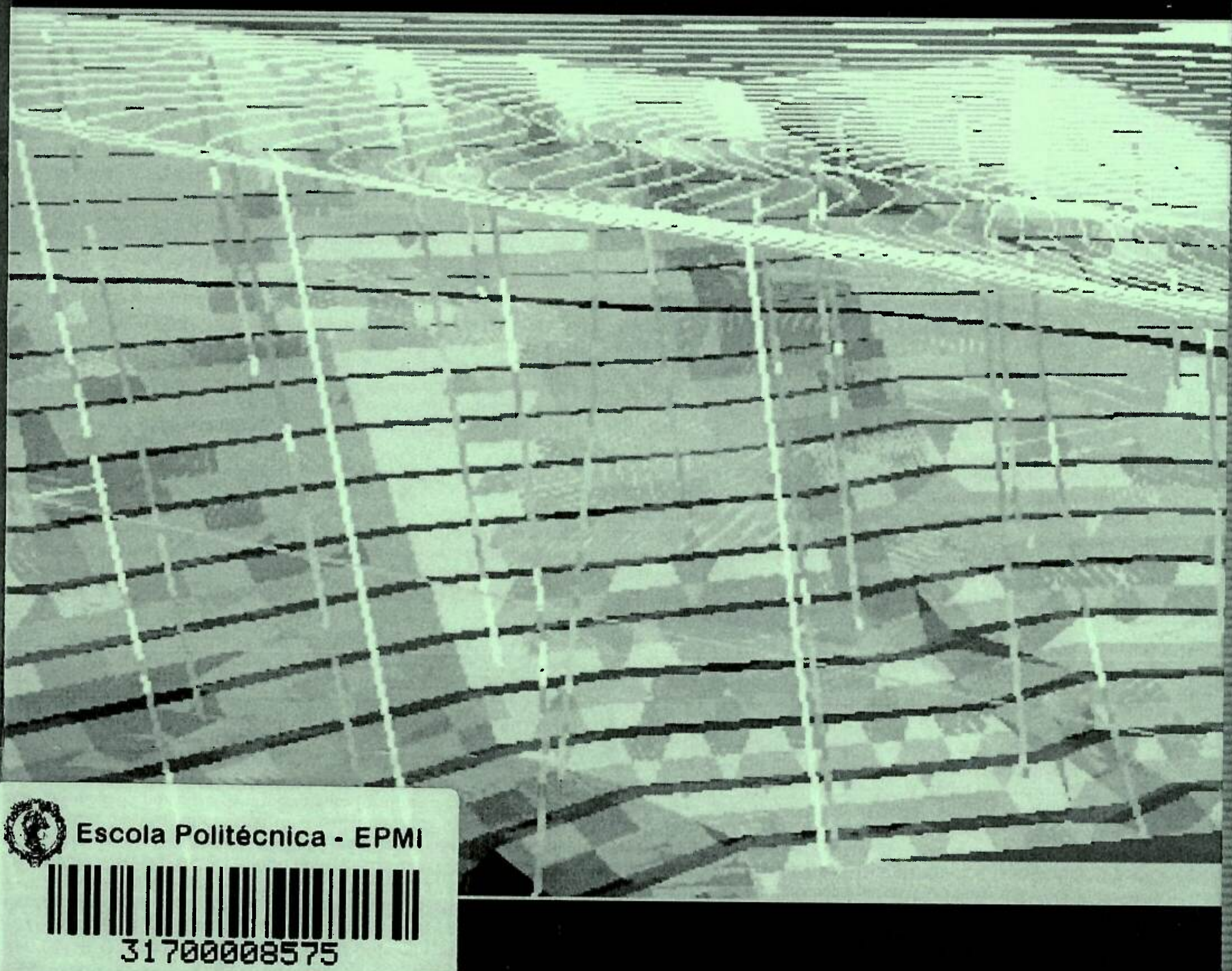
36th APCOM

Applications of Computers and Operations Research in the Mineral Industry



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EDITORS
João Felipe Costa
Jair Koppe
Rodrigo Peroni

DYNAMIC SIMULATION APPLIED TO MINING

Dennis Travagini Cremonese; Brazil Lead; Dynamic Simulation Group; HATCH; Rua Gomes de Carvalho, 1195; 04547-003; São Paulo/SP; Brazil; +55 11 9 9655-0346; dcremonese@hatch.com.br.

Marco De Amicis; Dynamic Simulation Specialist; Iron Ore; HATCH; Rua Gomes de Carvalho, 1195; 04547-003; São Paulo/SP; Brazil; +55 11 3195-8157; mamicis@hatch.com.br.

Giorgio Francesco Cesare de Tomi; Professor; Mining and Petroleum Engineering Department; University of São Paulo; Av. Prof. Mello Moraes, 2373; 05508-900; São Paulo/SP; +55 11 3091-6033; +55 11 9155-0148; gdetomi@usp.br.

ABSTRACT

This work adds the dynamic simulation, not only to the equipment design, but to an existing operation obtaining circuit bottlenecks and reducing OPEX. After analyzing and collecting data from a mine located in the Central-West Region of Brazil, a model was built, and from that a management and analysis methodology of a mine in operation was created. This work shoes the innovative advantages of using dynamic simulation as a tool for planning the operation of the mine. In the end, it is concluded that the creation of a model to be used in the study and operation of mining is a profitable investment.

INTRODUCTION

The mining operation is focused on ore production as safely, efficiently and profitably as possible. This focus has been crucial, in recent years, for mining companies to invest in improving the level of automation, and this is changing the way that mines are operated and managed. One of the biggest challenges of mining remains improving equipment operation utilization rates and mine development.

The use of equipment can be expressed by the ratio of productive and nonproductive hours during a given period (Lees, 2003). This ratio is associated with a series of internal and external factors to the mine operation, such as the maintenance strategy used, company's management and administrative policies, and their effects on working conditions in the mine.

This work aggregates the dynamic simulation technique, not only in the fleet, but in the existing operation thus obtaining the circuit bottlenecks and decrease of OPEX. After data collection and analysis from an underground mine located in the Central-West Region of Brazil, a model was built and from it a management methodology and analysis of an operating mine was created. It has as innovation the advantages of using dynamic simulation as a tool for studies in any type of mining, either underground or open pit.

One of the major limitations of the conventional methods of analysis is the lack of interaction among the different pieces of equipment. A simplistic example is a loader that receives material continuously, followed by a truck. When capacity of this "small-mining" is calculated using conventional methods, its output should be:

SIMULATION

$$Production = \min(Cap_L \times (\sigma_L); Cap_T \times (\sigma_T)) \quad (1.1)$$

Being:

Cap_L = Loader capacity

σ_L = Loader operational yield

Cap_T = Truck capacity

σ_T = Truck operational yield

This conventional calculation shown in eq. (1.1) serves as an approximation to the capacity, because it considers the smallest capacity among the pieces of equipment used; however, the interaction between them is disregarded due to failures in unrelated periods.

The eq. 1.2 presents a more conservative calculation, considering all the breaks (failures) as occurring at different times, resulting in an oversized fleet.

$$Production = Min(Cap_L \times (\sigma_L \times \sigma_T); Cap_T \times (\sigma_L \times \sigma_T)) \quad (1.2)$$

Correction factors can be multiplied in the equations, though each mine has its peculiarities and using only one factor found in the literature could result in erroneous conclusions. Thus, to obtain the closest value to the reality it is required that one use dynamic simulation, where interactions between devices will be evaluated.

METHODOLOGY

LITERATURE REVIEW

Literature indicates that increasing productivity in mining can be achieved by better controlling mining production processes and improving operational security (Dey, 2005; Hall *et al*, 2000; Burger, 2006).

However, many measures improve more than one goal, making the most important factors to be mechanization, shift model, workers transport, dust reduction, and automation, as described below.

Although mine mechanization is currently most common, some mines are not mechanized. The mechanization of mines provides great reduction of the workforce, increasing the skills and responsibilities of workers. The increase in productivity achieved in a specific mine was from 2.5 to 5.5 t / man / shift. Monthly production increased from 30,000 t / month to 47,000 t / month. The total number of employees decreased from 1200 to 790 (Harrison and Da Silva, 1999).

By the standard model used in most mines, each shift makes drilling, charging, blasting, transportation and concreting, requiring very complex skills of all workers and supervisors. However, to avoid the need for men with such complex skills, some mines use a model of turns in each group is responsible for one or two operations. In many mines, this model cannot be adopted because there must be multiple workspaces and amount of work to fill 8 hours per shift. However, where it was used, this method allowed each group to improve their operations, improving control and greatly increasing their productivity (Lyman, 2003).

The transport of workers by bus and train in underground mines achieved the goal of increasing the use of equipment. Furthermore, it reduced lost time accidents to less than 10% compared to what it was before the deployment of these transports. With these transports, the workers' fatigue decreased, thereby decreasing their distraction, which was a major cause of accidents; and with the extra time the worker spent at the machine, it was no longer necessary to perform the work imprudently to achieve the expected productivity (Harrison and Da Silva, 1999).

Improving the transport by elevators also presents a large increase in productivity, as seen in gold mining, where special elevators were built, allowing workers and ore to be transported separately, increasing productivity by three times and greatly reducing operational costs (Harrison and Da Silva, 1999).

According to Lee (2003), the introduction of pneumatic drills in South Africa resulted in increased cases of silicosis. However, since 1902 the reduction of drilling dust has been managed through the use of water on the rods. Recent improvements in this direction include the isolation of operators in cabins with air-conditioning, to eliminate the risk of exposure in front of drills.

Automation is the procedure by which it is possible to increase productivity, improving safety and working conditions, and reducing operational costs.

Modern control systems allow the drilling to be more controlled, which improves the productivity and precision. Now it is possible for the operator to follow a standard drilling displayed on a screen and maneuver the rods, which are also represented on the screen, to position them correctly. This allows the contour of the tunnel to be more controlled, reducing the need for overbreak and support. It is also possible to make the perforation contour automatically.

The introduction of control systems by computer brought new prospects to drilling, if well deployed. For example, people often rely on new technology as the ultimate solution to their problems, when in fact the solution is based on people and their management rather than on technology itself. The Atlas Copco drills, for example, can now be equipped with: Measure While Drilling (MWD), Mine Map Navigation (MMN), Mine Drill Plan Generator (MDPG) Rig Remote Access (RRA), and Single Machine Remote Control (SMRC). The MWD system records a number of key drilling parameters during drilling of drill holes. The analysis of these data can provide information about ground conditions ahead of the tunnel, allowing corrective action plans before reaching an area where bad conditions are predictable. The MMN was developed primarily for mining applications to remove underground navigational errors. The MDPG allows you to generate your own drilling plan on the face, based on the conditions of the face and its position inside the mine. The RRA allows the drill to be integrated with the computer network. With the equipment being part of the network, drilling plans, data records and other information can be transmitted to the machine and from it. The SMRC is an extension of the RRA, which enables the machine to be operated remotely (Reynolds, 2003). Another example of new technology that increases productivity by increasing safety is a robotic drill (RDM - Robotized Drilling Machine). It was developed by "China University of Mining & Technology", mainly to increase worker safety in coal mines. The RDM is controlled by computers and may couple and uncouple rods, and the holes can be drilled automatically. Under the conditions of a coal mine, the RDM control system is very secure (Jifei *et al*, 1997).

An automation system called AutoMine, created by Sandvik, is one step towards mine automation. The system has semi-automated cycles, including automatic transport and unloading of LHDs teleoperated by the controller in a control room. The operator can control the machine conditions, monitor the production, and control the LHD and the truck traffic in a very safe way, not exposed to the dangerous conditions of the mine. The system provides greater production and constant level of performance, since it allows the machines to operate more than 20 hours a day without the necessity to transport the operator to the equipment at shift change. This provides a potential for fleet reduction, and economy from 60% to 75% in labor per year. With real time information, the process can be optimized and the maintenance costs reduced in about 10% to 15%. With this, and with preventive maintenance, there is less material damage (Automation Resources, 2010).

Dynamic simulation was developed to fill the gaps of information that static analysis cannot cover. An example is the dynamic simulation performed for the company Resource Generation, which owns coal mines in South Africa and Tasmania. The simulation challenge was to obtain the bottlenecks and capacity of the plant and determine the volumes of the ROM and product piles. With the possibility of generating several scenarios, much information that cannot be reached by static analysis may be generated, such as the sensitivity of the railroad and the key factors that affect the processing capacity of the plant (Simulation Analysis, 2010). The sensitivity of the railway today is a key factor, because the costs of storage piles and warehouse can be reduced, thereby avoiding working capital locked (Steinberg and Tomi, 2010). In a competitive economy like today, the company needs to have its working capital as liquid as possible to adapt to changes in the market and not be consumed. The reduction in the cash flow, allowing this greater liquidity, requires the adoption of operational actions, involving the shortening of deadlines, storage, production, operation and sales (Fleuriet *et al*, 2003).

Dynamic simulation has as its basis the modeling and simulation. Modeling is defined as a simplified representation of an entity or complex process. Simulation is an imitation of some real device or business state (Franklin and Gertenbach, 2005). In essence, modeling is a way to solve problems that occur in the real world and simulation is the process of implementing the model.

Dynamic simulation is applied in decision-making, as in the choice of transport mode, balance resources, system capacity, optimization of capital, and minimization of risks from alternatives, offering better opportunities (Franklin and Gertenbach, 2005; Lebedev, 2007). Without the need to scale trials, a model can show, in an illustrative way, an overview of the process, Figure 1, thus allowing the analysis of several alternatives quickly and with low cost, leading to maximization of investment profit and reducing the risks inherent to the project.

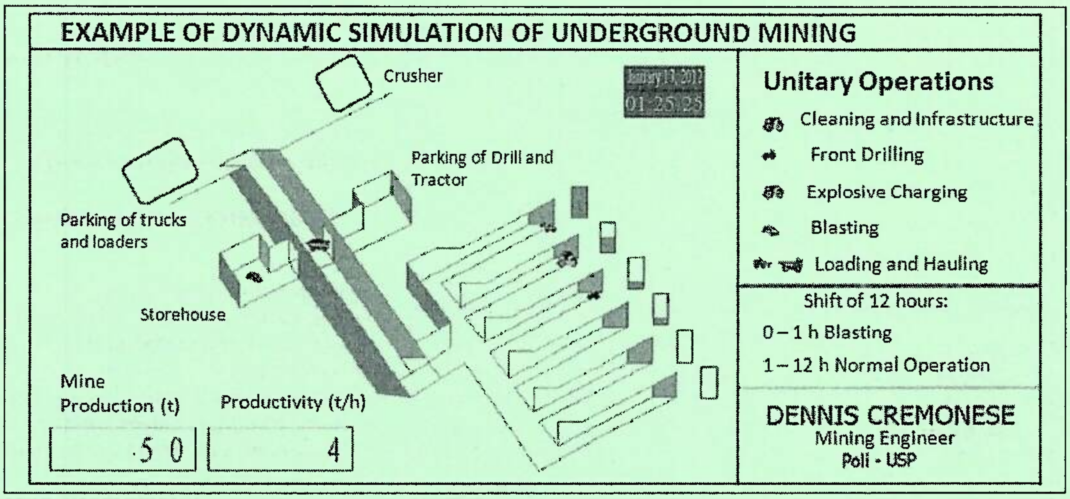

Figure 1 – Example of a dynamic simulation animation.

GENERAL STUDY OF MINING DATA

This work presents a study of alternatives for increasing productivity in a small-sized gold mine located in the Central-West Region of Brazil. Data was collected during the month of February 2010.

Figure 2, containing production by month, shows considerable stability of mining production over the period studied, showing that the data from the month in study is ideal for analysis. The Production of 100% is considered the average production of the mine.

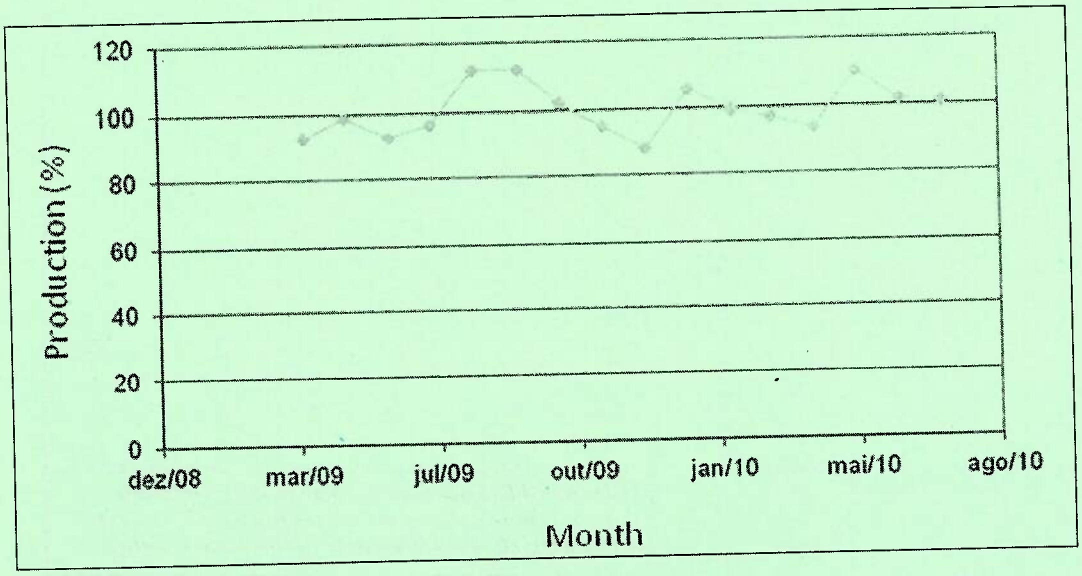

Figure 2 – Mining production.

The mining works with four groups (A, B, C and D) that perform rotation daily. Classes A and C perform 3-2-2-3 rotation, which means 3 days at shift 1, 2 days at shift 2, 2 days at shift 3 and 3 days off. Classes B and D perform 2-3-2-3 rotation, as exemplified in Table 1. Shift 1: 7-15h, 2: 15-23h, 3: 23-7h. The detonations are performed during shift changes

Table 1 – Groups rotation.

Shift 1	Shift 2	Shift 3
A-1	B-3	C-6
A-2	B-4	C-7
A-3	B-5	F
D-1	A-4	B-6
D-2	A-5	B-7
C-1	D-3	A-6
C-2	D-4	A-7
C-3	D-5	F
B-1	C-4	D-6
B-2	C-5	D-7

The equipment studied were the trucks, loaders, tractors that perform cleanup of the fronts and loading of explosives, and drills. Due to the confidentiality agreement, the absolute numbers are not presented, just relative numbers.

DEVELOPMENT

The flowchart in Figure 3 summarizes the methodology that will be applied in the study.

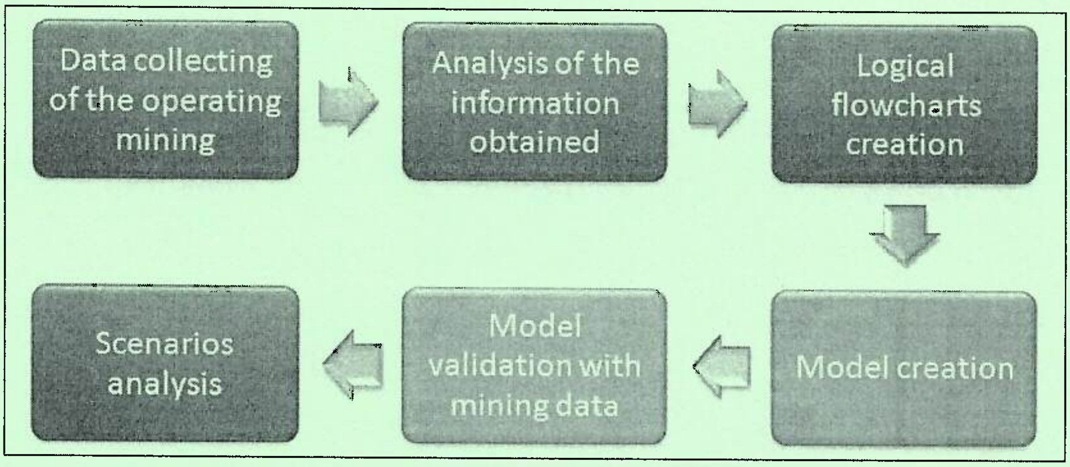

Figure 3 – Methodology.

DATA COLLECTING OF THE OPERATIONAL MINING

Data collection is performed in two parts:

- Historical data mining
- Instantaneous data

The historical data is the mechanical equipment available, preventative maintenance schedules, periods during which the equipment is broken down, among others.

The instantaneous data is the unit operation cycles. The model can be as detailed as you want, considering the unit operations of an underground mine as Front preparation, Drilling, Loading explosives, Blasting, Loading and Transportation of the dismantled materials; in this study they are as detailed as in Figure 4.

ANALYSIS OF THE INFORMATION OBTAINED

The data obtained for each cycle is adjusted to probability distributions, such as exponential functions, triangular or uniform, to obtain the random variations present in a real system. This is the main difference between a conventional study and a dynamic study, because due to these random variations it is possible to estimate the queues and the actual capacity of the project.

CREATION OF THE LOGIC FLOWCHART

In a simple and didactic way, flowcharts should contain all the processes to be included in the model. An example is in Figure 5.

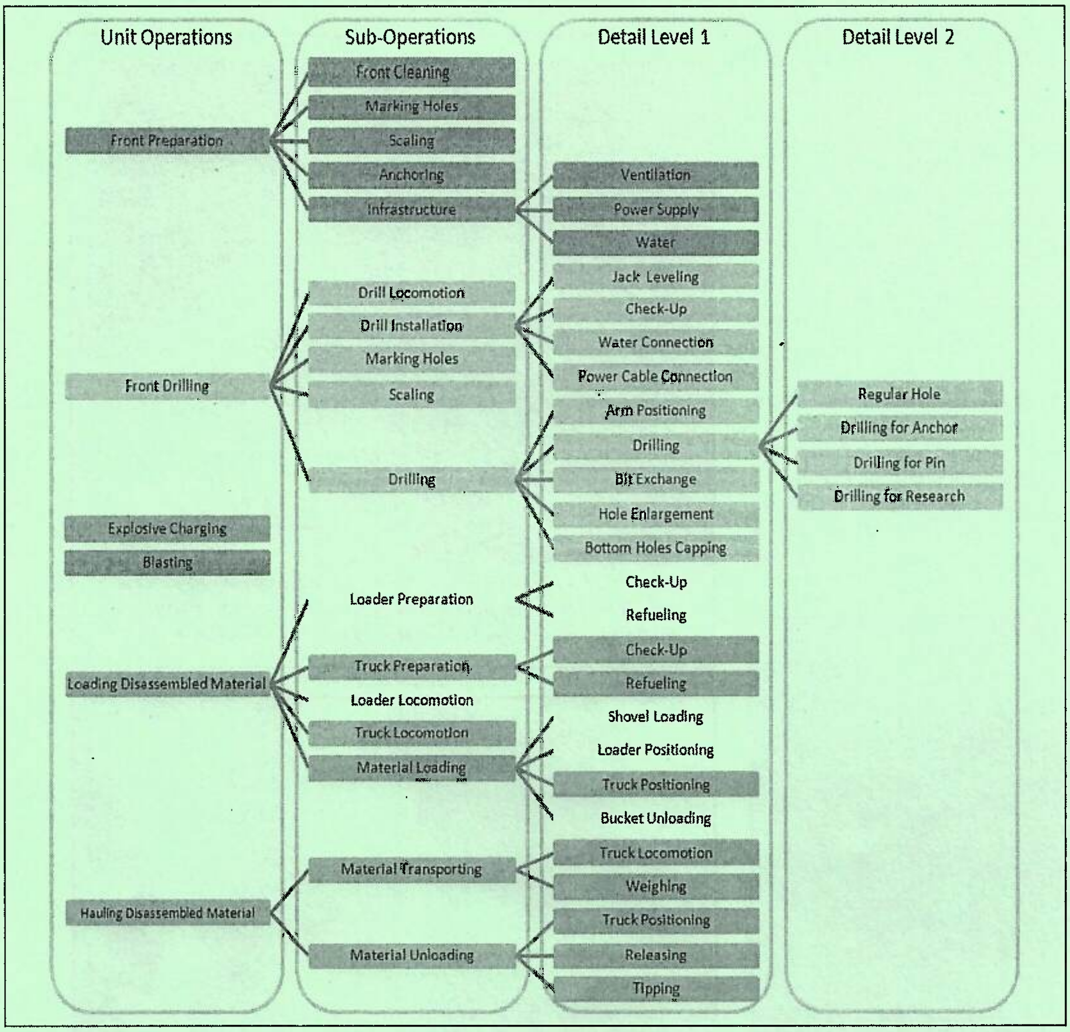

Figure 4 – Detailing of unit operations used in the model.

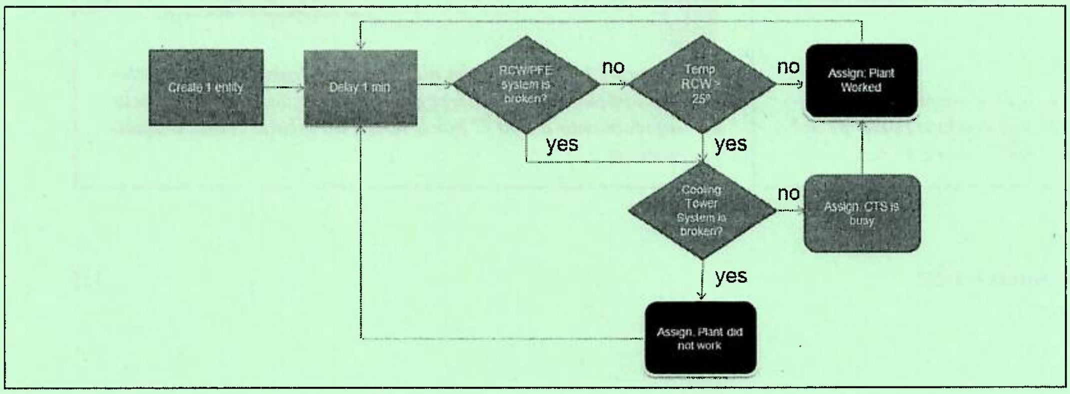

Figure 5 – Logic flowchart example.

SIMULATION

MODEL CREATION AND VALIDATION

One of the keys for a successful simulation study is to follow a complete methodology in an organized and well-managed way. A comprehensive and disciplined methodology allows complex models to be built quickly and accurately for maximum benefit. Due the iterative nature of the method, which does not necessarily follow a list of sequences, so some activities may be performed simultaneously and/or repeated, but the initial idea of the flow simulation study is shown in Figure 6.

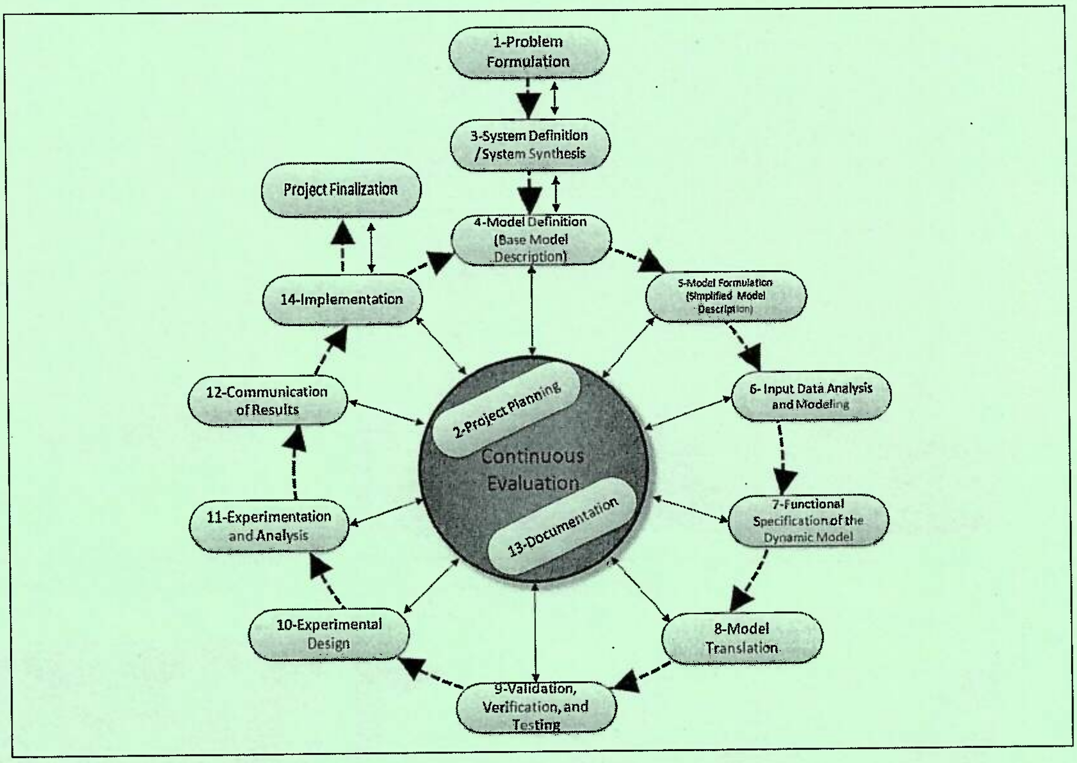

Figure 6 – Simulation Methodology.

One of the steps is to pass from the logic flowchart, made in the previous phase, to computational logic, creating a model. After the model is ready, it is validated with the current mine operation.

RESULTS

With the validated model, some scenarios were performed to estimate the gain in capacity after the implementation of new equipment, current and new systems cycles improvements of preventive maintenance. Table 2 shows some of the results for the analysis of the number of equipment and truck capacity.

SIMULATION

Table 2 – Team rotation.

Fronts Actives	Number of Equipments: Truck	Loader	Tractor	Drilling	Truck Capacity (t)	Annual Production Average
5	A	B	C	D	18.75	100.0%
6	A	B	C	D	18.75	114.2%
5	A	B	C	D	25	102.6%
6	A	B	C	D	25	116.7%
5	A	B	C+1	D	18.75	119.0%
5	A	B	C+2	D	18.75	120.0%
6	A	B	C+1	D	18.75	137.8%
6	A	B	C+2	D	18.75	139.6%
5	A	B	C	D+1	18.75	101.5%
5	A	B+1	C	D	18.75	101.7%
5	A	B+1	C+1	D	18.75	121.9%

With the simulation results, it can be shown that the acquisition of new trucks, loaders and drills would not increase production significantly. However, by opening another front mining and acquiring one tractor, which is the bottleneck of the operation, it would be possible to achieve an increase in production of over 35%.

Nonlinear correlations, such as the machines occupation or the amount of equipment required, were shown by the model results.

The results showed some important information, such as costs that were included in OPEX, sequencing for purchasing equipment that optimized the capital investment program, and relations between the equipment used and the maximum capacities tangible.

The results also showed that there are a lot of technical materials that must be mastered before performing a good study. The model presented checks before some answers that seemed correct; but, actually, they were not. It was clear that the model looked like the system; however, it did not act like it.

CONCLUSIONS

Development of a dynamic logistics simulation model is a prudent investment for ensuring that system designs/expansions are capable of achieving targeted capacities and efficiencies prior to implementation. Besides, it may be used as design validation and optimization; the model can be used by the mine planning group to obtain the goals for the operation team.

Using dynamic simulation, the capital investment program has been optimized in its entirety, providing the option to postpone short-term investments (which would have little or no benefits) to later stages of expansion, shifting the schedule of other capital investments.

The model being used for mine planning generates a control in which the best and most important areas can be prioritized, and the consequences of production can be observed in real-time, in the short, medium or long term.

The results show the importance of evaluating the system as a whole, since the simulation allowed to evaluate and provide visibility to unnoticed information, which resulted in not intuitive conflicts.

The simulation provided a powerful tool to increase understanding of the system operations dynamics, identifying capacity limits and enabling testing various scenarios.

The main disadvantage of dynamic simulation is that the simulation model accuracy is limited by the precision of the input data, though the use of a discrete event simulation in a continuous production system was satisfactory, since the processing of turning continuous events into discrete events did not affect the results.

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