

A high-level dynamic analysis approach for studying global process plant availability and production time in the early stages of mining projects

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Abstract

In the early stage of front-end studies of a Mining Project, the global availability (i.e. number of hours a plant is available for production) and production (number of hours a plant is actually operated with material) time of the process plant are normally assumed based on the experience of the study team. Understanding and defining the availability hours at the early stages of the project are important for the future stages of the project, as drastic changes in work hours will impact the economics of the project at that stage. An innovative high-level dynamic modeling approach has been developed to assist in the rapid evaluation of assumptions made by the study team. This model incorporates systems or equipment that are commonly used in mining projects from mine to product stockyard discharge after the processing plant. It includes subsystems that will simulate all the component handling, and major process plant systems required for a mining project. The output data provided by this high-level dynamic simulation approach will enhance the confidence level of engineering carried out during the early stage of the project. This study discusses the capabilities of the approach, and a test case compared with standard techniques used in mining project front-end studies.

Keywords: mining, dynamic simulation, high-level simulation model.

1. Introduction

The efficiency of complete mineral processing facilities depends on the utilization of various subsystems and their degree of decoupling (Miller, 1979). The intermediate stockpiles and surge bins are important components that help to avoid unscheduled shutdowns (Berton *et al.*, 2013). In the current economic conditions, every investment dollar required to be spent on surge storage systems in these facilities should match the production system utilization. Any deviation from it will result in either losing production or poor capital investment efficiency.

All current major mining projects go through some form of front-end (FEL) studies, in line with IPA definitions (Stange and Cooper, 2008), before reaching the implementation stage. The investment community is not willing to take as many risks in the year ahead and puts more pressure on mining companies to deliver the project efficiently (Nikkhah and Ander-

son, 2001; Ernst & Young, 2013). Many projects start with a scoping study (FEL1), followed by a pre-feasibility study (FEL2) and a feasibility study (FEL3), before being approved for implementation. For all the stakeholders, it is very important to sustain project viability throughout these phases, with the exception of the identified risks that may change the project course in the future. The changes in the project configuration established in the early stages are expected to include mitigation of risks identified in the previous phase or additional data availability that supports a better definition of the project. Most of the stakeholders understand and agree to most of these changes when they are related to better definition of the process or mitigation of the risks foreseen in the previous stage(s). However, some of the parameters that form these studies, which are not scrutinized a great deal during the early stages, are the sizing of stockpiles,

effective utilization of the plant as a total system, etc. The values for these items are assumed based on experience in most studies; the estimated values may cause change in the costs in the future phases of the project. These assumptions can impact the current study outcome or the later phase. Any major changes to these parameters can influence the cost of the project. To enjoy investor confidence in the long term, it would be prudent to carry out front-end studies of the project with a better-defined set of utilization and storage parameters, since future project changes are directly related to mining or process changes or identified risks. This will reduce some of the uncertainty caused by assumptions based solely on experience during the early stages of the project.

In an iron ore project, the surge or storage stockpiles and bin installations contribute to the major cost as they are of high capacities and are mostly mecha-

nized. The utilization of the system is adversely impacted if the surge capacity or anticipated decoupling of the plant is not sufficient. At the same time, excess surge/stockpile capacity may decrease the capital efficiency and may result in poor project economics in the early stages, which may make it lose its investment attractiveness. During initial studies, it is better to size the surge capacities that will address both plant utilization and capital efficiency. This is essential to improve the sustainability of future operations (Gomes *et al.*, 2015).

The objective of the ‘High-level Dynamic Analysis Approach’ is to drive engineering to an improved definition of plant availability, considering the storage or surge capacity sizing, during the early stages of mining projects, using the total system concept. This will also help as a project parameter verification tool to ensure that the plant utilization and

individual production rates are less prone to surprises during future project phases.

Steady-state simulation is less complicated to develop and to operate, but dynamic simulation has a higher potential to predict the actual behavior, as it considers the impacts of process and material handling disturbances (Bergquist, 2012; Asbjörnsson *et al.*, 2013). By simulating a system in its totality, and not as isolated subsystems, the simulation approach yields globally optimal solutions that meet overall system objectives (Cardoso and Teles, 1997; Altioik, 2010), as some investments in a determined area do not increase the global performance (Juliá, 2010).

The evaluation model is detailed enough to be accurate, as accuracy is dependent on the simulation success, but detailed simulation will be expensive to model and difficult to operate. Utilizing the information obtained by an inappropriate

or inaccurate model can lead to unexpected plant behavior, such as underperformances in critical areas (Asbjörnsson *et al.*, 2012; Le Roux *et al.*, 2013; Vasabi *et al.*, 2014).

An innovative high-level dynamic modeling approach has been developed by making a generic model that could be easily set to evaluate a mining project in a few hours (around 8–16 h). As the model requires less time to be set than traditional models (which require weeks), it can be used in the scoping study (FEL1) and pre-feasibility study (FEL2).

The contribution of this work is to show that a dynamic analysis can be used in the early stages of mining projects (FEL1 and FEL2), helping in the early detection of capacity and utilization issues of the complete system, and allowing corrective action to update the configuration and design of equipment and storage.

2. Materials and methods

One of the keys to 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 to the iterative nature of the method, which does not necessarily follow a list of sequences, some activities may be performed simultaneously

and/or repeated; the initial idea of the flow simulation study is shown in Figure 1 (Cremonese, 2014). The complete methodology in the development of a dynamic simulation model is described by Cremonese (2014).

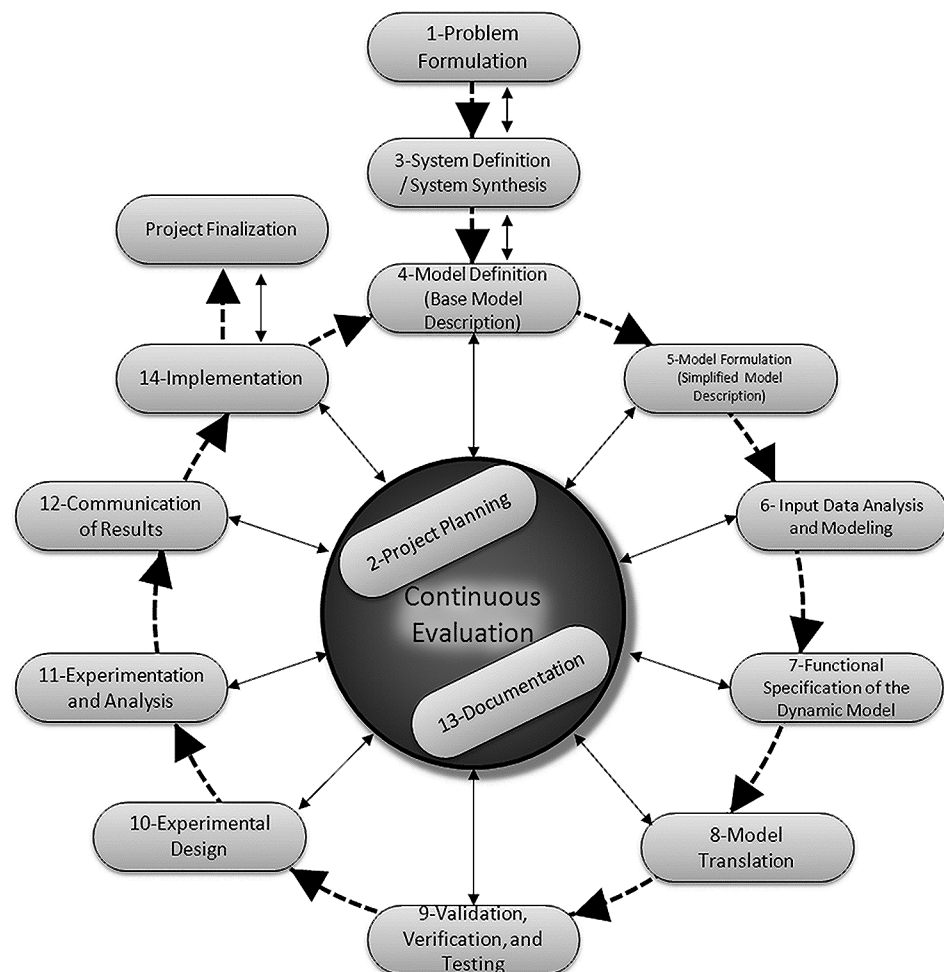


Figure 1 Simulation Methodology (Cremonese, 2014).

To develop the model with a sufficient level of detail, the following assumptions were considered:

- Only solid flow is considered. This means that the water and particle size are not considered in the model. Inclusion of other parameters would increase model complexity and could make it difficult to use; however, further works are to include these modes, which could lead to studies not intended at the early stage of the project;
- The equipment capacity varies in a triangular statistical distribution, and all the parameters are defined by the user with the interface provided;
- Unplanned maintenance occurs in a triangular statistical distribution that considers the minimum value to be 50% and the maximum value 150% of the most

3. Results and discussion

An iron ore project was used as a test case. There are 230 pieces of equipment at the process plant, made up of 100 categories. There are 47 pieces of process equipment (Crushers, Screens, Spiral Classifier, Thickeners, Mills, Cyclones, etc.) and 53 of

likely value. This most likely value is the time-between-stops as defined by the user with the interface provided.

The model could be developed in any commercially available discrete simulation software (Cremonese and Livoratti, 2012); however, for this study, the model was developed in the Arena (by Rockwell Automation) software. The input data were grouped into tabs in the Microsoft Excel file (Interface), where each tab describes a unique project system block. The model design allows for continuous improvement and expansion, as well as the inclusion of additional process steps as necessary.

The model input data template for the equipment includes the flow of the material, equipment capacities, planned and unplanned maintenance. The typical

resulting data stored are annual throughput, maximum, minimum and average stock levels, and equipment utilization. All the data of stockpiles, bins and the necessary information along the simulated time are stored.

The model components are developed to allow various combinations or a configuration of equipment with no customizing effort at the programming level. When the model is set to run, the Visual Basic for Applications (VBA) obtains the input data from the MS Excel interface and inserts it into the Arena model, making the links between the system blocks, such as the Primary Crushing to Stockpile 1 and so on. This interface allows an engineer with minimal experience in simulation software to set the input data and run the model.

Table 1
Production time and average plant capacity.

Area	Production time (hours/year)	Plant average capacity (t/h)
Primary Crusher System	5400	1400
Process Plant	6400	1200

The static analysis shows that the Primary Crusher System achieves 5400 h/year x 1400 t/h = 7.56 Mtpa; and the Process Plant achieves 6400 h/year x 1200 = 7.68 Mtpa. Both are at least 8% higher than the necessary

material handling equipment (Belt Conveyors, Bins, Piles, Stacker-Reclaimers, etc).

The FEL2 study data were used as input to the model. It is therefore possible to analyze whether the model output gives useful information to the

FEL 3 stage of the project.

The Run of Mine (ROM) ore is 7 million tons per annum (Mtpa), and the production time and average capacity defined by the project team are shown in Table 1.

7 Mtpa.

However, the production times of 5400 and 6400 hours/year are based on the experience of the project team and do not account for all the system interrelations and interdependencies. It does not

consider the sizes of stockpiles, bins and unexpected failures of the system, etc.

The ‘High-level Dynamic Analysis Approach’ considers the statistical variation occurring in the process, such as equipment through capacity variation,

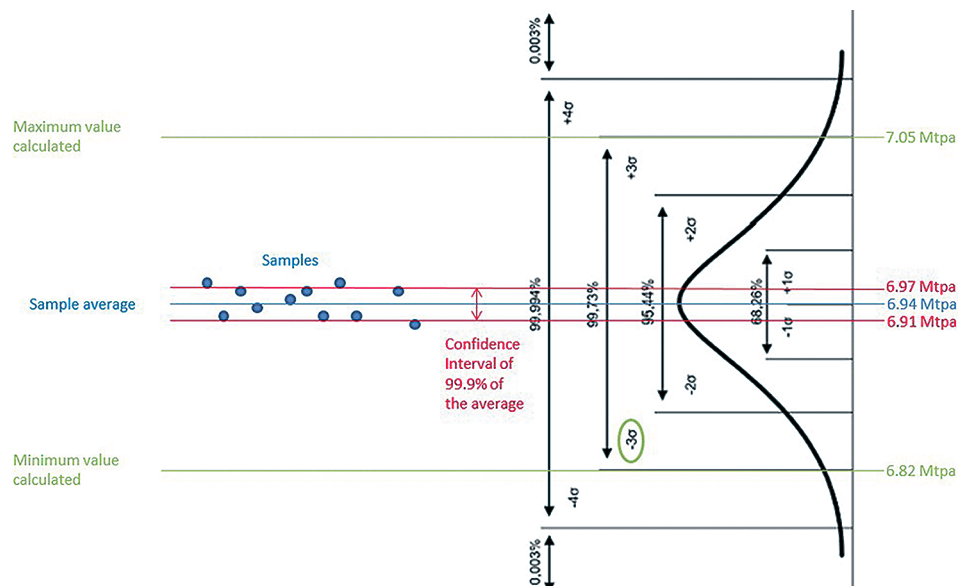


Figure 2
ROM considering confidence interval of the mean and sigma intervals.

unexpected failures, bin levels, etc.

Considering planned and unplanned maintenance, equipment data, and storage capacity, the model shows that the plant availability and production time will not be achieved. The ROM ore achieved an average of 6.94 Mtpa. Figure 2 shows that considering a confidence level of 99.9% of the mean, the mean ROM achieved along the year is between 6.91–6.97 Mtpa, which is less than the 7 Mtpa target.

Furthermore, at the 3-sigma level,

99.73% of the years will achieve a capacity of between 6.82–7.05 Mtpa.

For a 7 Mtpa capacity, estimated from team experience, using the same configuration, the dynamic simulation shows that in some years, the capacity can only be 6.82 Mtpa.

It is therefore evident that capacity will not be achieved. The question is: “why this is, and what can be done to achieve it?”

The first step is to analyze the bin and stockpile utilization over a period.

The intermediate stockpile has a capacity of 200 kt and is almost full or completely full after half the simulation time. This shows that the mine and primary crushing area are not the bottleneck.

Figure 3 shows the utilization of the main equipment as a percentage of time. The dotted red line represents the separation (battery limit) between the crushing plant and the process plant. The number inside the “(#XXX)” is the block number. Each block is one equipment in the model.

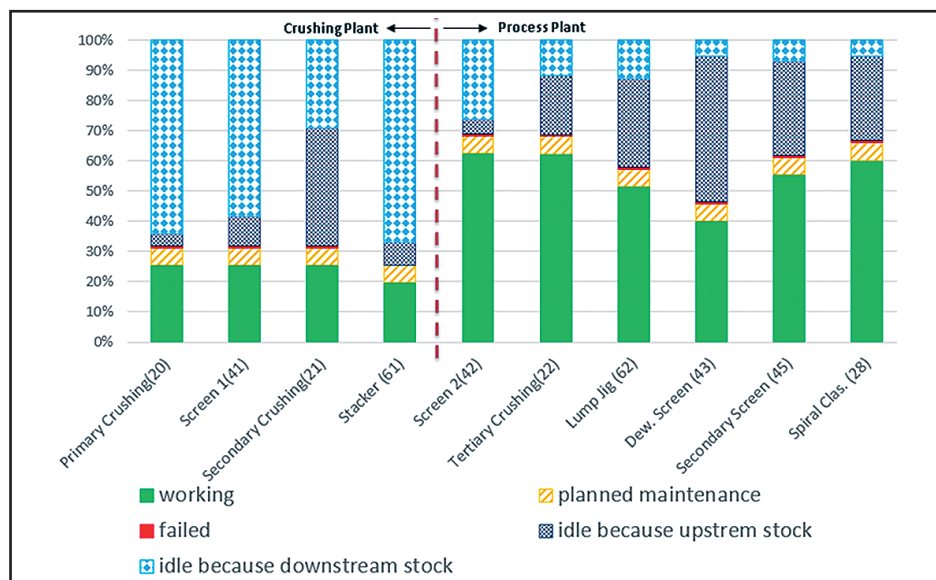


Figure 3
Equipment utilization.

Figure 4 shows the storage level of each bin/tank (#189 to #199) and of the

intermediate stockpile (#180) as a percentage of time. The dotted red line represents

the separation (battery limit) between the crushing plant and the process plant.

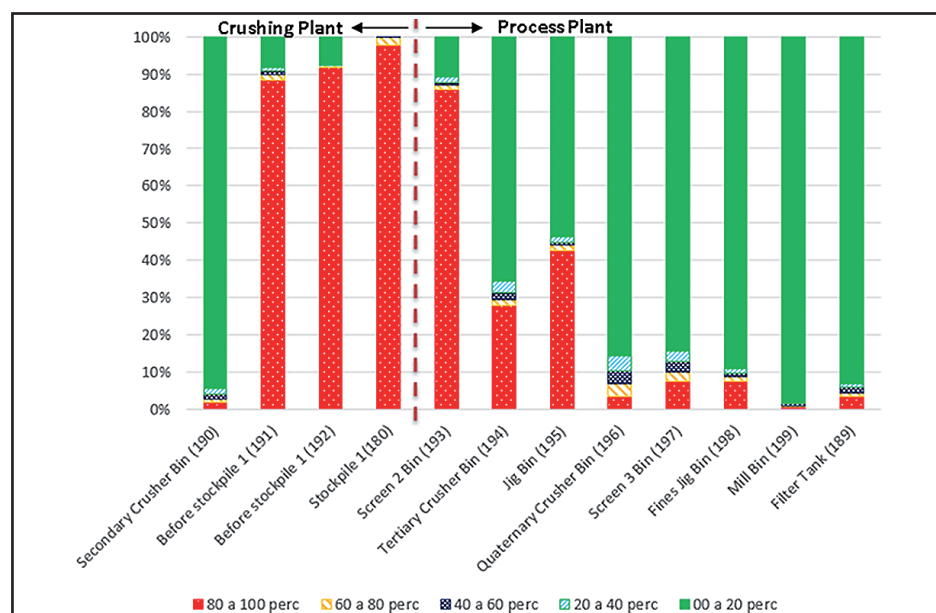


Figure 4
Bin and stockpile utilization.

The analysis from Figure 5 shows that the capacity of the process plant was reduced by the dynamic behavior of the equipment. One way to increase the capacity is to enable decoupling of

the equipment and bins.

To test the influence of bin capacity on global availability, the Screen 2 Bin (#193) and Tertiary Crusher Bin (#194) were made variable from

200–800 t. Both of these bins were sized at 500 t. The two bins were in a critical area, as they filled between 80–100% of the capacity about 30% of the time.

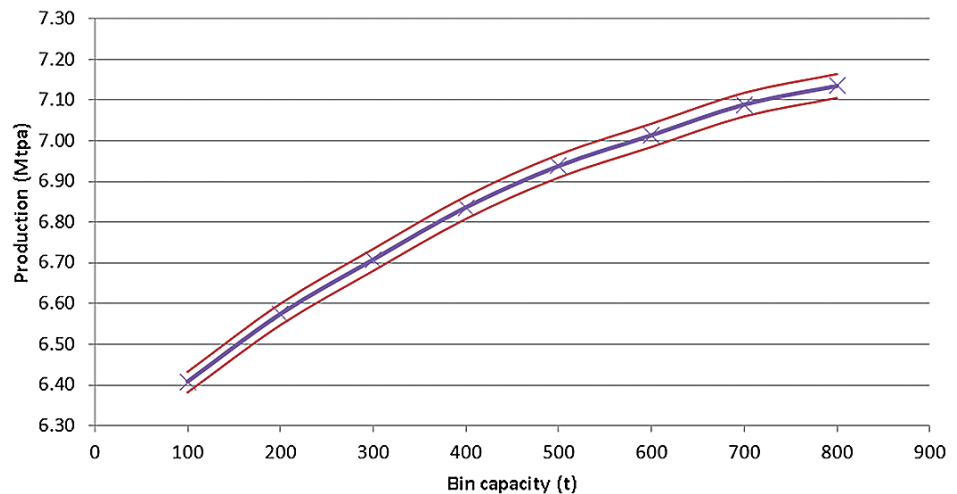


Figure 5
Production (Mtpa) versus bin capacity (t).

The plant's mean production capacity is achieved by increasing the bin capacities to 650 t, and is expected to achieve a confidence level of 99%.

This bin capacity change in the FEL 2 stage to achieve the plant capac-

4. Conclusions

The "High-level Dynamic Analysis Approach" evaluates capacities considering all the system blocks of the project; the results are closer to global availability. The work is carried out with standard information available to the study team in the early stage of the project, but with less engineering effort compared to a detailed dynamic simulation model. Domain expert judgment or the operating staff input on systems or the experience of the user is required to obtain reliable results from this tool. However, it does not require modeling software experience.

Using this approach and based on the system dependability and system dynamics, one can assure that the plant availability is sized to achieve the anticipated utilization of the systems included in the project. This innovative way of

ity is minor compared to the changes that need to be carried out in FEL 3 and project implementation or worse, in plant operation.

In this test case, insufficient bin capacity was discovered in a complete

dynamic simulation model at the end of FEL 3. Discipline engineering, such as Mechanical and Civil, needed to be revised, since the belt conveyor length had to be changed, and the load of the structure was increased.

ensuring the quality of the engineering work can enhance investors' confidence in the project as the project evolves into the next level. The results also show that evaluating the system as a whole rather than in isolation would drive the values closer to the optimized system. However, the High-level Dynamic Analysis Approach is not meant to be used in the later stages of the project, as it is necessary to simulate the system with more details to optimize the project systems or when more details of the system are available. The approach helps to combine the total project systems and to provide data for sizing the storage systems, instead of intuitive sizing based on experience, which may lead to surprises in future phases of the project. This approach can help in the early detection of capacity and utilization

issues of the complete system, and allows corrective action to update the specific system configuration and design.

As shown in the test case, the utilization of the High-level Dynamic Analysis Approach in the FEL 2 would lead to defining the bin capacities in the early stages. This would avoid the need of revised discipline engineering, such as Mechanical and Civil, once the belt conveyor length had to be changed and the load of the structure increased. This occurred at the end of FEL 3.

Further work to enhance the model is being undertaken to incorporate related systems, such as water storage requirements, to make this approach more effective by considering all the systems that influence the production or sizing in the early stages of the project.

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References

- ALTIOK, T. Large-scale simulation modeling of ports and waterways: approaches and Challenges. In: WORKSHOP ON GRAND CHALLENGES IN MODELING, SIMULATION AND ANALYSIS FOR HOMELAND SECURITY. *Anais...* Washington: US DHS - Science and & Technology Directorate, 2010.
- ASBJÖRNSSON, G., HULTHÉN, E., EVERTSSON, M. Modelling and dynamic simulation of gradual performance deterioration of a crushing circuit – Including time dependence and wear. *Minerals Engineering*, v. 33, p. 17–19, 2012.
- ASBJÖRNSSON, G., HULTHÉN, E., EVERTSSON, M. Modelling and simulation

- of dynamic crushing plant behavior with MATLAB/Simulink. *Minerals Engineering*, v. 43–44, p. 112–120, 2013.
- BERGQUIST, B. Traceability in iron ore processing and transports. *Minerals Engineering*, v. 30, p. 44–51, 2012.
- BERTON, A. et alii. Ore storage simulation for planning a concentrator expansion. *Minerals Engineering*, v. 40, p. 56–66, 2013.
- CARDOSO, C.R.O., TELES M.B. Simulação de terminal portuário. In: ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO, 17. *Anais...* Gramado (RS): ABEPRO, 1997.
- CREMONESE, D.T. *Desenvolvimento e aplicação de metodologia para estudos de simulação dinâmica na cadeia do minério de ferro*. São Paulo: Escola Politécnica, Universidade de São Paulo, 2014. 157 p. (Master's Dissertation in Mineral Engineering).
- CREMONESE, D.T., LIVORATTI, P. Simulation tools: a study of application at the Nouadhibou Port. In: INTERNATIONAL CONFERENCE ON INTELLIGENT PROCESSING AND MANUFACTURING OF MATERIALS, 7. *Anais...* Foz do Iguaçu (PR): IPMM, 2012.
- ERNST & YOUNG. Canadian mining companies focused on cost control, project execution in 2013. Ernst & Young. News Release, 7th Feb 2013. Available at: <http://www.newswire.ca/news-releases/canadian-mining-companies-focused-on-cost-control-project-execution-in-2013-ernst--young-511933581.html> [Last accessed: 10 March 2016].
- GOMES, R. B., DE TOMI, G., ASSIS, P. S. Impact of quality of iron ore lumps on sustainability of mining operations in the Quadrilátero Ferrífero Area. *Minerals Engineering*, v. 70, p. 201–206, 2015.
- JULIÁ, A. F. *Desenvolvimento de um modelo de simulação para dimensionamento de um sistema integrado pátio-porto na cadeia do minério de ferro*. São Paulo: Escola Politécnica, Universidade de São Paulo, 2010. 165 p. (Master's Dissertation in Logistic Systems Engineering).
- LE ROUX, J. D. et al. Analysis and validation of a run-of-mine ore grinding mill circuit model for process control. *Minerals Engineering*, v. 43–44, p. 121–134, 2013.
- MILLER, M. J. Stockpiling and reclaiming systems in mill design. SME. *SME-AIME Fall Meeting and Exhibit*, Tucson, Arizona, v. 79, p. 326. 1979.
- NIKKHAH K, ANDERSON C. Role of simulation software in design and operation of metallurgical plants: a case study. In: SME ANNUAL MEETING. Denver Colorado, v. 1, p. 176, 2001.
- STANGE W., COOPER B. *Value options and flexibility in plant design, metplant - metallurgical plant design and operating strategies*. Perth (Australia): Australasian Institute of Mining and Metallurgy, 2008.
- VASEBI, A., POULIN, E., HODOUIN, D. Selecting proper uncertainty model for steady-state data reconciliation – Application to mineral and metal processing industries. *Minerals Engineering*, v. 65, p. 130–144, 2014.

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