DENNIS TRAVAGINI CREMONESE

Mineral project design using ABC methodology and dynamic simulation

São Paulo

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To my friends and family

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RESUMO

Este trabalho apresenta duas maneiras inovadoras de avaliar projetos de mineração. A primeira é a Abordagem de Custeio Baseado em Atividades em operações de mineração com mix de produtos. Após coletar e analisar dados de uma mineração de agregados localizada no Brasil, um modelo de custo foi desenvolvido, e a partir deste, uma metodologia de análise e gerenciamento dos custos da mineração é criado. Este trabalho tem a vantagem de inovar ao usar a abordagem ABC como uma ferramenta de planejamento da operação de mina, identificando os produtos mais rentáveis. A segunda é o uso de simulação dinâmica nos estágios iniciais de estudos “Front End Loading” (FEL) de Projetos de Mineração. Nos estágios iniciais o tempo de disponibilidade global (número de horas que está disponível para operação) e de produção (número de horas que está realmente operando com material) da usina de beneficiamento são normalmente assumidos baseados na experiência da equipe de projeto. É importante definir estes tempos nos estágios iniciais do projeto, visto que mudanças drásticas nas horas trabalhadas impactará sobre a economia do projeto. Uma inovadora abordagem de modelagem dinâmica de alto nível foi desenvolvida para auxiliar numa avaliação rápida das premissas adotadas pela equipe de projeto. Este modelo incorpora sistemas e equipamentos comumente usados em projetos de mineração, da mina até o descarregamento de material nos pátios de estocagem de produtos depois da usina de beneficiamento. Este modelo inclui subsistemas que simulam todos os componentes de manuseio e principais sistemas da usina de beneficiamento requeridos para um projeto de mineração. Os dados de saída fornecidos por esta abordagem aumentarão o nível de confiança da engenharia realizada durante a fase inicial do projeto. Este trabalho discute as vantagens técnicas e econômicas de utilizar esta metodologia e apresenta uma comparação de cinco casos testes com as técnicas tradicionais usadas nos projetos de mineração em estudos FEL. No final, é concluído que a criação de um modelo de custo para ser usado na operação de mineração é um investimento recompensador, pois mostra os produtos rentáveis e não-rentáveis, e que o uso de simulação dinâmica nos estágios iniciais é tecnicamente e economicamente vantajoso.

Palavras-chave: Mineração. Custeio baseado em atividades. Simulação dinâmica.

# ABSTRACT

This work presents two innovative ways to evaluate mining projects. The first is the Activity-Based Costing Approach in mining operations with a product mix. After analyzing and collecting data from an aggregate mine located in Brazil, a cost model was built, and from that, a cost management and analysis methodology of a mine is created. This work has the innovation advantages of using ABC as a tool for planning the operation of the mine, identifying the more profitable products. The second is the use of dynamic simulation in the early stage of Front End Loading (FEL) studies of a Mining Project. In the early stages the global availability (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 hours available 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 a fast evaluation of assumptions made by the study team. This model incorporates systems or equipment commonly used in mining projects from mine to product stockyard discharge after the process plant. This model includes subsystems that will simulate all the handling components, major processing 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 work discusses the technical and economic advantages in using this approach and five test cases comparing with the standard techniques used in mining project FEL studies. At the end, it is concluded that the creation of a cost model to be applied in mining operations is a rewarding investment as it shows the profitable and unprofitable products, and that the use of dynamic simulation in the early stages is technically and economically advantageous.

Keywords: Mining. Activity-based costing. Dynamic simulation.

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1. GENERAL INTRODUCTION

With the evolution of technology, it is imperative to evolve the way that projects are planned, managed and executed in the mining sector.

Currently, mining models can be widely applied to answer questions previously only estimated by project team experience. These models can answer questions about the real cost of a product, considering all the mining costs in a real time basis, or the process plant production capacity, considering all the main equipment capacities and availabilities.

This study presents two innovative ways to evaluate mining projects. The first is the Activity-Based Costing Approach in mining operations with a product mix. The second is the use of dynamic simulation in the early stage of Front End Loading (FEL) studies of a Mining Project. Both use models to evaluate the systems and give the answers that are only estimated by project team experience.

The first innovative way to evaluate mining projects, the Activity-Based Costing (ABC) Approach, is a cost and management tool for decision-making on product mix. The direct and indirect costs (such as administrative, warehouses, sales, maintenance …) can be mapped to identify the relationship between activities and products. The appropriate apportionment of costs and the product mix, thus obtaining the actual profitability of each.

A common challenge in mining is the realistic apportionment of actual costs for each product, co-product, and sub-product that are part of the operation product mix. When cost sharing is done improperly, the profitability assessment of each product can be undermined by incorrect information that compromises the strategic decision-making. The introduction of an analysis methodology of indirect costs properly associated with each specific product can have a significant impact on the operation competitiveness.

Arbitrary division of the indirect costs causes distortions, which affect the profitability of each product. As in a new project, where underestimating the costs may cause an unprofitable project’s ongoing progress and fail, while overestimation of cost could result not progressing ahead a potentially profitable project (Sayadi et al., 2014), the same happens with products in a product mix in a mining operation.

Unprofitable products continue in production, negatively affecting the cash flow. Products that are more profitable are not prioritized, reducing the overall profitability of the mine. With a control of the actual costs of each product, the sales price can be adequate and the most profitable products can be prioritized, positively affecting the company.

The second innovative way to evaluate mining projects, the ‘High-level Dynamic Analysis Approach’, has the objective 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.

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 mechanized. 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.

1.1. OBJECTIVES

- To develop a methodology to quantify the individual cost of each product in a mix of products generated in a mining;
- To evaluate the impact of the use of dynamic simulation to analyse the process plant availability and production time in the first stages of mining projects;
- To assess the economic impact of the use of dynamic simulation in the first stages of mining projects.

1.2. STRUCTURE OF THIS THESIS

According to the outlined objectives, this thesis is organised as follows:

- Chapter 1: Problem presentation and objectives discussion;
- Chapter 2: Literature review, methodology, results and research analysis involving activity-based costing approach in mining operations;
- Chapter 3: Literature review, methodology, results and research analyses involving dynamic simulation for studying process plant availability and production time;
- Chapter 4: Literature review, methodology, results and research analyses of the economic advantages in using dynamic simulation in the early stages of mining projects;
- Chapter 5: Conclusions of the tree studies developed and the relationship with the research objectives;
- Chapter 6: References of all studies.

2. COST MODELLING OF THE PRODUCT MIX FROM MINING OPERATIONS USING THE ACTIVITY-BASED COSTING APPROACH

2.1. INTRODUCTION

This research topic is part of a published article by the author in 2016[1]. A common challenge in mining is the realistic apportionment of actual costs for each product, co-product, and sub-product that are part of the operation's product mix. When cost sharing is done improperly, the profitability assessment of each product can be undermined by incorrect information that compromises the strategic decision-making. The introduction of an analysis methodology of indirect costs properly associated with each specific product can have a significant impact on the operation competitiveness.

Arbitrary division of the indirect costs causes distortions, which affect the profitability of each product. As in a new project, where underestimating the costs may cause an unprofitable project's ongoing progress and fail, while overestimation of cost could result not progressing ahead a potentially profitable project (Sayadi et al., 2014), the same happens with products in a product mix in a mining operation.

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[1] CREMONESE, D.T., DE TOMI, G., NEVES, M.R. **Cost modelling of the product mix from mining operations using the activity-based costing approach**, REM: Revista Escola de Minas, v. 69, n. 1, p. 097–103, 2016. (DOI: http://dx.doi.org/10.1590/0370-44672015690137)

The introduction of new management practices, due to mines size, increased automation and the outsourcing of non-core activities, increased the indirect costs and decreased the direct costs (Sartorius and Kamala, 2007; Crowson, 2003). Curry et at. (2014) showed that in a study with 63 mines, the cost related to General and Administration represents up to 42% of the total mine cost. Therefore, the indirect costs are a significant part of the amount to be arbitrarily divided between the products.

The Activity-Based Costing (ABC) Approach is a cost and management tool for decision-making on product mix. The direct and indirect costs (such as administrative, warehouses, sales, maintenance …) can be mapped to identify the relationship between activities and products. The appropriate apportionment of costs and the product mix, thus obtaining the actual profitability of each. The steps to implementing ABC described by Chartered Institute of Management Accountants (2008) are reviewed and applied to the mining industry.

In order to overcome observed bottlenecks in the cost apportionment in product mix in the mining area, this paper emphasis on the introduction of a methodology to deal with the problem.

2.2. METHODOLOGY

There is no best cost-benefit analysis, but as Lind (2001) identified, the Activity-Based Costing (ABC) approach is more appropriate to obtaining operating costs in a South African coal mine than the traditional costing techniques.

ABC is a cost accounting methodology, aimed at allocating costs properly. ABC uses cost drivers to appoint the costs to activities and basis of a cause and effect relationship with the products (Kostakis et al., 2008).

According to Chartered Institute of Management Accountants (2008), there are four steps to implementing ABC. Following are these steps applied to the mining industry.

1. Determine activities

   The mining needs to make an analysis of all operating processes that consist of one or more activities required to generate the product mix.

2. Select resource costs to activities

   Determine why the cost occurred by tracing costs to cost objects. Costs are categorized in three categories:

   i. Direct costs are traceable directly to one product. The blast and drilling cost that it takes to generate a product in one mine front are an example of it.

   ii. Indirect costs are not traceable to an individual product. They are used to generate more than one product, but not all of them. Truck and shovel maintenance costs that are used in more than one product are example of this.

   iii. General costs are not traceable to any product. Whatever product is produced, these costs remain unchanged. Security costs are an example of this.

   The classification above is different from the standard Direct, Indirect and Fixed Costs used in which the items are related to production (Pascoe, 1992), not the specific product.

3. Determine products

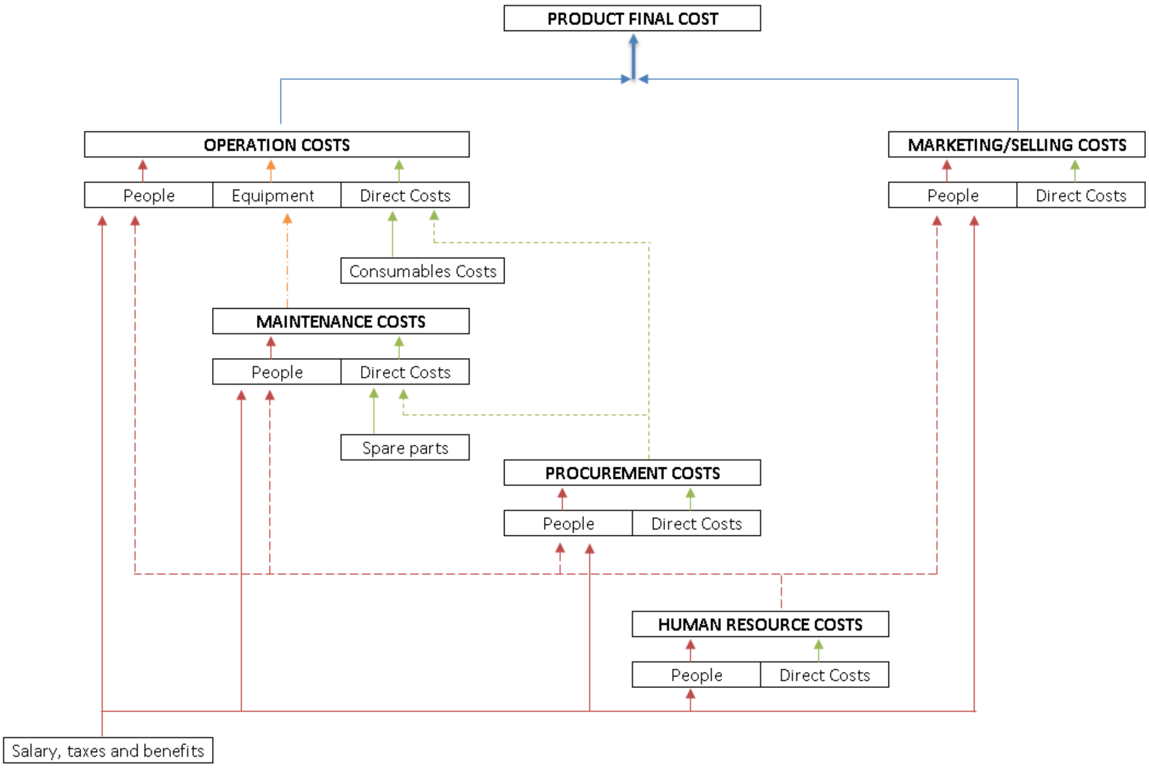
   Determine products for which an activity segment executes activities and utilizes resources.

4. Appoint activity costs to products

Activity drivers appoint activity costs to products based on the utilization for each activities. The key to accurate cost measurement is the correct distribution of the cost drivers (Ai-hua et al., 2009; Gomes et al., 2015).

Figure 1 shows the cost flow in the case study using the ABC approach.

Figure 1 – Cost Flow in the case study using the ABC approach



Source: Personnel file

2.3. THEORY / CALCULATION

2.3.1. COST EQUATIONS

The Total cost of each product has many related activities that generate a lot of cost information to be included in each product. Below is described each step to get the Total cost, considering the Cost Flow described in Figure 1.

- **People**

The cost of the Human Resources (Employees and Direct Costs) is divided equally between the employees of the other areas. Therefore, the cost of an employee (excluding the Human Resources employees) is:

$$\boxed{C_{peY} = S_{peY} + \frac{C_{HR}}{(N_{pe} - N_{peHR})}} \qquad \text{Equation 1}$$

Where: $\mathbf{C_{peY}}$ = Cost of the employee “Y”; $\mathbf{S_{peY}}$ = Salary and charges of the employee “Y”;

$\mathbf{C_{HR}}$ = Total Cost of Human Resources; $\mathbf{N_{pe}}$ = Number of employees in the mine;

$\mathbf{N_{peHR}}$ = Number of employees in the Human Resources.

- **Direct Cost**

The Direct costs are:

$$\boxed{C_{dcZ} = DC_{Z} + C_{pe\mathrm{Pr}} \bullet \frac{NO_{Z}}{NO_{\mathrm{Pr}}}} \qquad \text{Equation 2}$$

Where: $\mathbf{DC_{Z}}$ = Direct Cost of item “Z”; $\mathbf{C_{pePr}}$ = Procurement Cost;

$\mathbf{NO_{Z}}$ = Number of orders related to item “Z”; $\mathbf{NO_{Pr}}$ = Total Number of orders.

- **Equipment**

The cost of any equipment is:

$$\boxed{C_{eqK} = C_{MAeqK} + C_{dceqK}}$$ Equation 3

Where: **C_{MAeqK}** = Cost of the maintenance the equipment “K”;

C_{dceqK} = Direct cost of equipment “K” (oil, gas, spare parts, …).

- **Maintenance**

Ali and Reza (2013) showed that maintenance and overhaul represent from 32% to 64% of the total operating cost for a wheel loader equipped with a cable shovel. So, maintenance cost needs to be evaluate with attention.

The cost of equipment maintenance is:

$$\boxed{C_{MAeqW} = \sum_{i=1}^{n} (C_{peMi} \bullet \%T_{peieqW}) + C_{dcMeqW}}$$ Equation 4

Where: **C_{peMi}** = Cost of the maintenance employee;

$\%T_{peieqW}$ = Percentage of time that maintenance employee “i” works in equipment “W”;

C_{dcMeqW} = Direct maintenance cost of equipment “W” (broken parts, …).

- **Marketing**

The cost of any marketing/selling is:

$$\boxed{C_{MarkX} = C_{dMarkX} + \sum_{i=1}^{n} (C_{peMai} \bullet \% T_{peMaiPX})}$$

Equation 5

Where: $\mathbf{C_{dMArkX}}$ = Direct Cost of Marketing/selling related to product “X”; $\mathbf{C_{peMai}}$ = Cost of the Marketing employee “i”; $\mathbf{\%T_{peMaiPX}}$ = Percentage of time that marketing/selling employee “i” works related to product “X”.

- **Total Product Cost**

The total cost of the Product “X” is:

$$\boxed{C_{PX} = \sum_{k=1}^{n_1} (C_{eqk} \bullet \% T_{eqkPX}) + \sum_{y=1}^{n_2} (C_{pey} \bullet \% T_{peyPX}) + \sum_{z=1}^{n_3} (C_{dcz} \bullet \% P_{dczPX}) + C_{MarkX}}$$

Equation 6

Where: $\mathbf{C_{eqk}}$ = Cost of the equipment “k”; $\mathbf{\%T_{eqkPX}}$ = Percentage of time that equipment “k" operating in product “X” or related to it; $\mathbf{C_{pey}}$ = Cost of the employee “y”; $\mathbf{\%T_{peyPX}}$ = Percentage of time that employee “y” works related to product “X”; $\mathbf{C_{dcz}}$ = Direct Cost on step “z”; $\mathbf{\%P_{dczPX}}$ = Percentage of direct cost “z" related to product “X”; $\mathbf{C_{MarkX}}$ = Marketing and Selling costs related to product “X”.

Expanding Equation 6:

$$
\begin{aligned}
C_{PX} = {} & \sum_{k=1}^{n_1}(((\sum_{i=1}^{n_4}(C_{peMi} \bullet \%T_{pekeqk}) + (DC_{Meqk} + ((S_{pe\Pr} + \frac{C_{HR}}{(N_{pe} - N_{peHR})})) \bullet \frac{NO_{Meqk}}{NO_{\Pr}})) + C_{dceqk}) \bullet \%T_{eqkPX}) \\
& + \sum_{y=1}^{n_2}((S_{pey} + \frac{C_{HR}}{(N_{pe} - N_{peHR})}) \bullet \%T_{peyPX}) \\
& + \sum_{z=1}^{n_3}((DC_z + (S_{pe\Pr} + \frac{C_{HR}}{(N_{pe} - N_{peHR})}) \bullet \frac{NO_z}{NO_{\Pr}}) \bullet \%P_{dczPX}) \\
& + (DC_{MarkX} + (S_{pe\Pr} + \frac{C_{HR}}{(N_{pe} - N_{peHR})}) \bullet \frac{NO_X}{NO_{\Pr}} + \sum_{i=1}^{n_5}((S_{peMarki} + \frac{C_{HR}}{(N_{pe} - N_{peHR})}) \bullet \%T_{peMaiPX}))
\end{aligned}
$$

Equation 7

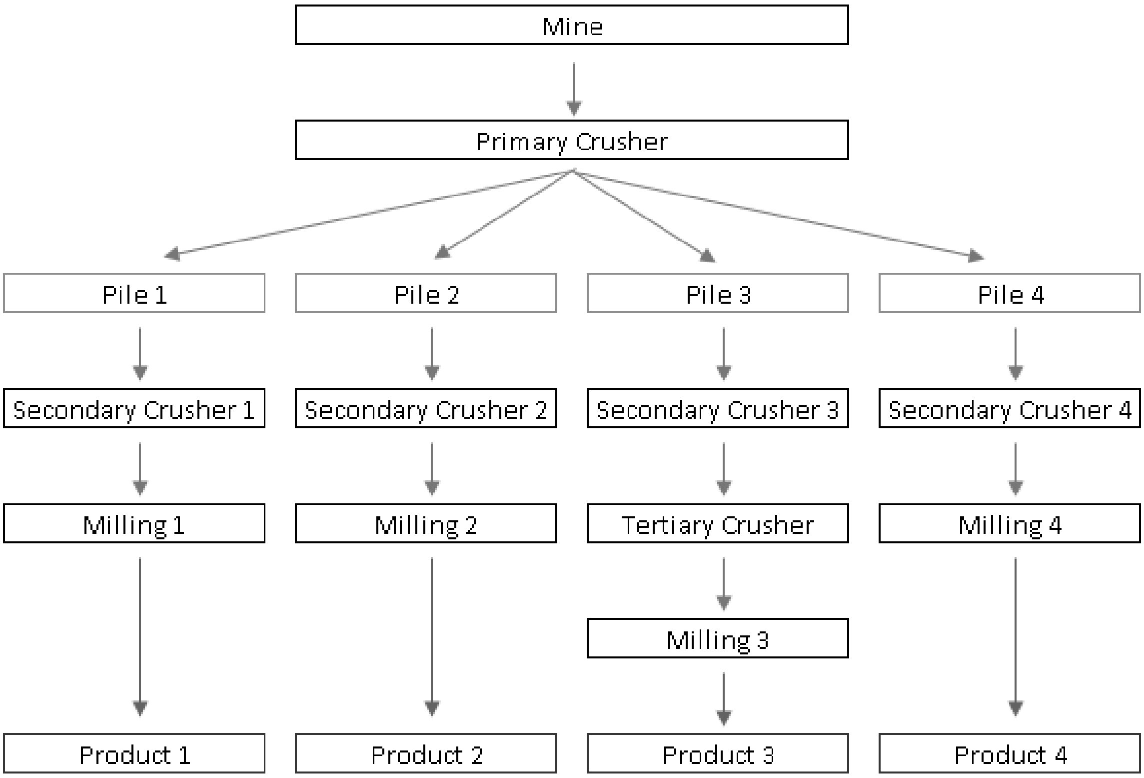
2.3.2. SHARED RESOURCES

Section 2.3.1 describes the equation of each cost. The focus of this section is to define the cost drives in shared resources, like equipment and employees.

2.3.2.1. EQUIPMENT

In Figure 2 the equipment from secondary crushers are “working” in just one material, which will become the product. Therefore, this equipment “works” 100% of time in the equivalent product. The difficulty is for the equipment that will produce material for more than one product, like a primary crusher. In this case, the primary crusher operates in batches that produce material for each pile, so the cost drive is the time of production for each pile.

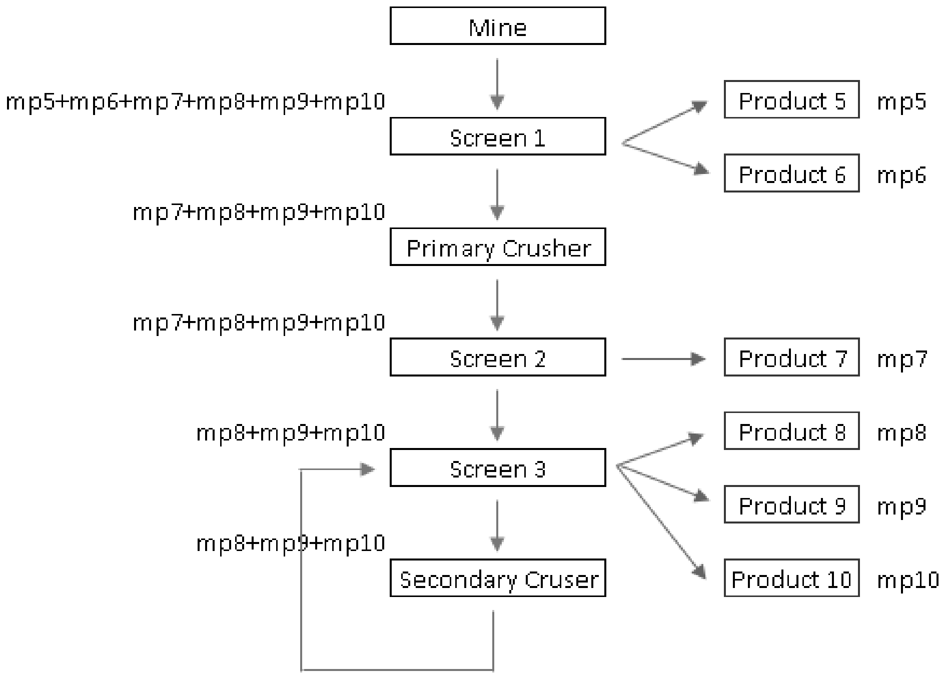
Figure 2 – Material Flow – Example 1



Source: Personnel file

In the following figure, there is equipment that produces more than one product and that produces material for other products in continuous operations. The cost drive in this situation is the mass that the equipment operates. Considering the mass of each product “X” as “mpX”, Figure 3 shows the mass that enter in each equipment.

Figure 3 – Material Flow with mass – Example 2



Source: Personnel file

Equation 8 shows the equipment cost of product 10.

$$\sum_{i=1}^{5}(C_{pei} \bullet \%T_{peiPX}) =$$
$$C_{pe1} \bullet \%T_{pe1P10} + C_{pe2} \bullet \%T_{pe2P10} + C_{pe3} \bullet \%T_{pe3P10} + C_{pe4} \bullet \%T_{pe4P10} + C_{pe5} \bullet \%T_{pe5P10} =$$
$$mp10 \bullet \left(\frac{C_{pe1}}{mp5 + mp6 + mp7 + mp8 + mp9 + mp10} + \frac{C_{pe2}}{mp7 + mp8 + mp9 + mp10} + \frac{C_{pe3}}{mp7 + mp8 + mp9 + mp10} + \frac{C_{pe4}}{mp8 + mp9 + mp10} + \frac{C_{pe5}}{mp8 + mp9 + mp10}\right)$$

Equation 8

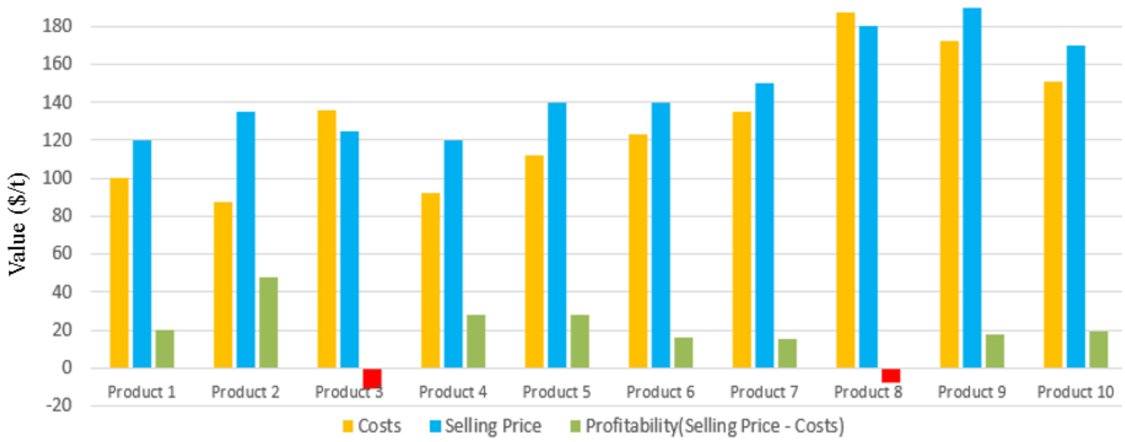
2.3.2.1. EMPLOYEES

The operation, marketing/selling and maintenance employees have the time spent at each equipment or product as cost drive. The procurement employees have the number of purchase orders as cost drive. The human resources cost is shared equally by the number of employees.

2.4. RESULTS AND DISCUSSION

The Cost Model used the information collected in the period with the equations shown in section 2.3. The result shown in Figure 4 shows the costs, selling price and profitability of each product.

Figure 4 – Profitability of each product



Source: Personnel file

The products 3 and 8 have negative profitability and decrease the mining global profitability as shown in Figure 5.

Figure 5 – Global Profitability

Source: Personnel file

Considering that the selling price could not be modified and that there is demand for other products, the material that generates product 3 can be changed to product 4, which has positive profitability.

As seen in Figure 3 the product 8 is produced simultaneously with product 9 and 10. The Product 8 decreases a lot the profitability of Products 9 and 10. Considering that the selling price can be changed, the Product 3 and 8 can be reviewed to a higher value.

The most common difficulty was to define the data collection, identification of activities and selection of cost drivers. As shown by Briers and Chua (2001), the changes are cyclical in a company, and the input information needs to be always in reevaluation not to make the product cost evaluation obsolete and then abandoned. Even with the advance of information technology and computer application to the mineral sector (Nader et al., 2012), the innovative approach faces challenges to be used in the mineral area.

3. A HIGH-LEVEL DYNAMIC ANALYSIS APPROACH FOR STUDYING GLOBAL PROCESS PLANT AVAILABILITY AND PRODUCTION TIME IN THE EARLY STAGES OF MINING PROJECTS

3.1. INTRODUCTION

This research topic is part of a published article by the author in 2017[2]. 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 loading (FEL) studies, in line with Independent Project Analysis (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 Anderson, 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

[2] CREMONESE, D.T., KARANTH, B., DE TOMI, G. **A high-level dynamic analysis approach for studying global process plant availability and production time in the early stages of mining projects**, REM – International Engineering Journal, v. 70, n. 2, p. 215–220, 2017. (DOI: http://dx.doi.org/10.1590/0370-44672016700043)

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 mechanized. 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 (Bergquisst, 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; Altiok, 2010), as some investments in a determined area do not increase the global performance (Juliá, 2010).

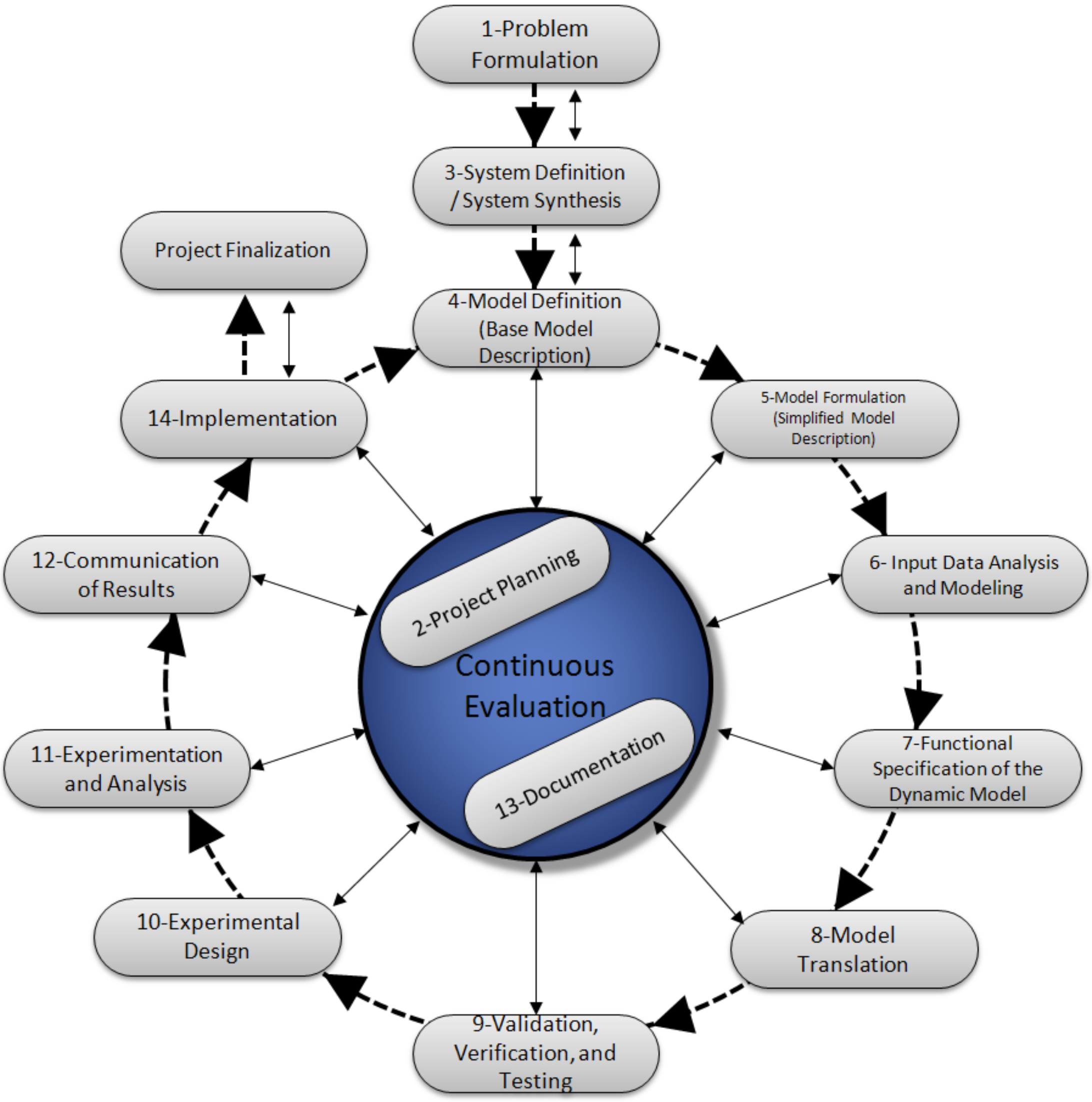
The evaluation model is detailed enough to be accurate, as accuracy is dependent on the simulation success, but detailed simulation will be expensive to model and difficult to operate. Utilizing the information obtained by an inappropriate or inaccurate model can lead to unexpected plant behavior, such as underperformances in critical areas (Asbjörnsson et al., 2012; Le Roux et all., 2013; Vasebi et all., 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.

3.2. METHODOLOGY

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 repeatedly; the initial idea of the flow simulation study is shown in Figure 6 (Cremonese, 2014). The complete methodology in the development of a dynamic simulation model is described by Cremonese (2014).

Figure 6 - Simulation Methodology.



Source: 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 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 throughout, 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.

3.3. 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 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.

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

Source: Personnel file

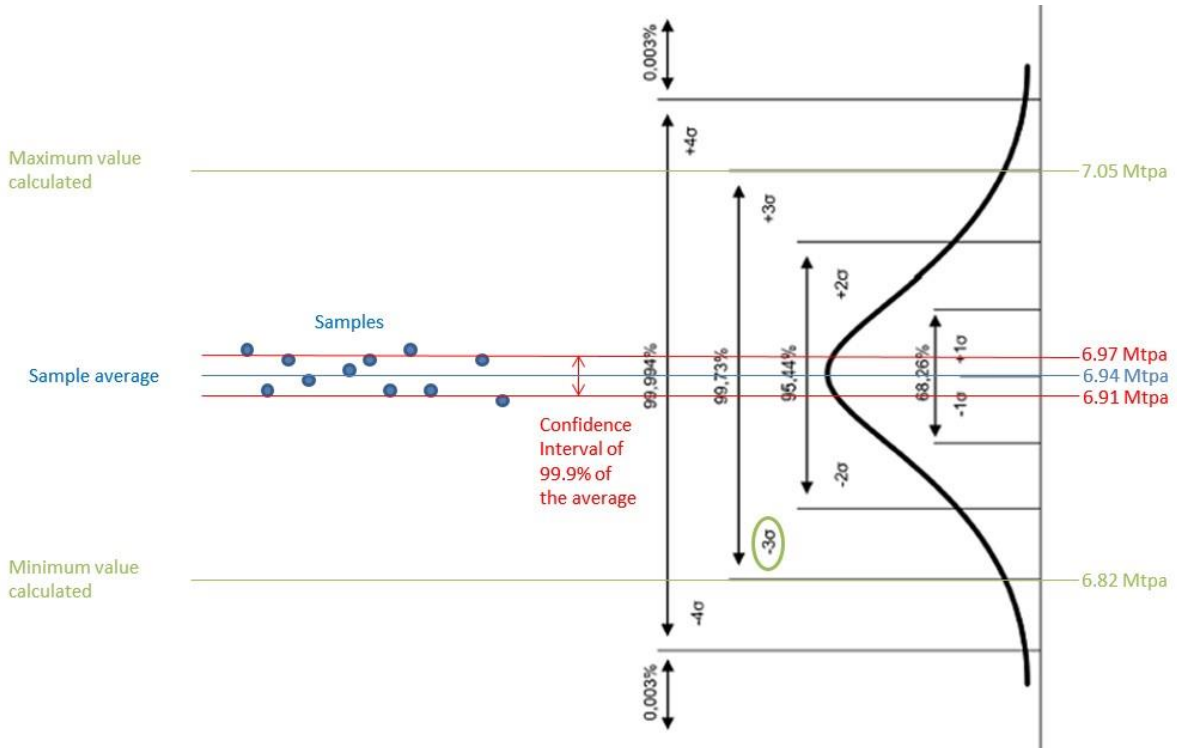
The static analysis shows that the Primary Crusher System achieves 5400 h/year x 1400 t/h = 7.56 Mtpa; and the Process Plant achieves 6400 h/year x 1200 = 7.68 Mtpa. Both are at least 8% higher than the necessary 7 Mtpa.

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, 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 7 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.

Figure 7 – ROM considering confidence interval of the mean and sigma intervals.



Source: Personnel file

Furthermore, at the 3 x standard deviation (3-sigma level), 99.73% of the years will achieve a capacity of between 6.82–7.05 Mtpa.

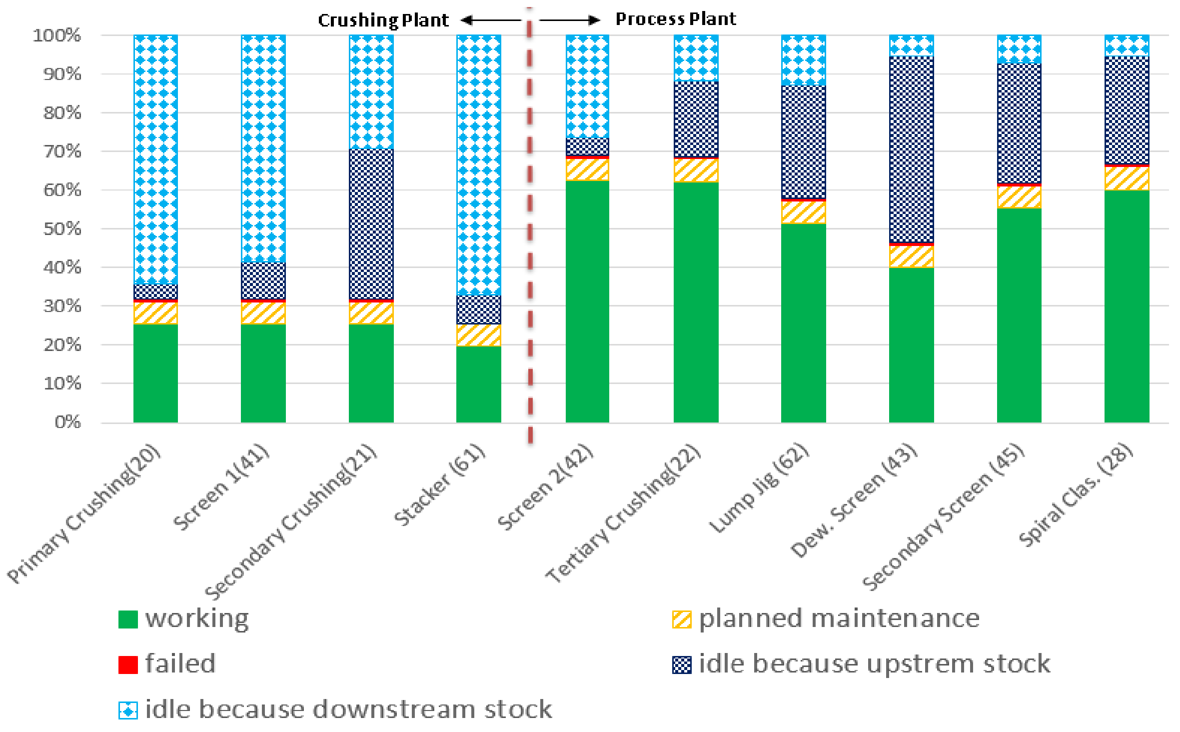
For a 7 Mtpa capacity, estimated from team experience, using the same configuration, the dynamic simulation shows that in some years, the capacity can only be 6.82 Mtpa.

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 8 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.

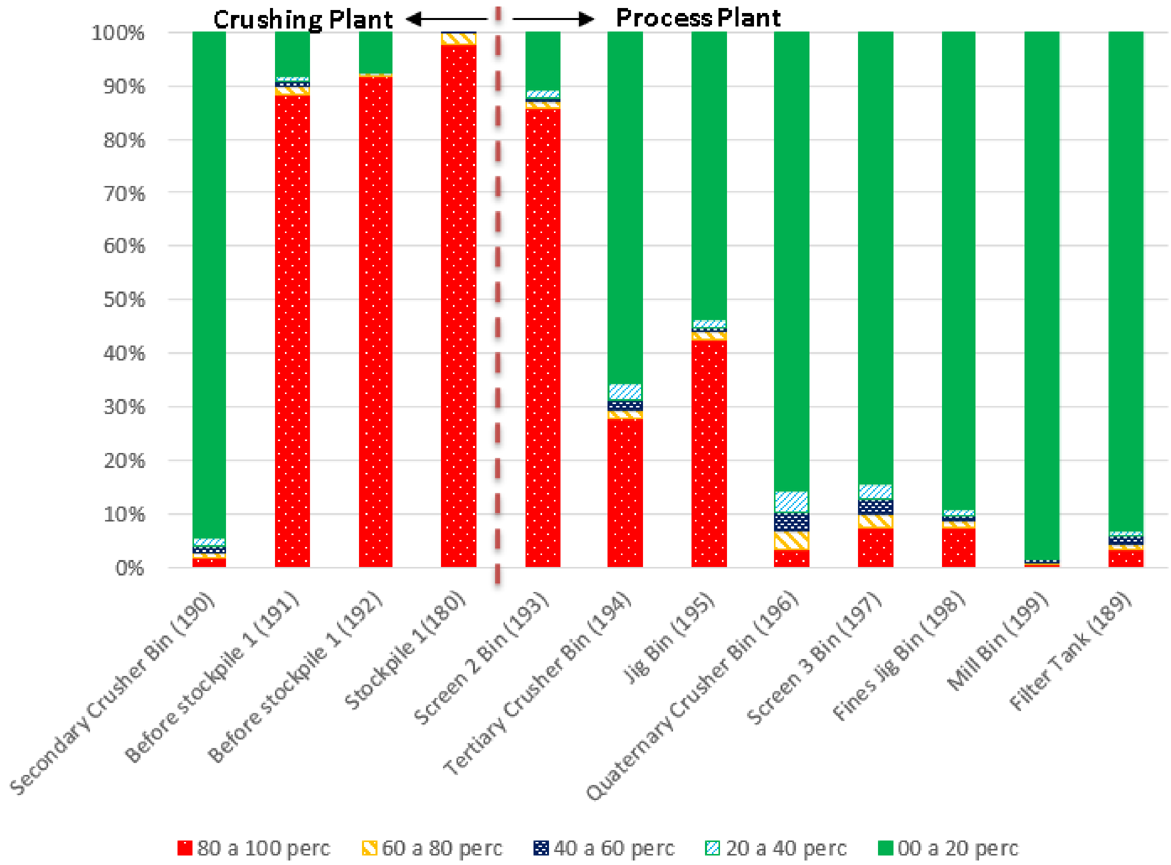
Figure 8 – Equipment utilization.



Source: Personnel file

Figure 9 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 9 – Bin and stockpile utilization.

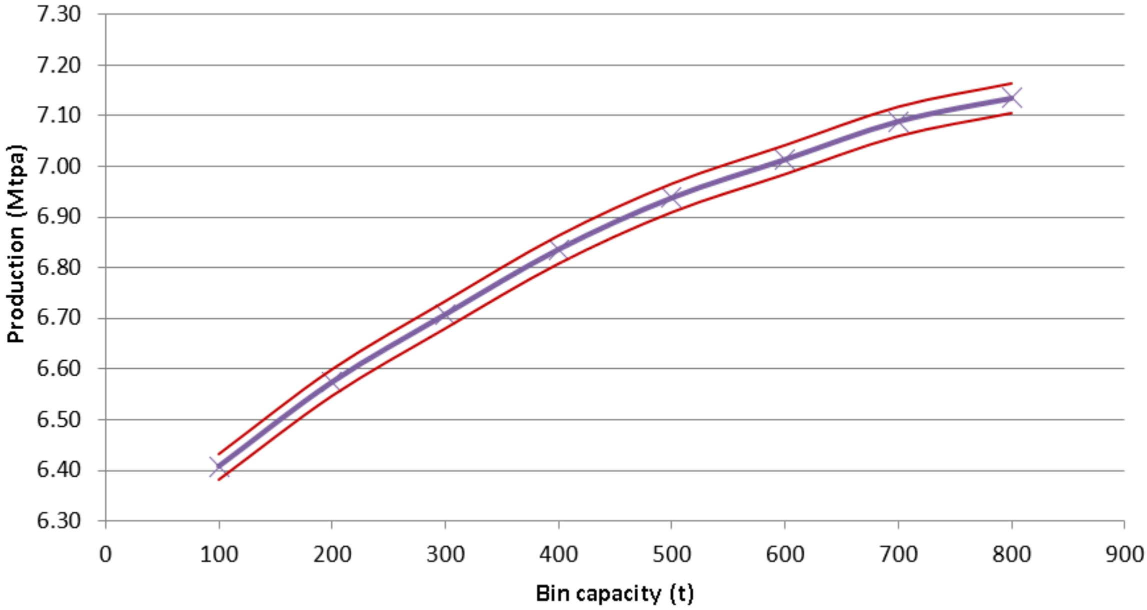


Source: Personnel file

The analysis from Figure 9 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 100–800 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 10 – Production (Mtpa) versus bin capacity (t).



Source: Personnel file

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 capacity 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.

4. ECONOMIC ADVANTAGES OF DYNAMIC ANALYSIS IN THE EARLY STAGES OF MINING PROJECTS

4.1. INTRODUCTION

This research topic is part of a published article by the author in 2018[3]. In the last decades we have seen a great growth in the use of simulation for risk analysis (Wu and Olson, 2013). In mining projects, the simulation is used in production and profitability optimization, modeling of operations, modeling for mining scheduling and decision-making aid for multi-criterion conditions (Chinbat and Takakuwa, 2009, Parreira et al 2012, Pop-Andonov, 2012, Botín et al., 2015, Lagnika, 2017). However, the simulation is underutilized in plant engineering, where it is generally applied to evaluate the variation of costs as a function of delivery date (Gutfeld, et al., 2014, Jessen et al., 2015).

Most of mining projects go through some form of front-end (FEL) studies, in line with IPA definitions before reaching the implementation stage (Stange and Cooper, 2008). Many of the projects start with a scoping study (FEL1), followed by a pre-feasibility study (FEL2) and a feasibility study (FEL3) before it is approved for implementation (Albishri, 2016; Motta et al., 2014).

The estimation accuracy of the preliminary project (FEL 1) is -15% to +30%, improving to -2% to +10% in FEL 3 (Hayati and Ganji, 2016). Project detailing costs time and money. The smaller the amount of errors in the preliminary design, the less the effort will be in the later phases of the project.

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[3] CREMONESE, D.T., MARIN, T., DE TOMI, G. **Economic advantages of dynamic analysis in the early stages of mining projects**, REM – International Engineering Journal, v. 71, n. 3, p. 451-455, 2018. (DOI: http://dx.doi.org/10.1590/0370-44672017710140)

The use of dynamic simulation is technically advantageous for the project as shown by various authors (Cardoso and Teles, 1997; Altiok, 2010; Juliá, 2010; Bergquisst, 2012; Asbjörnsson et al., 2013; Cremonese et al., 2017). It is usual to apply dynamic simulation in FEL3 phase. Time to develop a study and lack of information are the main reason why the simulation is not used in the FEL1 and FEL2.

As the innovative work shown by Cremonese et al (2017), the time to develop a study can be decreased to hours (not weeks as usual) and the information obtained to make the model and the outputs of the simulation will decrease the information lack. The dynamic simulation will decrease the number of project changes and uncertainties.

This research asks three questions: (1) Can we use simulation in the FEL 1 and FEL 2 phases? (2) What is needed to apply simulation in the preliminary phases of the project? (3) Is it economically advantageous?

4.2. METHODOLOGY

For evaluation of the economic potential of the use of dynamic simulation in FEL1 and FEL2, five case studies were used. The case studies were iron ore process plants with CAPEX of around US$ 300 million. Each process plant has around 50 pieces of process equipment (Crushers, Screens, Spiral Classifier, Thickeners, Mills, Cyclones, etc,) and 50 of material handling equipment (Belt Conveyors, Bins, Piles, Stacker-Reclaimers, etc).

In all cases, it was necessary to make project changes in the later phase due to the size of the bins. The influence of the bin size in the process plant capacity is not the purpose of this work and can be seen in Cremonese et al (2017). These changes could have been avoided if the simulation had been carried out in the previous phase.

To calculate the potential economic benefit of the use of simulation, the following methodology was used:

1. Estimation of the “man hours” necessary to make the changes in each project (Considering Mechanics and Civil disciplines)
2. Estimation of Project Management and Control cost, due to the changes per Project Phase (FEL2 and 3);
3. Estimation of the delay in the project, due to the changes and consequently the delay in the beginning of the enterprise’s implementation;
4. Estimation of the “man hours” necessary to develop a dynamic simulation study considering high-level dynamic analysis developed by Cremonese et al. (2017);
5. Calculation of the change cost in each project;
6. Calculation of the dynamic simulation cost per Project Phase (FEL1 and 2);
7. Calculation of the difference between the cost of dynamic simulation and changes in the project.

Mechanical and Civil disciplines are the most significant disciplines considering man effort. Due to this, they were the only ones considered in the study. It is known that other disciplines are affected by the alterations, but they were not considered. Project Management/Control and Schedule delay are considered as described below.

The man efforts to make the project alterations for Mechanical and Civil disciplines in FEL2 and FEL3 are shown in Table 2 and Table 3. These data were obtained for the efforts of an average man utilized in the five case studies.

Table 2 – Mechanical documents – Man efforts

	Mechanical documents (man hours for each Belt Conveyor alteration)							
	Equipment Calculations		Data Sheets		Drawings		Total for Belt Conveyor	
	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer
FEL2	6	2	6	2	12	4	24	8
FEL3	12	4	12	4	24	8	96	32

Table 3 – Civil documents – Man efforts

	Civil documents (man hours for each Building alteration)					
	Calculations		Drawings		Total for Building	
	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer
FEL2	12	4	12	4	24	8
FEL3	24	8	24	8	96	32

The delays occurring because of the changes were estimated in 3 weeks for FEL2 and 8 weeks in FEL3. These data were obtained as an average of delay in the five case studies. Consequentially the delay for the operation of the enterprise was considered the same. Project Management/Control were estimated for one Junior Engineer (16 h/week) and one Senior Engineer (8 h/week).

The cost for one-man hour considered for Simulation Specialist, Junior and Senior Engineer is shown in Table 4. Other categories were not considered in this study.

Table 4 – Cost for one-man hour

Cost for one-man hour (US$/hours)		
Junior Engineer	Senior Engineer	Simulation Specialist
150.00	300.00	500.00

Process Plant Implementation Cost of the five project analyzed can be estimated in US$ 300 million. The estimated cost of the projects are US$ 900,000.00 (FEL1), US$ 2,250,000.00 (FEL2) and 5,850,000.00 (FEL3). These values considered that in this type of enterprise, the FEL1, 2 and 3 are around 3% of the implantation cost and divided into 10%/25%/65%.

4.3. RESULTS AND DISCUSSION

Five projects were used as test cases, three from FEL3 and two from FEL2. The project information is shown in Table 5.

The plant mean production capacity was achieved, increasing the bin capacities. This bin capacity change in the FEL 1 and FEL 2 stages to achieve the plant capacity is minor as compared to the changes that need to be carried out in FEL 2, FEL 3 and project implementation or worse, in plant operation.

The bin capacity change results for alterations in the building and belt conveyor projects.

Table 5 – Projects information

Nº	Country	Simulation did with information of	Alteration in	Number of altered bins	Number of altered belt conveyors	Number of altered buildings
1	India	FEL2	FEL3	2	4	2
2	Mauritania	FEL2	FEL3	3	6	2
3	Brazil	FEL2	FEL3	2	4	2
4	Mauritania	FEL1	FEL2	2	4	1
5	Brazil	FEL1	FEL2	4	8	2

The time spent on alteration is shown in Table 6.

Table 6 – Time spent on alterations

	Time spent on alterations (hours)					
	Mechanical discipline		Civil discipline		Total	
Nº	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer	Junior Engineer	Senior Engineer
1	384	128	192	64	576	192
2	576	192	192	64	768	256
3	384	128	192	64	576	192
4	96	32	24	8	120	40
5	192	64	48	16	240	80

Using the “High-level Dynamic Analysis Approach” the time spent to model and simulate the entire process plant was two and four days (16 and 32 working hours) for FEL1 and FEL2, respectively.

Considering the time spent on alteration, and the cost of a high level dynamic simulation in the early study of the project, the summary results are present in Table 7.

Table 7 – Summary cost before Project Management/Control Costs

	Alterations cost (US$)			Time spent on Simulation (hours)	Simulation cost (US$)	Variance (US$)		
Nº	**Junior Engineer**	**Senior Engineer**	**Total**	**Simulation Specialist**	**Total**	**Total**		
1	86,400.00	57,600.00	144,000.00	32	16,000.00	128,000.00		
2	115,200.00	76,800.00	192,000.00	32	16,000.00	176,000.00	**144,000.00**	**Average in FEL2**
3	86,400.00	57,600.00	144,000.00	32	16,000.00	128,000.00		
4	18,000.00	12,000.00	30,000.00	16	8,000.00	22,000.00	**37,000.00**	**Average in FEL1**
5	36,000.00	24,000.00	60,000.00	16	8,000.00	52,000.00		

The results shown that the average earned by a dynamic simulation study in FEL1 and FEL2 are 37 and 144 thousand dollars respectively.

Table 8 – Summary cost with Project Management/Control Costs

Use the simulation in	Saves (US$) considering Manag./Control Cost	% of saves, considering the project cost in next FEL	Avoid delay in the start of the implementation of the project in
FEL2	**182,400.00**	3.1%	8 weeks
FEL1	**44,200.00**	2.0%	3 weeks

5. CONCLUSIONS

The creation of a cost model to be used in the operation of mining is a rewarding investment as it allows the identification of the profitable and unprofitable products. Moreover, the use of dynamic simulation in the early stages is technically and economically advantageous.

ABC analysis is more expensive and time-consuming than a traditional cost allocation system, but it can assist in understanding the economic impact of management decisions and in controlling indirect costs.

A balanced cost appropriation of the products mix shows the actual profitability of each. This has shown that some product were not profitable and the range of alternatives that can be followed, such as increasing the selling price, decreasing the costs or no longer produce the product.

This study indicates that an ABC approach is efficient for analysing mining costs with product mix. Activity Based Costing has far wider applications than the aspect described here. One of these applications is as a management-reporting tool that is covered in other sources.

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 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 demonstrated by the test cases, utilization of the "High-level Dynamic Analysis Approach" in FEL 1 and FEL 2 would lead to defining the project parameters (as bin capacities) in the early stages. This would avoid the need of revised discipline engineering, such as Mechanical and Civil, since the belt conveyor length had to be changed and the load of the structure increased. The cost evaluation shows in the five case studies that it is advantageous to use the proposed approach. The saved average are US$ 44,200.00 and US$ 182,400.00 for FEL 1 and FEL 2 respectively.

The percentage cost saves for FEL2 (2.0%) and FEL3 (3.1%) are significant. The estimated delay avoidance for FEL2 (3 weeks) and FEL3 (8 weeks) is directly related to the implementation delay, whose cost is expressive, greater than the savings shown, but was not estimated in this study due to its complexity.

The use of dynamic simulation is technically and economically advantageous for the project as previously shown. However, it is only possible using the innovative "High-level Dynamic Analysis Approach", since the development of a simulation model from scratch is more time-consuming and expensive.

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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