DYNAMIC SIMULATION APPLIED TO MINING[1]

Dennis Cremonese[2]

Marco De Amicis[3]

Giorgio de Tomi[4]

Resumo

Este trabalho agrega a técnica da simulação dinâmica, não apenas no dimensionamento da frota, mas na operação existente obtendo-se assim os gargalos do circuito e diminuição do OPEX. Após análise e coleta de dados em uma mineração localizada na região Centro-Oeste do Brasil, um modelo foi construído, e a partir deste, uma metodologia de gerenciamento e análise de uma mina em operação é criada. Tem como inovação as vantagens da utilização da simulação dinâmica como ferramenta para planejamento da operação da lavra. Ao final, conclui-se que a criação de um modelo para ser utilizado no estudo e na operação da mineração é um investimento vantajoso.

Palavras-chave: Simulação Dinâmica, Lavra, Planejamento de mina, Operação de mina

Abstract

This work adds the dynamic simulation, not only in the equipments design, but in a existing operation obtaining the circuit bottlenecks and reducing OPEX. After analyzing and collecting data from a mine located in the Center-West region of Brazil, a model was built, and from that, a management and analysis methodology of a mine in operation is created. This work has the innovation advantages of using dynamic simulation as a tool for planning the operation of the mine. At 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

Key words: Dynamic Simulation, Mining, Mine planning, Mine operation.

[1] *Technical Contribution to 36th Applications of Computers and Operations Research in the Mineral Industry, November 3-8th 2012, Porto Alegre – RS – Brazil.*

[2] *Mining Engineer, Brazil Lead – Dynamic Simulation Group, DYNAMINE, São Paulo, Brazil, dennistravagini@dynamine.com.br*

[3] *Marine Engineer, Dynamic Simulation Specialist - Iron Ore, HATCH, São Paulo, Brasil. mamicis@hatch.com.br*

[4] *Mining Engineer, LAPOL researcher and Teacher Doctor in the Escola Politécnica da USP, São Paulo, Brazil, gdtomi@usp.br*

INTRODUCTION

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

The use of equipment can be expressed by the ratio of productive and nonproductive hours during a given period (Lees, 2003 [1]). This retio is associated with a series of internal and external factors to the mine operation, such as the maintenance strategy used, management and administrative policies of the company, 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 Midwest region of Brazil, a model has been built, and from this, a management methodology and analysis of an operating mine is 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 between the equipments. A simplistic example is a loader that receives material continuously, followed by a truck. When is calculated the capacity of this "smal-mining" using the conventional methods, its output will be:

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

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 equipments used, however disregarded the interaction between them due to the fails in not related periods.

The eq. 1.2 presents a more conservative calculation, considering all the breaks (fails) occur at different times, resulting in an oversizing 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 has mining its peculiarities and use only one factor found in the literature could result in erroneous conclusions, thus to obtain the closest value to the reality is required using dynamic simulation, where interactions between devices will be evaluated.

DEVELOPMENT

Literature Review

The literature indicates that increasing productivity in mining can be achieved from better control of mining production processes and improvement in the operational security (Dey, 2005 [2], Hall et. Al., 2000 [3]; and Burger, 2006 [4]).

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

Although the mine mechanization is currently the most common, some mines are not mechanized. The mechanization of mines provides great reduction of the workforce and 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 e Da Silva, 1999[5]).

By the standard model shifts 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 mans with such complex skills, some mines use a model of turns in each group is responsible for one or two operations. In many mining this model cannot be adopted because it is necessary to have multiple workspaces and amount of work to complete 8 hours per shift. However, where it was used, this method allowed each group improving their operations, improving the control and greatly increase their productivity (Lyman, 2003 [6]).

The transport of workers by bus and train in underground mines achieved the goal of increasing the use of equipment. Furthermore, reduced lost-time accidents to less than 10% compared to what 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 in the machine, was no longer necessary to perform the work with many imprundent to achieve the expected productivity (Harrison e Da Silva, 1999[5]).

Improving the transport by elevators also presents a large increase in productivity, as seen in gold mining where were deployed special elevators that allowed workers and ore being transported separately, increasing productivity by three times and greatly reducing the operational costs (Harrison and Da Silva, 1999 [5]).

According to Lee (2003) [1], the introduction of pneumatic drills in South Africa resulted in increased cases of silicosis. However, since 1902 the reduction 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 drilling.

Automation is the procedure by which is possible to increase productivity, improves safety and working conditions, and reduces 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 more 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 parameters of drilling during drilling of drill holes. The analysis of these data can provide information about ground conditions ahead of the tunnel, allowing corrective action plan 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 to generate your own drilling plan in the face, based on the conditions of the face and its position inside the mine. The RRA allows the drill to be integrated at 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 [7]). 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. RDM is controlled by computers and may coupling and uncoupling rods, and the holes can be punched automatically. Under the conditions of a coal mine, the RDM control system is very secure (Jifei et al., 1997 [8]).

An automation system called AutoMine, created by Sandvik, is one step from the mine automation. The system has semi-automated cycles, including automatic transport and unloading of LHD ‘s, 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 safety way, not exposed to 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 reducing and economy between 60 to 75% in labor per year. With the information in real time, the process can be optimized and the maintenance costs reduced about 10 to 15%. With this, and with preventive maintenance, has less material damage (Automation Resources, 2010 [9]).

The 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 products piles. With the possibility of generating several scenarios, many information may be generated, that cannot be reached by static analysis, as the sensitivity of the railroad and the key factors that affect the processing capacity of the plant (Simulation Analysis, 2010 [10]). The sensitivity of the railway today is a key factor, because the costs with storage piles and warehouse can be reduced, thereby avoiding working capital locked (Steinberg and Tomi, 2010 [11]). In a competitive economy like today, the company needs to have its working capital as liquidity 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 [12]).

Dynamic simulation has as its basis the modeling and simulation. Modeling is defined as a simplified representation of a entity or complex process. Simulation is an imitation of some real device or business state (Franklin and Gertenbach, 2005 [13]). 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 applied in decision-making, as in the choice of transport mode, balance resources, system capacity, optimization of capital and minimizing risks from alternatives, offers great opportunity (Franklin and Gertenbach, 2005 [13] ; Lebedev 2007 [14]). Without the need to scale trials, a model can show, in a 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 investments profit and reducing the risks inherent at the project.

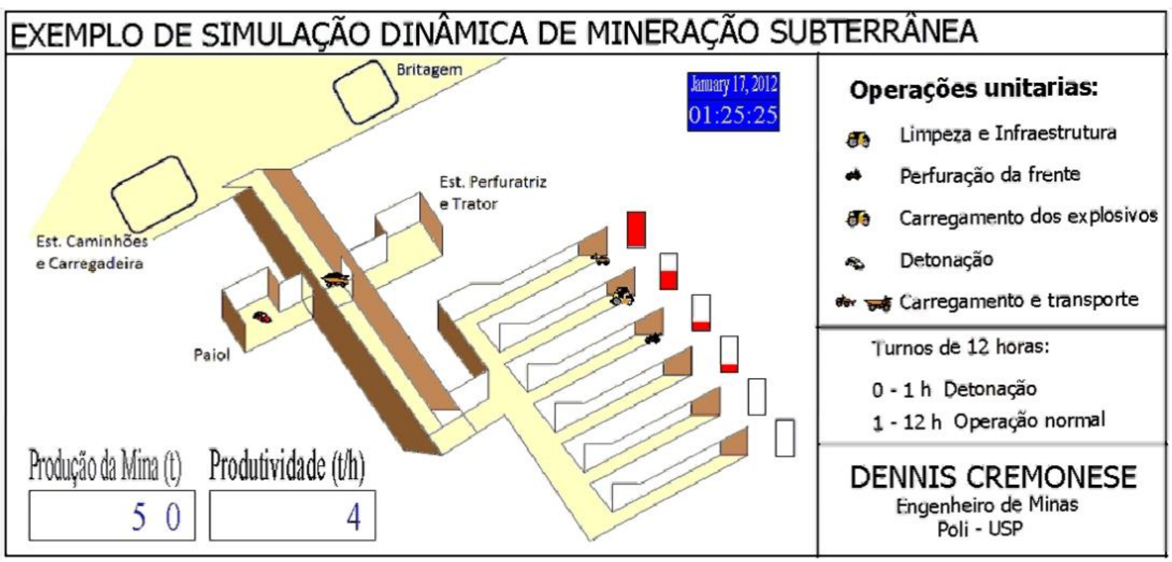

Figure 1 - Exemple of a dynamic simulation animation

General Data of the Mining in Studing

This work presents a study of alternatives for increasing productivity in a small-sized gold mining located in the Midwest region of Brazil. Data were collected during the month of February 2010.

The **Erro! Fonte de referência não encontrada.**, containing production by month shows considerable stability of mining production over the period studied, showing that the data from the month in study are ideal for analysis.

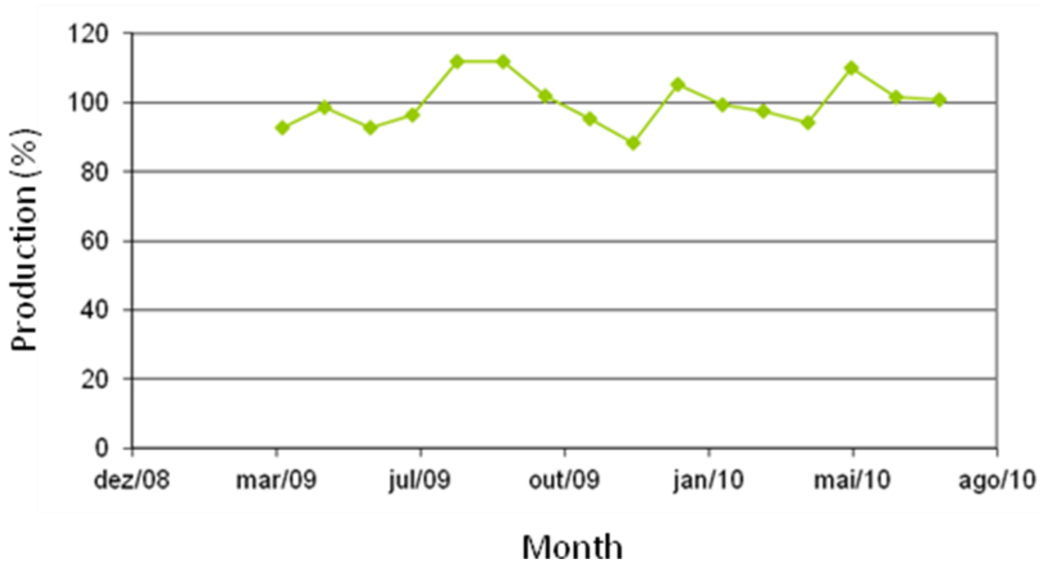

Figure 2 - Mining production

The mining works with four groups (A, B, C and D) that perform rotation daily. Classes A and C perform the rotation 3-2-2-3, 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 the rotation 2 -3-2-3, 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 equipments 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.

Methodology

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

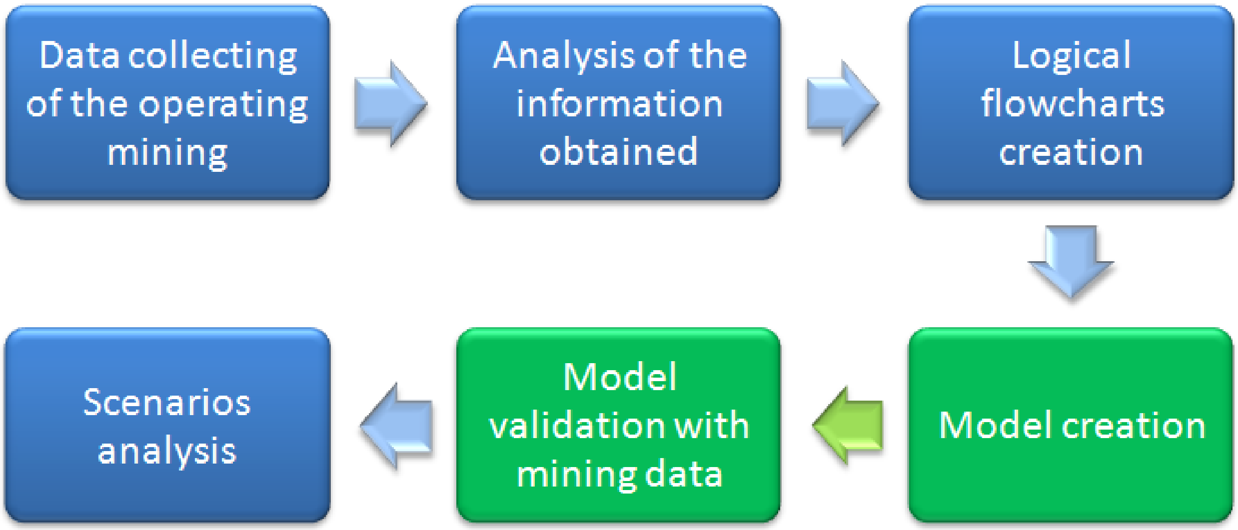

Figure 3 – Methodology

Data collecting of the operational mining

Data collection is performed in two parts:A coleta de dados é realizada em duas partes:

- Historical data mining
- Instantaneous data

The historical data are the mechanical equipment available, preventative maintenance schedules, periods that the equipments are broken, among others.

The instantaneous data are the unit operations cycles. The model can be as detailed as you want, considering the unit operations of an underground mining as Front preparation, Drilling, Loading explosives, Blasting, Loading and Transportation of the dismantled materials, in this study they are as detailed as in **Erro! Fonte de referência não encontrada.**.

Analysis of the information obtained

The data obtained for each cycle are 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 is possible to estimate the queues and the actual capacity of the project.

Creation of the logic flowchart

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

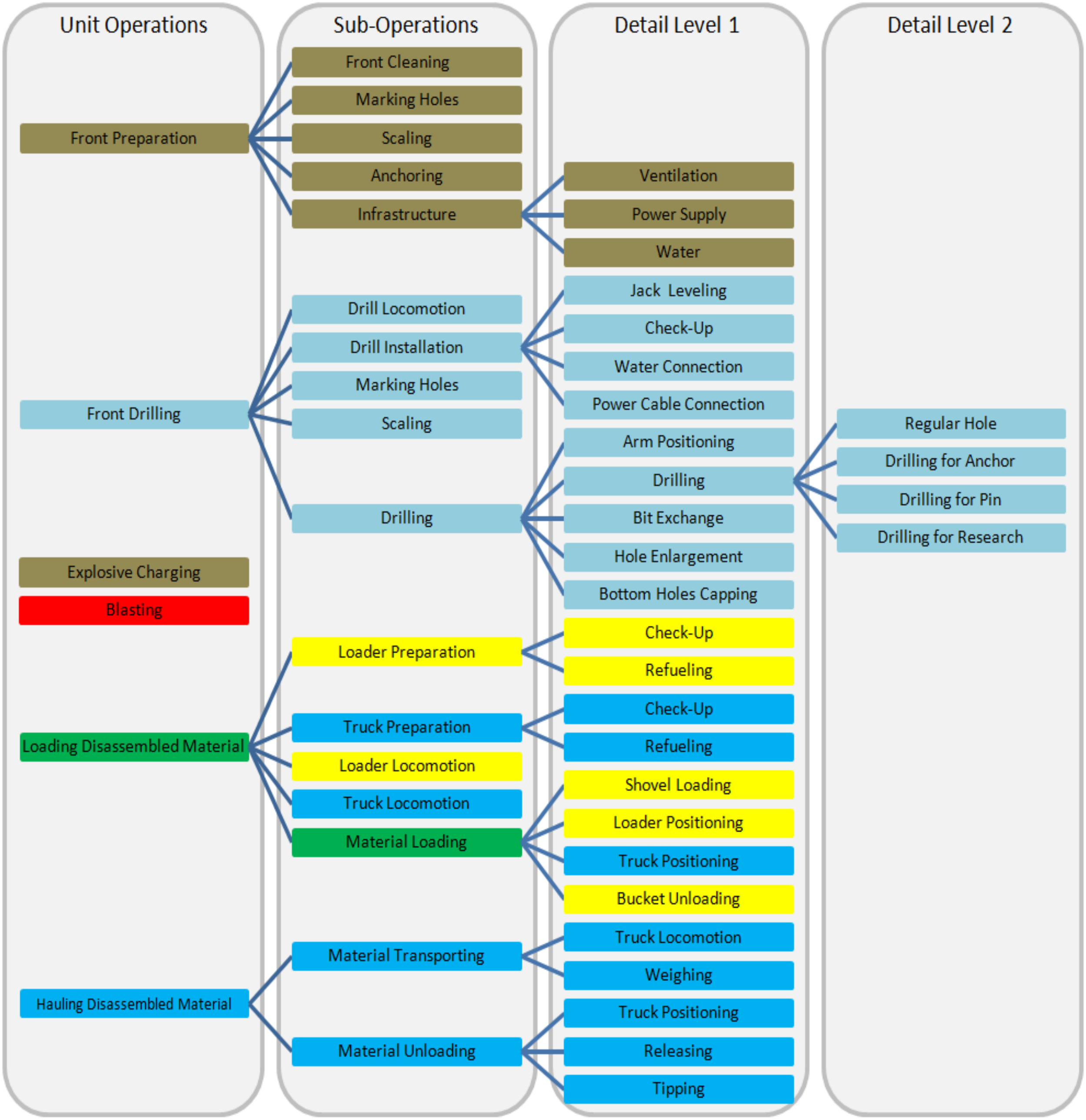

Figure 4 - Detailing of unit operations used in the model

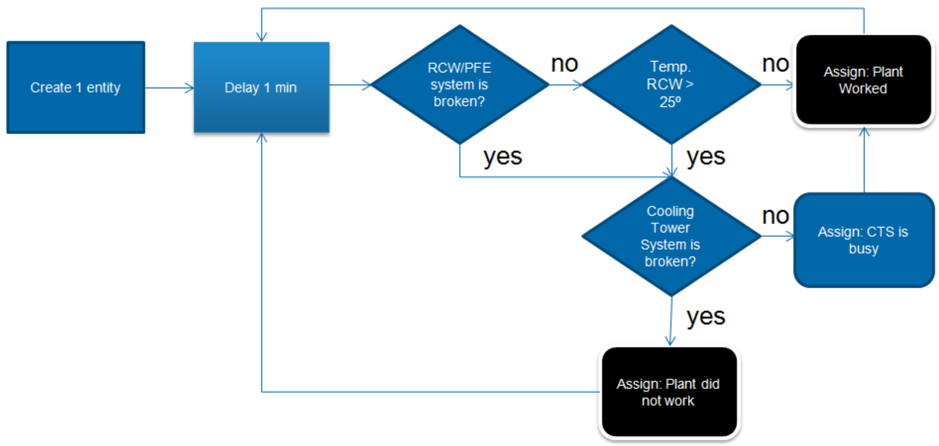

Figure 5– Logic flowchart exemple

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.

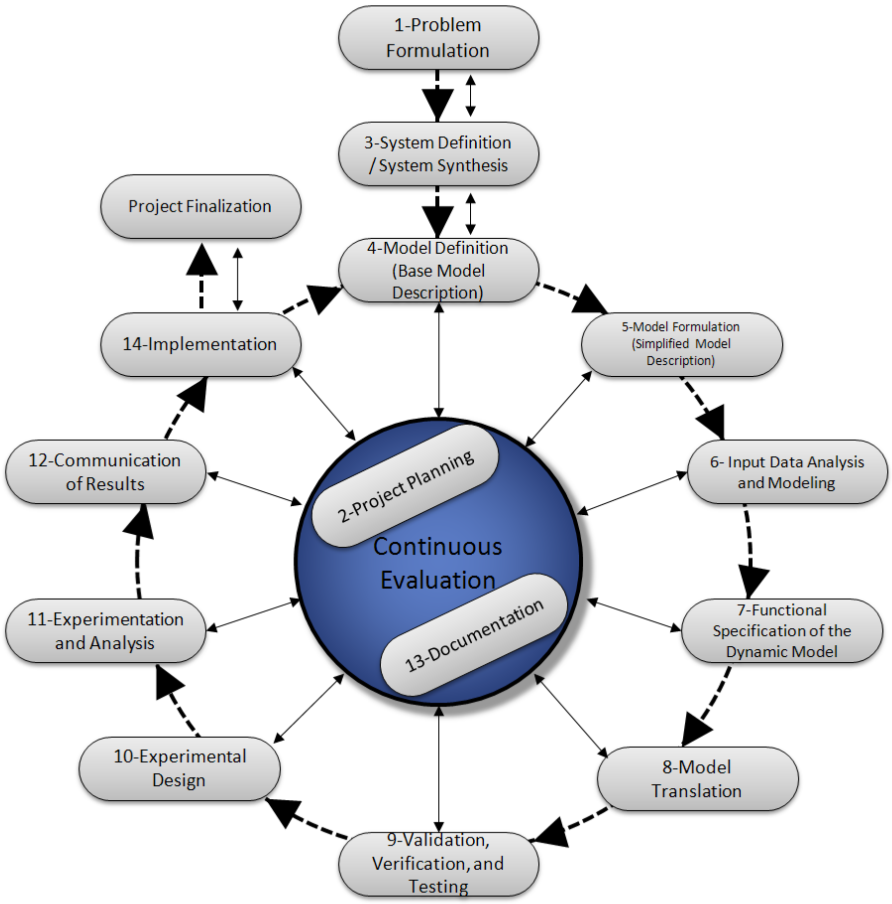

Figure 6–Simulation Metodology

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 the capacity after the implementation of new equipments, 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.

Table 2 - Team rotation

Fronts	Number of Equipments				Truck	Annual Production
Actives	Truck	Loader	Tractor	Drilling	Capacity (t)	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, opening another front mining and the acquisition of one tractor, which the bottleneck of the operation, would be possible to achieve an increase in production of over 35%.

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

The results showed some important informations, such as costs that were included in OPEX, sequencing for purchasing the equipments 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 you make 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 with the system, however did not act like it.

CONCLUSION

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, that have little or non benefits, to later stages of expansion, shifting the schedule of other capital investments.

The model being used for mine planning generates a control on which the best and most important areas can be prioritized, and observe in real-time the consequences in production 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 the unnoticed informations, 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 dynamic simulation main disadvantage 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 in discrete events did not affect the results.

REFERENCE

[1] Lees, D. History of Drill and Blast. SME, USA. 2003

[2] Dey, N.C. Role of Drill Machine and Fleet of SDL on Underground Mine Operating System. IE I Journal, MN, Vol. 86. August 2005, pp. 13-19.

[3] Hall, R.A.; Knights, P.F.; Daneshmend, L.K. Pareto analysis and condition-based maintenance of underground mining equipment. Trans. Inst. Min. Metall. Sect. A: Min. technol., 109, January–April 2000. The Institution of Mining and Metallurgy 2000, pp. A14-A22.

[4] Burger, D.J. Integration of the mining plan in a mining automation system using state-of-the-art technology at De Beers Finsch Mine. The Journal of South African Institute of Mining and Metallurgy, Vol. 106. August 2006, pp. 553-560.

[5] Harrison, J. C.; Da Silva, M. V. T. Case study of efforts to reduce costs and increase production at a mid-sized international mining company, SME Annual Meeting, Março 1999.

[6] Lyman F. Wolf creek upper narrows project— South Fork, Colorado: Construction of a large cross-section drill and blast highway tunnel in alpine conditions with multiple staggered headings". Kiewit Western Co., 2003.

[7] Reynolds, J M, Atlas Copco Construction and Mining Australia, Modern Drilling Equipment for Underground Applications. 2003

[8] Jifei. H.; Fengyou, H.; Shifan, X. Robotized Drilling Machine. IEEE International Conference on Intelligent Processing Systems. China University of Mining & Technology, October 1997. Beijing, China

[9] Automation Resources. Sandvik automates mining operations with AutoMine System. Disponivel em: <http://www.automation.com/resources-tools/application-stories/machine-monitoring-control/sandvik-automates-mining-operations-with-automine-system>. Acesso em: 10 de Abril de 2010.

[10] Simulation Analysis. Simulation Analysis of the Coal Processing Plant of Resgen's Boikarabelo Mine. Disponivel em: <http://www.simio.com/case-studies/boikarabelo_mine.html>. Acesso em: 17 de Novembro de 2010.

[11] Steinberg J. G.; Tomi G. Lean Mining: principles for modeling and improving processes of mineral value chains. International Journal of Logistics Systems and Management, Vol. 6, No. 3, 2010.

[12] Fleuriet, M.; Kehdy, R. e Blancc G. O modelo Fleuriet: a dinâmica fincanceira das empresas brasileiras: um novo método de Análise, Orçamento e Planejamento. Rio de Janeiro, Campus. 2003.

[13] Franklin, M.; Gertenbach J. Applying Modeling & Simulation as part of Business Process Improvement of Complex Mining Logistics. Business Process Improvement in the Extractive Industries, Denver CO, September 2005.

[14] Lebedev, A. Dynamic Simulation of conveyor systems in underground hard rock mines. Beltcon 14, The South African Institute of Materials Handling, Lynnwood Ridge, South Africa, 2007.