# Automated Mine Optimization System for Diamond Mines

Xiaowei. Pan

*Abstract*—A diamond mine generally consists of mining and mineral beneficiation operations. Mining operation includes planning, drilling, explosion, loading; hauling and mineral processing normally has the following operations: crushing; screening; washing; transporting; separation; sorting; storing; water treatment, etc. The operation could be described as a complex and expensive balancing act where material flow rates, size, density and other factors must all be in required balance if any degree of plant optimization and efficiency is to be achieved. One of the main objectives to optimally operate a mine is to maintain balanced production among all product streams.

To achieve a balanced and optimal production at a mine, two tasks at least must be considered. The first is to have an optimal production plan, including a set of optimal production targets for all process units. And the second task 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, equipment and systems at the mine must be available in real time, particularly those critical measurements such as weightometers, densitometers, ore types; stockpile levels. 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. Over the past ten years, a large amount of work has been done to develop the system, started from forming the concept to testing and implementation at various mines. The system can potentially help improve the production throughput up to 30% at the mineral processing operation of a mine.

*Keywords*— Diamond mine, process optimization, process control, soft sensor, smart sensor

## I. INTRODUCTION

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 to process ore in accordance

Xiaowei. Pan is with the Department of Metallurgy, University of Johannesburg, PO Box 17011 Doornfontein, 2028 Johannesburg, South Africa, phone: +27 11 559 6371; fax: +27 11 559 6194 ; e-mail: xpan@uj.ac.za

with the characteristics of ore bodies, considering the production requirement and process constraints.

To operate a mine properly, production throughput must be balanced so that bottlenecks or under-utilization of plant equipment is minimized 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 Fig. 1. 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.
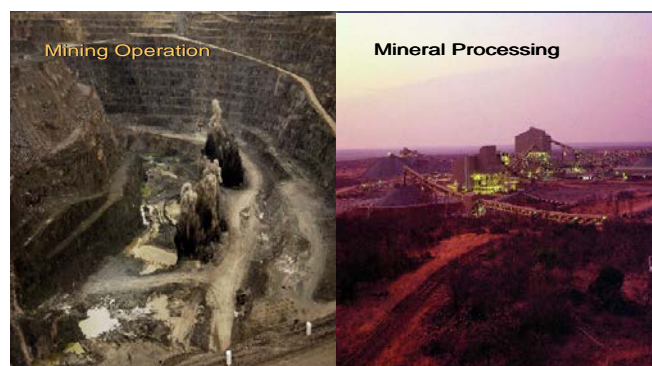


Fig. 1 Depiction of a mine production including mining and mineral process operations

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.

## II. CONCEPT OF AUTOMATED MINE OPTIMIZATION SYSTEM

Mineral beneficiation processes could be described as a complex and expensive balancing act where material flow rates, size, density and other factors must all be in required

balance if any degree of plant optimization and efficiency is to be achieved. One of the main objectives to optimally operate a mine is to maintain balanced production among all product streams. 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. A typical mineral processing operation is shown in Fig. 1, including: primary crushing; primary scrubbing and screening; secondary crushing; secondary scrubbing 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.
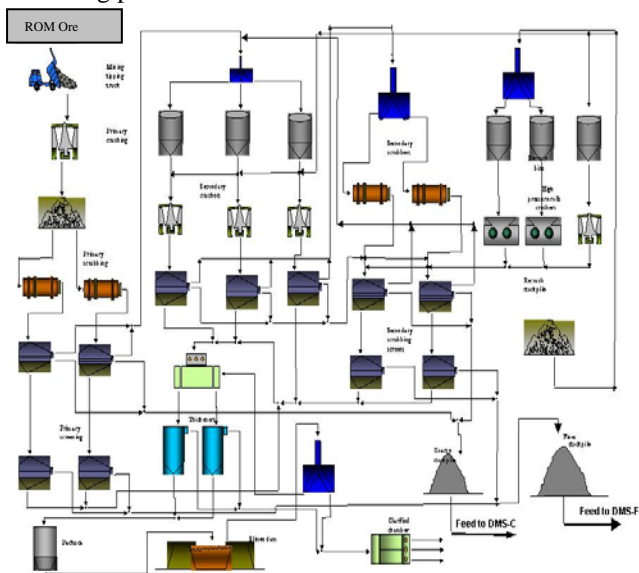


Fig. 2 Mineral processing operation with crushing; scrubbing; screening; separation; storing; and water treatment

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 stockpiles reaching full level and/or one or more of the stockpiles becoming low or empty at the same time. When a stockpile level is low, the feed rate to its down-stream has to be reduced or even stopped, which results in a lower utilization of all down-stream 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 up stream 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 task is to have an optimal production plan, including a set of optimal production targets for all process units. And the second task 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, equipment 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 (AMOS) with the following 3 levels: (1) mine production optimizer; (2) various dynamic controllers; and (3) a set of soft sensors, see in Fig. 3.
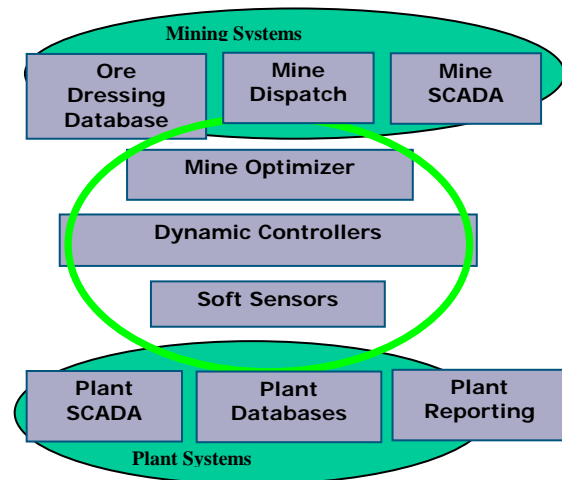


Fig. 3 Concept of automated mine optimization system, consisting of mine production optimizer; various dynamic controllers; and a set of soft sensors, in association with mining systems and plant systems

## III. STRUCTION OF AUTOMATED MINE OPTIMIZATION SYSTEM

### A. Mine Production Optimizer

The mine production optimizer is developed using the principle of constraint based global optimization [1]. The production optimizer includes the following basic components:

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

In general optimization system 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 optimization 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 = Maximum f(X)         (1)
Subject to
           g(X)                         (2)

Where F is the objective of production throughput in t/h, f(X) the objective function, X is n-dimensional variable vector representing an optimal solution with n-dimensional vector of 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 should be, 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 [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 Fig. 4.

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.
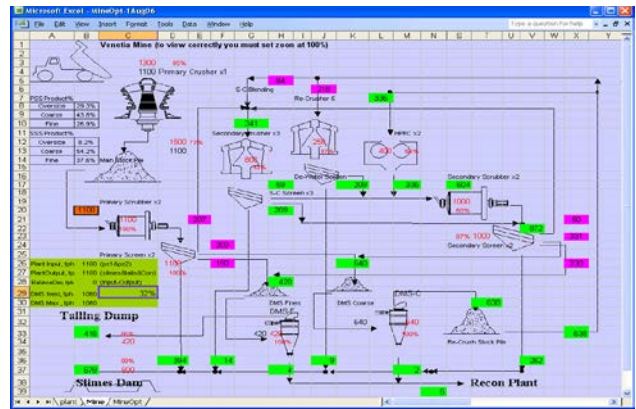


Fig. 4 Illustration of an optimal mine production with required throughput targets indicated in pink, resulting in an improvement of 32%

### B.  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 [2, 4], see in Fig. 5 and 6.
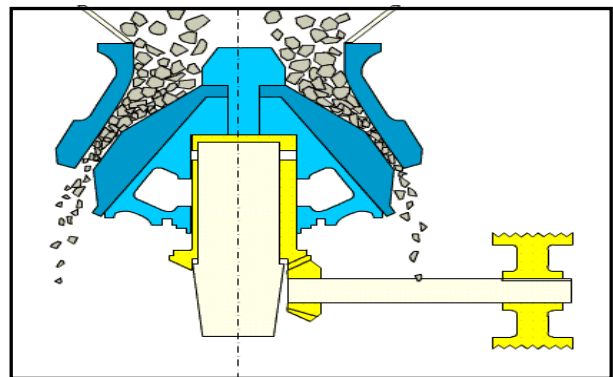


Fig. 5 Illustration of a cone crusher used widely in mineral processing operation
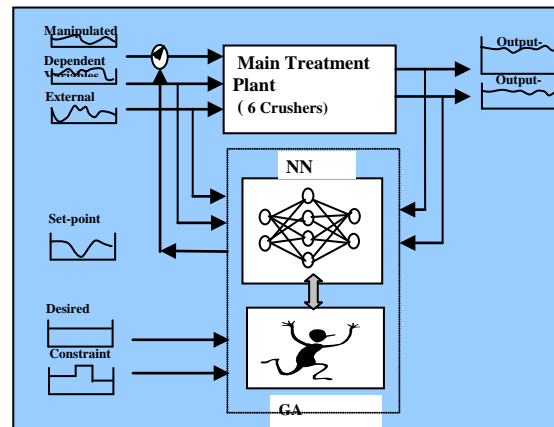


Fig. 6 Crusher neuro-controller to control the ore size range determined by mine production optimizer

The crusher neuro-controller was developed and tested at a diamond mine. The technology used to develop crusher controllers includes CSense (Csense Systems, a company of GE group ); Pavilion8 (Pavilion Technology, a company of Rockwell group.

### C. 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 behavior 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.

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
- 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 used in a mineral processing operation by using mining data available in real time in geological database and truck dispatch database (Wenco DB). The architecture of ore type soft sensor is shown in Fig. 7. The ore type soft sensor providing ore type information to all production units in a mineral processing operation is displayed in Fig. 8, 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 Fig. 8.

A lot of efforts has been made to develop, testing and implementation of soft sensors, including densitometer soft sensor and weightometer soft sensors [2, 6, 7]. A soft sensor is developed to monitor copper grade in flotation processes [8].
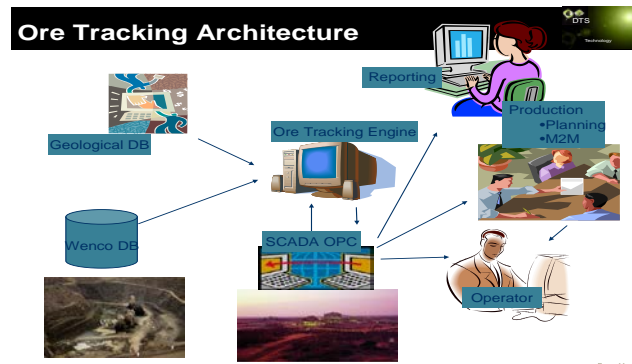


Fig. 7  Ore type soft sensor (ore tacking system), providing ore type information to all production units by using real time mining data
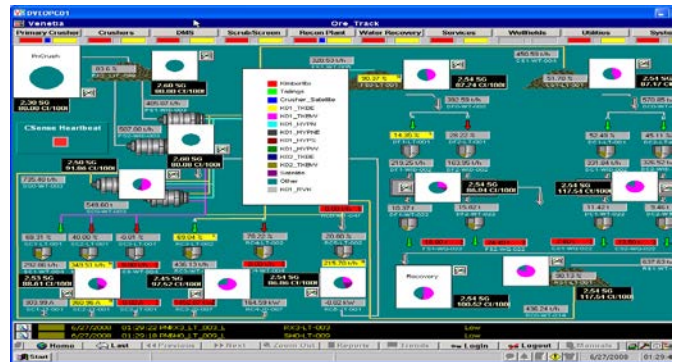


Fig. 8 Display of ore type soft sensor in a SCADA window providing ore type information to all process units at a mine, including percentage of mixed ore (colored pie), ore grade and ore density

The main components of a weightometer soft sensor are shown in Fig. 9. Real-time data is checked by the input validation model before being sent to the weightometer model that calculates the rate of flow of ore/concentrate in t/h. The calculated flow rate is compared with that supplied by the weightometer and if the difference is greater than a set tolerance, an alarm is triggered and the calculated t/h value rather than that from the physical weightometer is sent to the database for use by the SCADA and production reporting systems.

Soft sensors have proved to be a useful and powerful tool in the determination of process variables that are difficult to measure directly. In general, for this kind of variables, it is necessary to have proper dynamic models that can reproduce the behavior 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 modeling.
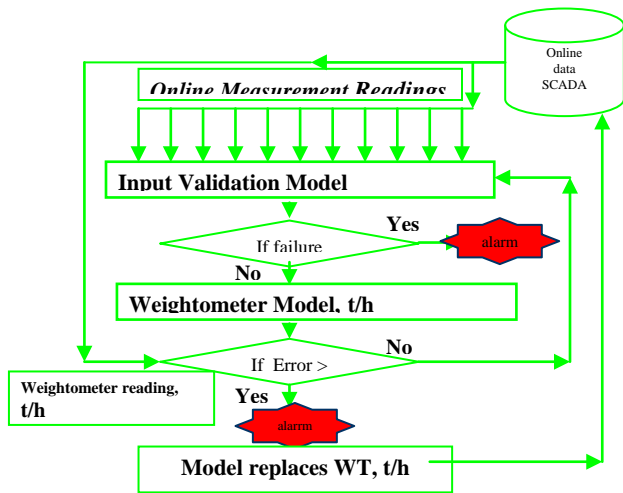
Fig. 9 Structural diagram of weightometer soft sensor, with functions of input validation; dynamic models; fault detection and data reconciliation

## IV. CONCLUSION

To achieve a balanced and optimal production at a mine, two tasks must be achieved at least. The first task is to have an optimal production plan with a set of optimal production targets for all process units. The second task is to make sure that all those optimal targets in the mentioned optimal production plan must be achieved at all process units by using resources available. To achieve the mentioned two tasks, all measurements, equipment and production systems at the mine must be available and operational all time. It is particularly true when those critical measurements are concerned such as weightometers, densitometers, ore types; stockpile levels.

To help achieve that, a system, called automated mine optimization system, is developed. The system consists of three main functional levels:

(1) Mine production optimizer
(2) Dynamic controllers
(3) Soft sensors

A mine production optimization system (Mine Optimizer) has been developed, using the principles of constraint-based global optimization. It includes (1) objective function; (2) system transfer functions; and (3) a global search engine using generalized reduced gradient non-linear programming. The mine optimizer helps to determine "what" the optimal size requirements should be at all processing plant and units, including blasting; crushing; screening; separating, etc. The mine optimizer will take into amount of those changing conditions, such the availability of production equipment and systems, the changes of ore types. Various dynamic controllers are used to achieve the optimal production at all process units, including crusher controllers; feed controllers. A set of soft sensors are developed to help provide real time measurements required by the mine optimizer and various dynamic controllers. Those soft sensors provide information

either critical or unavailable to control the production processes, such as weightometers, densitometers, stockpile levels, ore types.

Over the past ten years, a large amount of work has been done to develop the system from forming the concept to testing and implementation at various mines. The automated mine optimization system can potentially help improve the production throughput up to 30%.

## REFERENCE

1. XW. Pan, Constraint-Based Mine Production Optimization for A Diamond Mine, Proceedings of the 33 International Symposium on Application of Computers and Operations Research in Mineral Industry, April 24 to 27, 2007, Santiago, Chile, pp477-483

2. XW. Pan, Application of Soft Sensors in De Beers, Presentation of International CSense Conference, Pretoria, 2007

3. Dennis, Soft Sensor Technology helps improve De Beers Production, 32-33

4. XW. Pan; B. Viljoen, Development of Crusher Neurocontroller for A Diamond Mine using Neural Networks and Genetic Algorithm, Proceedings of the 33 International Symposium on Application of Computers and Operations Research in Mineral Industry, April 24 to 27, 2007, Santiago, Chile, pp658-667

5. T. Slusser, Pavilion8 Model Predictive Control Technology for Crusher Process Optimization, Project Proposal, 18 May 2008

6. XW. Pan; T Letwaba; G Mentzner, etc, Development of Weightometer Soft Sensor for Diamond Mine, Proceedings of the 32 International Symposium on Application of Computers and Operations Research in Mineral Industry, Cape Town, 2004, pp207-212

7. XW. Pan; T Letwaba; G Mentzner, etc, Implementation of Weightometer Soft Sensor at Venetia Diamond Mine, Proceedings of International Mineral Conference, Cape Town, 2005, pp114-119

8. B Ramos; J Caceres; P Bustos, etc, Expert System for Column Flotation, Proceedings of the 33 International Symposium on Application of Computers and Operations Research in Mineral Industry, April 24 to 27, 2007, Santiago, Chile, pp467-476