System Integration of Automated Mine Optimization System

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ABSTRACT: With the advancement and applications of technologies in mineral processing industry, an automated mine optimization system is developed to include the following functions: mine production optimizer; various dynamic crusher controllers; and a set of soft sensors.

The system consists of a real-time engine to run optimizer, dynamic controllers and soft sensors. The real-time engine is integrated with process control systems at a mine, including mining dispatch system and geological data base through ODBC protocol, processing plant SCADA system and production reporting systems via OPC protocol. The system can potentially help increase production output up to 30% of a mine with mining and mineral processing operations, such as diamond mine, iron ore mine, chromite ore mine, manganese ore mine, coal mine, etc.

Key word: process optimization; process control; soft sensor; smart sensor.

1. INTRODUCTION

Traditionally, a mining operation has been perceived as two distinct stages: 1) mining to extract valuable minerals from the round, and 2) processing and converting the minerals into a marketable end-product. However, mining and processing are intimately linked, particularly when reducing particle size. The relationship between ore characteristics and downstream processing is well known in the mining industry. In fact, the very definition of a mineral deposit as an ore body depends on its susceptibility to processing in an economical manner.

Mines are usually comprised of ore bodies of varying characteristics. Some ore bodies are composed of extremely hard material that is difficult for crushers to handle and that therefore have repercussions with respect to downstream processes, while slippery ore bodies (with clay) clog up machinery and present another production problem. Amongst such variances, production has to remain steady, efficient and profitable. One way to meet the challenge of various ore bodies is to mine and process ore in accordance with the characteristics of ore bodies, considering the production requirement and process constraints.

A concept called mine-to-mill was described by Robertson and Sehic in 1993[1], and is often discussed by mine and processing operators. Unfortunately, it is difficult to accomplish simply for two reasons: 1) mining processes, including drilling, blasting, loading, and transport, may allow for segregation of mined ore by composition, mineralogy, or other characteristics important in subsequent processing; 2) processing facilities may not allow segregated storage of ore, at least not to the extent that might be used in an optimized operation.

To operate a mine properly, production throughput must be balanced so that bottlenecks or under-utilisation of plant equipment is minimised or even eliminated. A balanced operation requires all plants and process units to run at a designed throughput, from mining to mineral processing, including planning, drilling, explosion, crushing, separation, transporting, and water treatment, etc, see in figure 1[2].

An Imbalanced production means that plant units aren’t synchronized and this leads to stop-start operations, which are not only inefficient but can also result in increased maintenance costs. To achieve a balanced production at a mine, it is imperative to have a designed throughput target for each process units, and then to operate all
production units in accordance with the designed throughput targets.

Fig. 1. Depiction of a mine production including mining and mineral process operations

To be efficient in production throughput, we rely on the process availability at the mine. The process availability includes material availability, people availability, and equipment availability in particular. Process availability drops to zero the moment a weightometer or densitometer fails as the production cannot continue to operate without those critical measurements. Stoppages can cost as much as half a million Rand an hour and that is why equipment failure is receiving urgent attention. With the advanced capabilities of state-of-the-art mine control systems, it is possible to combine the knowledge of ore type, mineralogy, and other characteristics, to achieve an improved level of control in mineral processing and to allow optimization of the mine processes on a real-time basis [1-9].

2. CONCEPT OF AUTOMATED MINE OPTIMIZATION SYSTEM

In general, a mine operation consists mainly of mining and mineral processing. Mining operation includes planning, drilling, explosion, loading; hauling. Mineral processing normally has the following operations: crushing; screening; washing; transporting; separation; sorting; storing; water treatment, etc. The figure 2 shows a typical mineral processing operation, including: primary crushing; primary scrubbing and screening; secondary crushing; secondary scrubbings and screening; re-crushing; dense media separation; and water treatment. Run of mine ore is fed to primary crusher and ends in main stockpile. After primary scrubbing, ore is screened into oversize; coarse and fines. The oversize ore is fed to secondary crushing plant, and the coarse and fines are stored in coarse stockpile and fines stockpile before being fed to dense media separation plant. After dense media separation, coarse ore is fed to re-crushing stockpile prior being sent to re-crushing plant.

Fig. 2. Mineral processing operation with crushing; scrubbing; screening; separation; storing; and water treatment, etc

When the production is in balance, all levels of the four stockpiles should change at the same rate, which results in all stockpile levels move up or down simultaneously. When the production is not in balance, stockpile levels move up or down unevenly, which results in one or more of the four stockpiles reaching full level and one or more of the stockpiles becoming low or empty at the same time. When a stockpile level is low, the feed to its downstream has to be reduced or even stopped, which results in a lower utilization of all downstream processes. If, for instance, the main stockpile level is low, then the entire processing operation must be reduced or stopped due to lack of ore to feed. And on other hand when a stockpile is full, the production of its upstream processes must be reduced or even stopped, which results in a lower utilization of all upstream processes. It is imperative to maintain a balanced production at all time, in order to utilize all its production capability to achieve an optimal and sustainable production.

To achieve a balanced and optimal production at a mine, we must consider 2 tasks at least. The first is to have an optimal production plan, including a set of optimal production targets for all process units. And the second is to make sure that all those optimal targets in the mentioned optimal
production plan must be achieved at all process units by using all resources available. To achieve the mentioned two tasks, all measurements, equipments and systems at the mine must be running and available in real time, particularly those critical measurements such as weightometers, densitometers, ore types, stockpile levels. Consequently it is proposed to have a system so-called automated mine optimization system with 3 levels, see in figure 3 [9]:

(1) Mine production optimizer
(2) Various dynamic controllers
(3) A set of soft sensors

3. SYSTEM INTEGRATION

The system architecture of automated mine optimization system can be seen figure 4. It includes the following functions:

- ODBC connection to mining dispatch real time database (read)
- OPC communication with real time plant SACAD (both read and write)
- Automated mine optimization system engine
- Heart beat to monitor the communication
- Email dispatch function to send alert messages

The Amos engine consists of the following system blocks, see in figure 5:

- Mine production optimizer
- Dynamic nonlinear crusher controllers
- Ore type soft sensor (ore tracking system)
- Weightometer soft sensors
- Stockpile level soft sensors
- Email dispatch function to send alert messages

Data on the arrival of trucks at the primary crusher is available in the mining realtime database together with tons per truck and the ore type loaded. Amos engine reads this information from the mining database by using the ODBC protocol and provide to ore type soft sensor. Production data from the processing plant SCADA system is fed to Amos engine using the OPC protocol, such as bin levels, stockpile levels, crusher gaps, crusher power and currents, as well as feed rates around the plant. The communication system can be seen in figure 6.

Using internal models, the engine then calculates the rates at which the ore moves through the plant, and it also works out the characteristics of each ore type that is currently passing through each process stage including:

1) Primary crusher
2) Primary stockpile
3) Primary scrubbers
4) Secondary crushers
5) Recrush stockpile
6) Secondary scrubbers
7) Fines DMS
8) Fines stockpile
4. STRUCTURE OF AUTOMATED MINE OPTIMIZATION SYSTEM

Automated mine optimization system is developed to help achieve a balanced and optimal production at a mine, see in figure 7. Amos consists of the following main functions:

- Realtime communication to mining and processing plant systems
- A mine production optimizer
- Dynamic crusher controllers
- Weightometer soft sensors
- Stockpile level soft sensors
- Ore type soft sensor (ore tracking system)

4.1 Mine Production Optimizer

The mine production optimizer is developed using the principle of constraint based global optimization [2]. The production optimizer includes the following basic components:

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

Fig. 7. Structure of automated mine optimization system, including ODBC and OPC protocol communications, mine production optimizer, dynamic crusher controllers, various soft sensors

In general, an optimization should start with an objective at the business level, such as the profit of a mine operation in a certain period. An objective function for the profit of a mine is complicated and involves many factors, including product price; product volumes; production cost; cost of sales, stock control, etc. As soon as the production of a mine is concerned, the throughput of production may be selected as production objective, such as ton per hour (t/h), rather than profit. A production optimizer is used to find a solution that satisfies all constraints and maximizes the objective of production throughput at a mine. The following notation is used for a mathematic definition of the mentioned terms:
Maximum $F = \text{Maximum } f(X)$ \hspace{1cm} (1)

Subject to

$g(X)$ \hspace{1cm} (2)

Where $F$ is the objective of production throughput in t/h, $f(X)$ the objective function, $X$ is an $n$-dimensional variable vector representing an optimal solution with $n$-independent variables, $g(X)$ is the system transfer function in $n$-dimensional vector.

The system transfer function includes all forms of constraints that exist in the concerned mine, including: equipment capability; process limits and operational conditions. The system identification is used to find the minimal numbers of variables and what variables they are, so the optimal solution can be presented with those independent variables.

From those independent variables, other variables (dependent) can be calculated. Many those dependent variables are usually used to monitor and control the production. The optimal search engine is developed using generalized reduced gradient, non-linear programming. In accordance with the nature of the objective function and system transfer function, different techniques can be used to develop an optimal search engine, including linear programming; non-linear programming; dynamic programming and genetic programming. The abovementioned optimization techniques have their limitations and should be considered and be used differently with relevant applications.

With many applications\cite{1,2,3}, the mine production optimizer can help to improve the production throughput up to 30% when a mine is operated in accordance with the optimal throughputs of all process units determined by the mine production optimizer, see figure 8. To achieve those optimal throughput targets at all process units determined by the mine production optimizer as mentioned above, it is necessary to control the ore size at the following process units: drilling; blasting; and various crushers. At the primary screen, for instance, the ore size must be in the range: 207 t/h for oversize; 309 t/h for coarse and 190 t/h for fines. The ore size range is made by mining and primary crushing plant. If the mine uses different drilling and blasting, the primary crushing may not able to produce the ore size range required for an optimal production. If the ore has more oversize or coarse after primary crusher, it will require secondary crusher unit and re-crusher unit work harder, provided that those crushing units have more capacity.

![Fig. 8. Illustration of an optimal mine production with required throughput targets indicated in pink, resulting an improvement of 32%](image)

### 4.2 Dynamic Controllers

To achieve the required range of ore size, all crushers should be controlled, including primary crushers, secondary crushers, and re-crushers. Multi inputs and multi outputs, dynamic controllers can be developed and implemented to control all crushers\cite{2,4}, see in figure 9.

![Fig. 9. Crusher neuro-controller to control the ore size range determined by mine production optimizer](image)

The crusher neurocontroller was developed and tested at a diamond mine\cite{4}. The technology we can use to develop crusher controllers include CSense (Csense Systems, a company of GE group); Pavilion8 (Pavilion Technology, a company of Rockwell group; Aspen and Prime (Rand Control Systems).
4.3. Soft Sensors

A soft sensor is a piece of software that has the same function as a physical, real-time sensor but that relies on a virtual model of the physical sensor for its accuracy. So, a weightometer soft sensor, for example, can be created from knowledge of the behaviour of a physical weightometer at a specific location in the plant. Should the physical weightometer fail or provide readings that are obviously flawed, its soft equivalent can provide the required information and allow the plant to remain operative. At one mine, 31 individual weightometer models have been developed to work in conjunction with crushers, screens, scrubbers, conveyors, pumps, dense media separation cyclones and other equipment. Soft sensors have proved to be a useful and powerful tool in the determination of process variables difficult to measure directly. In general, for this kind of variables, it is necessary to have proper dynamic models that can reproduce the behaviour of variables in time. Often techniques used to construct soft sensors need high precision in order to develop accurate, dynamic models. A good approach is to use recursive linear models, but with a limited application, and in this case, neural networks have proven to be a powerful tool for non-linear modelling.

It is important to ensure that all critical measurements, used by the crusher controllers and mine optimizer, are available in real time and all time. The crusher controller will not function properly if one of the critical measurements has failed. A set of soft sensors have been developed and used to support the crusher controllers and mine optimizer, including:

- Ore type soft sensor
- Weightometer soft sensors
- Densitometer soft sensors
- Stockpile level soft sensors

Both weightometer and densitometer soft sensors provide a backup function to its relevant devices. The stockpile level soft sensors and ore type soft sensor provide the information regarding the levels and ore type, which are not measured and therefore not available in real time.

The ore type soft sensor provides ore type information real time to all production units by using mining data available in geological database and dispatch database (Wenco DB). Figure 10 displays the ore type soft sensor providing ore type information to all production units in a mineral processing operation, including percentage of mixed ore, ore grade, ore density, hardness, etc. The fines stockpile level provided by a stockpile soft sensor also can be seen in figure 10.

Fig. 10. Display of ore type soft sensor in a SCADA window providing ore type information to all process units at a mine, including percentage of mixed ore (colored pie), ore grade and ore density.

5. CONCLUSION

With the advancement and applications of technologies in mineral processing industry, an automated mine optimization system is developed to include the following three functions: (1) mine production optimizer; (2) various dynamic controllers; and (3) a set of soft sensors. The system consists of a realtime engine to run optimizer, dynamic controllers and soft sensors. The realtime engine is integrated with process control systems at a mine. It reads data from mining dispatch system and geological data base through ODBC protocol, and reads and writes data to plant SCADA system and production reporting systems via OPC protocol. The system can potentially help increase production output up to 30% of a mine with mining and mineral processing operations, such as diamond mine, iron ore mine, chromite ore mine, manganese ore mine, coal mine, etc.

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