465	440	0	106%	420	440	100%
14	Total-Slimes	DT0-wt-001	732	800	0	92%	800	800	100%
15	Tailings	DT2-WT-00	460	440	0	105%	420	440	100%
16	Total-DMS	DF5+DC5	1100	1100	0	100%	10	1100	100%
17									
18									
19									
20	**Objective**	**Carats, ph**			Revenue		Start MineOp	Start PlanOpt	
21	DMS-Feed,tp	DMS-C	DMS-F	Carat-Tot	USD, ph				
22	1100	0	0	0	#VALUE!				
23	1100								
24	Annual								
25									
26	**Rate Setting**						PS_OS+RS		978
27	PS-Slime%	SC-Slime%	SS_Slime%	DF-Yield%	DC-Yield%		SS_Total		675
28	35.8	4	30	1	0.34				
29									
30	**Independent Variables, tph**								
31	WT	PS_FS	PS_CS	PS_OS	SS_FS	SS_CS	SS_OS	PS total	
32	Value (tph)	40	385	345	425	250	0	770	
33	**C-product%**	5%	50%	45%	63%	37%	0%		
34									
35	**Dependent Variables, tph**								
36	PS_IN	SC_IN	SC_OUT	SS_IN	DF_IN	DC_IN	RS		
37	1199	345	331	964	465	635	633		
38									
39	PS_Slimes	S-C-Slimes	SSS_Slime	DF_CON	DC_CON	Tailings	Total_slime	Total_Con	
40	429	14	289	4.6	2.2	460	732	7	
41									
42									
43	**Independent Variables, tph**								
44	WT	PS_FS	PS_CS	PS_OS	SS_FS	SS_CS	SS_OS	DMS-feed	Deviation
45	RC800	59	170	540	381	185	135	795	-38%
46	RC800 pOpt	59	170	540	337	424	50	990	-11%
47	RC800 mOpt	60	361	349	380	299	50	1100	0%
48									
49	RC700	59	170	540	381	185	135	795	-38%
50	RC700 pOpt	59	170	540	337	424	50	990	-11%
51	RC700 mOpt	60	361	349	380	299	50	1100	0%

Mine / SizeC%10 / SizeC%30$ / Size(

Ready

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

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 optimisation 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 optimisation 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 scrubber/screen (PS-Slimes), slimes rate at secondary scrubber/screen (SSS-Slimes), feed rate at primary scrubber (PS-IN), feed rate at secondary crushing (SC-IN), feed rate at re-crushing crushing (RS), and etc, see in Figure 4.

3. Result and discussion

The effect of ROM ore size on the max production is shown in Figure 5. The total feed rate of dense media separation is used to measure the mine production. When the ROM ore is coarser with the feedrate of coarse stream at 50% or 70%, the processing plant can produce enough ore to meet the max feed rates of the coarse and fines modules of dense media separation. Consequently the plant production can reach its 100 percent capacity. When the processing plant is fed with a ROM ore with coarse stream of 30%, the plant will not reach it max production if the fines is less than 10% or more than 50% in the ROM ore, due to too much oversize or too much fine in the ROM ore. When the over size is too high in the ROM ore, the plant crushing capability is not big enough to produce enough fine ore to feed the fine dense media separation. On the other hand, when the fine size is too high in the ROM ore, the plant will not able to produce enough coarse ore to feed the coarse dense media separation, see Figure 6. Therefore less production occurs at the dense media separation and at the mine as a whole.

Furthermore when the processing plant is fed with a ROM ore with coarse stream of only 10%, the plant will not reach it max production if the fine is less than 40% or more than 50% in the ROM ore. In other word, the mine could only reach its max production, when the ROM ore is in the size range of 10% coarse, 40–50% fines and the rest of coarse size. 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 50% in the worst case.

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.

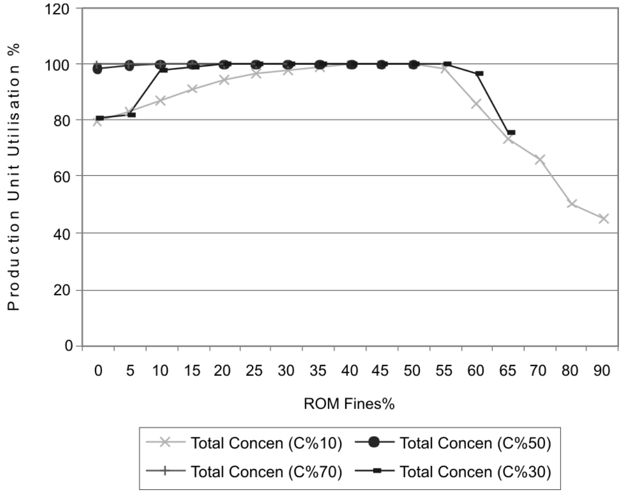

Fig. 5. Effect of ROM ore size on the production of a mine with 10–20% production loss, even 50% in the worst case, if the ROM ore is not in the required range

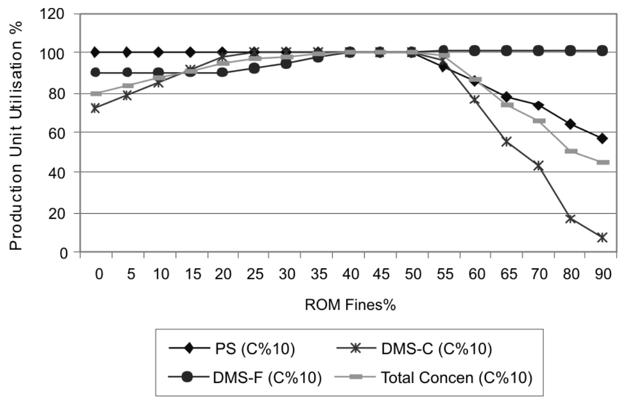

Fig. 6. Effect of ROM ore size on the production of coarse module and fines module of dense media separation with 10–20% production loss, even 50% in the worst case, if the ROM ore is not in the required range

A lower production or more capital expenditure occurs merely because the ROM ore is coarser. On the other hand, a finer ROM ore may result in a situation of lower utilisation of both crushing and coarse separation by 50%, see Figure 7. Meanwhile other process units are running at 100% capacity, such as slimes, tailing dumping, and primary crushing and screening, see in Figure 8.

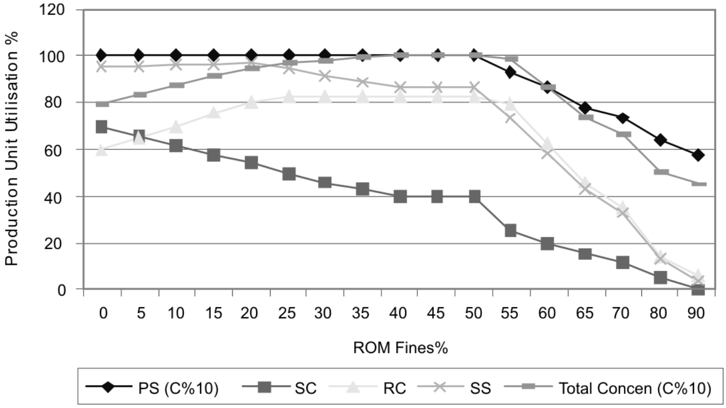

Fig. 7. Effect of ROM ore size on the utilization of production units, showing less 80% utilisation of re-crushing and 60% to 20% utilisation of secondary crushing, if the ROM ore is 10% coarse

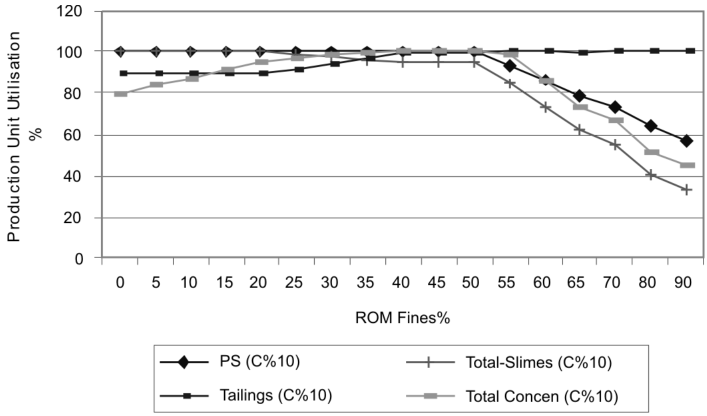

Fig. 8. Effect of ROM ore size on the utilization of production units, showing 100% utilisation at tailing and primary crushing and screen with 60% to 20% utilisation of secondary crushing, if the ROM ore is 10% coarse

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 if compared with a less coarse ore being processed. In such case, the mining operation will have more capacities and those extra capacities may be wasted, including drilling, loading and hauling. Due to the higher pressure imposed on the mineral processing operation, some capital expenditure may be required to add more crushers.

It is well-known that the ROM ore size has a profound impact on the production of mineral processing plants. Site specific models are developed for blast fragmentation, crushing, grinding and flotation by Metso [2, 3]. This allows customised blast patterns to be used for optimising performance of blasting, crushing and grinding. For each ore type, blast designs are recommended to generate the optimal fragmentation size for downstream processes. This may involve an increase or decrease in energy level (or power factor) depending on the rock characteristics of ore type.

4. 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. The Mine Optimizer can be regarded as the strategic plan for the operation of the mine. Next target comes the physical implementation of that plan through measurement and control.

A balanced production plays an important role at any mining operations 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 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.

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