SIMULATION AND OPTIMIZATION METHODS IN DAILY MINE PLANNING

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ABSTRACT

This work shows the development of an integrated web interface, that combines an optimizer and a simulator of mining operations, applied to a real problem of daily mine planning. It was developed a viable prototype software that met the functional requirements demanded by the company operations. It was presented an application of the software in a case study of an iron ore mine operation in Brazil.
Keywords mixed integer linear programming; discrete event simulation; mine planning; mining operations.

RESUMEN

Este trabajo describe el desarrollo de una interfaz web integrada que combina un optimizador y un simulador para operaciones mineras, aplicada a un problema real de planificación diaria de la explotación minera. Se desarrolló un prototipo funcional que cumplía con los requisitos operativos de la empresa. El software se aplicó en un estudio de caso sobre la explotación de una mina de mineral de hierro en Brasil.
Palabras clave: Programación lineal mixta en números enteros; simulación de eventos discretos; planificación minera; operaciones mineras.

1. Introduction

The open pit mine planning activities requires an efficient allocation of load and haul equipment by a fleet of trucks in order that short and long-term production plans can be implemented efficiently - seeking to meet the quality and ore mass demanded by the plant, and at the same time fulfill the ore strip ratio of mining plans.

Mathematical programming and simulation are important techniques of Operational Research with important applications in the mining industry[1 16, 17]. Chanda and Dagdelen[2] presented a linear programming model to solve a problem of coal mixture. The objective function takes into account economic criteria and minimizing deviations on production and the deviation of the lower and upper limits of quality. Merschmann[3] presents a linear programming model to work in an integrated manner with the simulator developed by Pinto[4]. In that study, two linear programming models were developed to allocate load equipment in the working faces. The first model is constructed to accomplish the dynamic allocation of trucks, i.e., considers that each truck can be allocated to different destination from previous trip, and the second model is built to accomplish the fixed allocation of trucks, i.e., consider that each truck always goes to the same destination in all cycles performed. Both models have an objective function to maximize the production, considering the quality specifications and ore mass demanded by the plant. Costa[5] enhanced the model developed earlier by Merschmann with specific aspects of mining operations. Moraes[6] presented a linear programming model that aims to optimize the composition of blocks of iron ore. Rodrigues[7] conducted a study comparing the methodologies used in the electronic dispatch systems for trucks used in Brazil. Different dispatch methods are based on linear programming, dynamic programming, and various heuristics. Pantuza et al.[8] developed in the software Lingo a linear programming model to determine the mining ratio, and this result is used in the Arena software to validate the optimizer solution. The authors' conclusion was that only increasing the number of trucks in a mine does not mean that production will be increased in order to coordinate limiting aspects, traffic and communication. Pantuza[9] also developed a heuristic multi-objective algorithm based on

NSGA-II[10] and an exact algorithm to find mine planning problem solutions in open pit mines, considering the dynamic allocation of trucks. The objectives were to minimize output gaps, quality and the number of trucks involved in the extraction. To validate both algorithms, heuristics and accurate, a simulation model was built. According to the experiments, the heuristic model NSGAII produced final solutions of better quality and in a shorter time than the solutions of exact methods.

Martins[11] work covered the simulation of mining operations in Brucutu mine in southeastern system of Vale. A simulation model and a mixed integer linear programming model address the operational fleets - drills, trucks, loaders and excavators - beyond the working faces, ore deposits, waste piles and crushers. The mathematical model is responsible for allocating the load equipment in working faces, and to report the amount of trips of each truck fleet must perform, respecting the restrictions concerning quality, granulometry and desired minimum mass for each discharge point. The simulation model interacts with the mathematical model and seeks to validate it, through the exercise of the various stochastic parameters of the problem.

Fioroni et al.[16], developed a simultaneous model simulation and optimization of mining planning. This work demonstrated how simulation and optimization models to run simultaneously, can obtain a precise solution, reliable and executable for mine planning problem. For such a simulation tool and optimization based on ARENA and LINGO was developed.

This work was developed based on recognized procedures on the market, such as SCRUM[13] and XP[14]. To ensure the quality of the prototype being developed and enable the delivery of results, it adopted a set of techniques that make up the current state of the art in software development: development directed to testing automation software testing, continuous integration, incremental design and design driven behavior.

2. Objectives

The objective of this paper is to show the development and application of a software, which combines simulation and optimization models and algorithms to mine planning robustly integrated with external data sources and with good usability. It is expected to disseminate the techniques of operational research and simulation for short and long-term mining planning, and to obtain better operational results from their use.

Integrated approaches of optimization and discrete event simulation enables more robust analysis of the results of the proposed plans and the adequate incorporation of restrictive features observed on the day to day operations of the mine[15].

3. Methods

3.1. Mathematical modelling

The mathematical modelling is an integer linear programming model solved by a commercial software with the following objective function:

$$min\left(eprod + \sum_d \sum_j \left(emax_{d,j} + emin_{d,j}\right) + erem\right) \quad (1)$$

The objective is to minimize the sum of production deviations ($eprod$), the sum of the upper and lower limits of grade controls (t) of each discharge (d) and the deviation ($erem$) of the waste/ore ratio, subject to allocation, quality, feed mass in crushers and waste/ore ratio constraints.

3.1.1. Sets

uml: Minimum mining unit
jm: Load equipement
te: Control grade
bl: Mining bench
de: Ore final destiny
kc: Haul equipement
gr: Control granulometry
$type$: Material type

3.1.2. Allocation constraints

- It is only allocated on a uml_i the load equipment jm_j that is available, or is not being repaired in the maintenance shop

- The amount of load equipment jm_j allocated by uml_i depends of its capacity
- It is only allocated on a bank b the load equipment jm_j that is available, or is not being repaired in the maintenance shop
- The equipment that was allocated on a uml_i must be allocated in the bank b to which the uml_i belong
- The mass coming out of each bank b should be less than the mass of the loader already allocated to it is able to do in the time period defined by the time input parameter
- The mass coming out of each bank b must equal the sum of the masses who leave their uml_i
- The mass coming out of each uml_i must be less or equal the mass available for the same
- The maximum travel performed by the fleet k between the uml_i and unloading d must be less than 60
- The maximum amount of travel by scheduled k truck fleet between each uml_i and each discharge d must be less than the maximum capacity of trips made by this fleet

3.1.3. Quality constraints

- The upper limit of control grades t for discharge d must be respected
- The lower limit of the control grades t for discharge d must be respected

3.1.4. Mass constraints

The mass of ore coming from each *uml i* one and goes to each discharge *d* must be greater than the production of each discharge *d*.

3.1.5. Waste/Ore ratio constraints

The relationship between the ore mass and waste extracted must respect the ratio defined.

3.2. Development of integrated application

From programming techniques and integration of databases, the application interface was developed as showed in Fig. 1.

Fig. 1.- Integrated user interface

3.3. Case study

A scenario were simulated for the monthly mining plan of an iron mine, located in Brazil. The following assumptions were adopted:

- 19 trucks with capacity of 91 tons
- 4 loading equipment
- 1 ore discharge (59% of iron)
- 1 waste dump
- Period: 30 days

- Five mining regions (North, South, East, West and Middle)

4. Results and discussion

All instances tested are real cases resulting from the daily activity of users. For each one are presented graphs resulting from optimizer data.

Fig. 2 shows the evolution of mining operations along the simulated time window. Due to stochastically defined parameters, there was a peak of waste/ore ratio, on the 19th day.

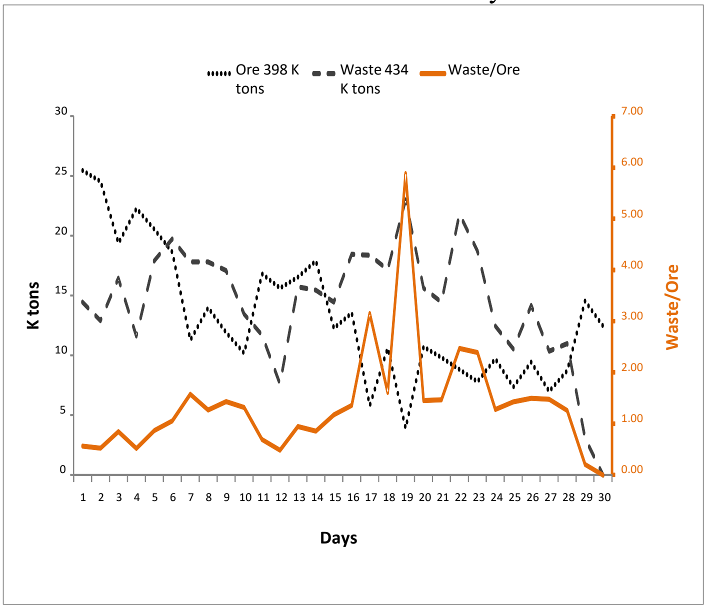

Fig. 2 Simulated movement, scenario with 19 trucks

Fig. 3 shows some Key Performance Indicators (KPIs) for the scenario simulated and Fig. 4 shows the variation of grade delivered in the plant.

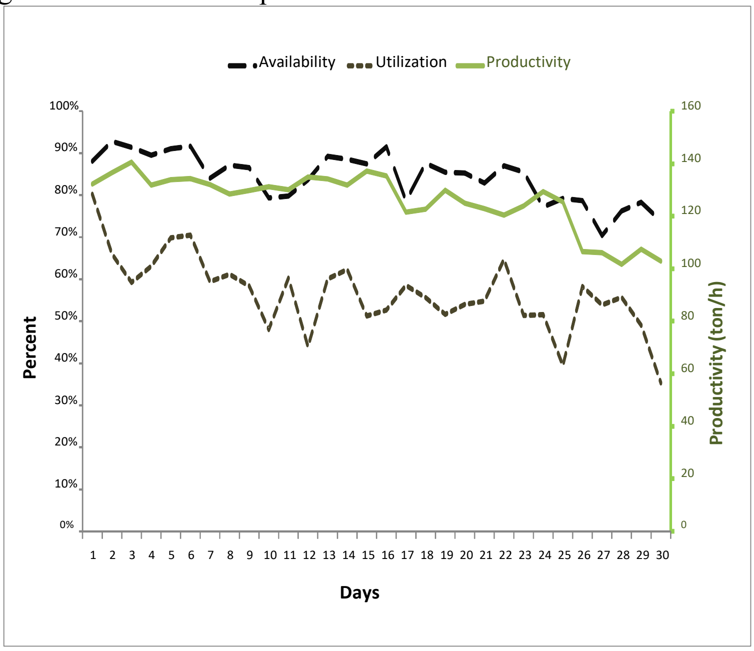

Fig. 3 Operational indicators simulated, scenario with 19 truck fleet

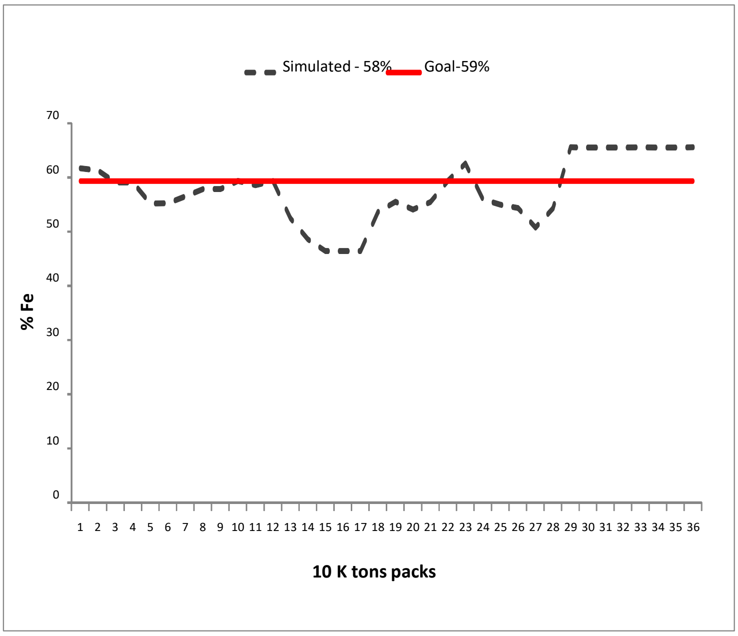

Fig. 4 Simulated quality delivered to Plant A, scenario with a 19 truck fleet

Finally, Fig. 5 shows the evolution of remaining mass in the four different mining zones. Note that as long the ore mass is extracted, different zones was exhausted in different time periods.

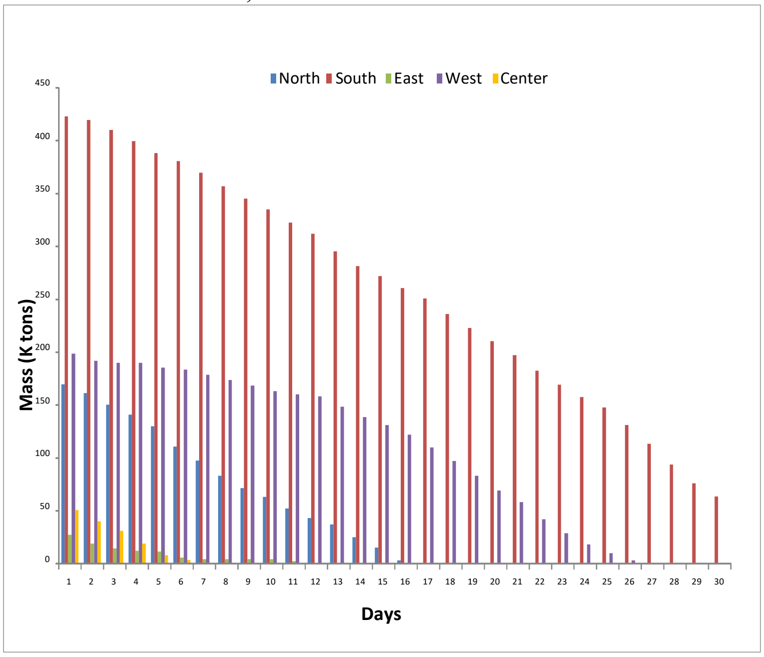

Fig. 5 Remaining mass, for mining areas, scenario with a 19 truck fleet

5. Conclusions

The software met its main goal, to generate the files needed to perform the integrated simulation the optimizer without errors. Running the simulation within the tool needs adjustment due to the instability of communication with Arena simulator and solver Lingo.

Although simulation programs are just used in the mining industry due to various reasons, including the lack of professionals to model processes, the software enables through its web interface perform extraction scenarios of different mines due to parameterization of the information entry, and analysis of results through graphics generated after each simulation.

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References

[1] B. Pimentel, G. R. Mateus e F. Almeida, "Mathematical Models for Optimizing the Global Mining Supply Chain," em Intelligent Systems in Operations: Methods, Models and Applications in the Supply Chain, IGI Global, 2010.

[2] E. K. C. Chanda e K. Dagdelen, "Optimal blending of mine production using goal programming and interactive graphics systems," International Journal of Surface Mining, Reclamation and Environment, vol. 9, pp. 203-208, 1995.

[3] L. H. C. Merschmann, "Desenvolvimento de um sistema de otimização e simulação para cenários de produção em minas a ceú aberto," Rio de Janeiro, 2002.

[4] L. R. Pinto, "Metodologia de análise do planejamento de lavra de minas a céu aberto baseada em simulação das operações de lavra," Rio de Janeiro, 1999.

[5] F. P. Costa, "Aplicações de técnicas de otimização a problemas de planejamento operacional de lavra em minas a céu aberto," Ouro Preto, 2005.

[6] E. Moraes, "Um modelo de programação matemática para otimizar a composição de lotes de minério de ferro da mina Cauê da CVRD.," Ouro Preto, 2005.

[7] L. Rodrigues, "Análise comparativa de metodologias utilizadas no despacho de caminhões em minas a céu aberto," Belo Horizonte, 2006.

[8] G. Pantuza, L. F. Rodrigues e M. J. F. Souza, "Modelo de simulação computacional para validação dos resultados de alocação dinâmica de caminhões com atendimento de metas de qualidade e de produção em minas a céu aberto," em XIV Simpósio de Engenharia de Produção, Bauru, 2007.

[9] G. Pantuza, "Métodos de otimização multiobjetivo e de simulação aplicados ao problema de planejamento operacional de lavra em minas a céu aberto," Ouro Preto, 2011.

[10] S. Dhanalakshmi, S. Kannan, K. Mahadevan e S. Baskar, "Application of modified NSGA-II algorithm to Combined Economic and Emission Dispatch problem," International Journal of Electrical Power & Energy Systems, vol. 33, pp. 992-1002, 2011.

[11] A. Martins, "Simulação das operações de lavra da Mina de Brucutu utilizando um modelo de programação linear para alocar os equipamentos de carga," 2013.

[12] T. Dingsøyr, T. Dybå e N. B. Moe, Agile Software Development: Current Research and Future Directions, Springer Berlin Heidelberg, 2010.

[13] L. Rising e N. S. Janoff, "The Scrum Software Development Process for Small Teams," IEEE Software, vol. 17, n. 4, pp. 26-32, 2000.

[14] K. Beck, "Embracing change with extreme programming," IEEE Computer, vol. 32, n. 10, pp. 70-77, 1999.

[15] G. F. Coelho, B. R. Oliveira, L. R. Pinto e A. G. Martins, "Análise do Congestionamento do Sistema Produtivo de uma Mina a Céu Aberto: Comparativo entre Soluções Propostas

[16] M. Mi Fioroni et al., "Concurrent simulation and optimization models for mining planning", Proceedings of the 2008 Winter Simulation Conference, p. 759-767, 2008.

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