Proceedings of the 2011 Winter Simulation Conference
S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.

MAINTENANCE FRAMEWORK TO ADDRESS THE INTERACTION OF COMPONENTS USING SIMULATION

Luiz Augusto G. Franzese
Daniel de Oliveira Mota
Marcelo Moretti Fioroni
Yuri Amaral C. L. Mourão
Douglas José da Silva
Isac Reis Santana
Johanna Gomez Quevedo

PARAGON Tecnologia
Rua Clodomiro Amazonas 1435,
5th Floor – Vila Olímpia
São Paulo, SP ZIP 04537-012, BRAZIL

Farley Santos Ribeiro
Marcelo Nazaro Silva
Fernando A. Lage Gonçalves
Thiago A. M. Brandão Diniz
Marcelo Barcelos Gomes

Anglo American – IOB Business Unit
Rua Guaicui 20, 9th floor – Coração de Jesus
Belo Horizonte, MG ZIP30380-380, BRAZIL

ABSTRACT

Maintenance has been a constant concern in industries. This paper intends to address the maintenance plan in a complex system. Based on the beneficiation plant of Minas Rio Project, the model proposed takes into consideration the consequences of the maintenance schedule in the whole production. In this production chain, a complex structure called "State Control" is used to simulate the information flow throughout the equipment. The visibility of the complete system under a maintenance perspective allows the decision maker to propose plans, test them and minimize losses, generating new strategies to the production and maintenance system. The application of Arena Professional (Distributed by Rockwell Automation) to develop the project allows the identification of bottlenecks, and expected production per year. The results obtained in the studied scenarios allowed identifying the bottlenecks and change the strategies of maintenance, to enable the beneficiation plant achieve the nominal productivity.

1 INTRODUCTION

Production systems used in industries deteriorate over time. It does not matter which business activity it relates to. In some cases, a failure can drive the whole company to lose customers, raw materials, credibility, etc. All those factors lead to a non desirable consequence: losing money.

To avoid losing money, according to Dekker (1996), the maintenance function has grown in the last 20 years. The mechanization and automation has reduced the manpower in production and increased the maintenance. The amount of funds spent in maintenance built-in to the total operational costs increased for the following activities: maintenance management, reliability, material quality, and manpower. According to Dekker, 30% of the operations workers in refineries are executing maintenance activities.

When maintenance is discussed, it is important to distinguish two different approaches: technological and managerial. Under the technological perspective (Contador 1997), it is desired to have reliable equipment with low failure rates that produces continuously under hostile conditions. Breakdowns and overheating can be minimized depending on the quality of the machine and environment control to monitor the temperature and the friction between the parts.

However, the most reliable machine tends to be extremely expensive. This factor can make the acquisition infeasible because the ROI may not be attractive. Furthermore, even the most reliable machine experience failures. So, while the technological consideration is important, managerial effort is fundamental.

Maintenance management rises in importance when it is analyzed under the perspective that together with the production management both should focus on delivering high productivity, and high service level. The role of the maintenance management is to provide policies of equipment repair and/or substitution in strategic moments minimizing the impact of a preventive maintenance in the production as a whole.

Many authors have investigated the maintenance problem under the perspective of identifying the optimal replacement time, based on the deterioration dynamics of the system. Sherif (1982) classifies the models according to its behavior (deterministic or stochastic) and the number of equipment jointly analyzed (single component or complex system). He primarily used the following optimization methods: linear and non-linear programming, dynamic programming, and Markov decision methods.

The higher the number of equipment considered, the higher the complexity of the modeling effort. The reason for this difficulty is the number of interactions between the components.

This papers aims to take advantage of simulation technique to address the maintenance management of a complex system, an iron ore beneficiation plant located in Brazil. The model considers the most important interaction between the components in a production chain: the lack of material feed and the blockage states. Both occur as a result of corrective maintenance (generated randomly) and preventive maintenance (scheduled) activities. The purpose of the model is to provide the visibility of the system, measuring performance in terms of productivity, identifying bottlenecks generated by the maintenance schedule and identifying policies which deliver the best production rate and higher service level.

The simulation model was developed in Arena (Rockwell Automation software) and was implemented, tested and approved by Anglo American – Iron Ore Brazil Business Unit (owner of the project).

2 MODELING APPROACH

2.1 Historical overview

According to Dekker (1996), the maintenance problem was first investigated scientifically in 50's and 60's. At the time, the focus was on reducing failures and unplanned downtime. By the 70's the use of operations research models attempting to optimize the time-based programs for preventive maintenance increased. The fast data processing delivered by computers allowed more detailed studies on maintenance function. Later, the Total Productive Maintenance concept was imported from Japan, providing the maintenance management some quality control techniques to measure and reduce its impact.

By the 2000s, the computer processing speed improved considerably. It allowed the creation of more sophisticated solutions based on mathematical tools. Simulation is one of those tools which allows holistic evaluation of a maintenance policy, accounting the KPIs of the system as a whole and not only of a specific machine.

Being a recent application area for simulation, not many simulation models were found in academic technical papers to study maintenance problems. One key reason is the difficulty of modeling several steps of the same process; another is the fact that entities in simulation models are generally related to movement or production parts (bolts, cars, trucks, pallets, etc.). However the use of an entity as an information piece to realize the communication between the components of a system is a new approach in the simulation body of knowledge.

2.2 Previous work

Even though no maintenance of complex system was modeled using simulation, there are some concepts used in this model which were used previously. The modeling of a continuous flow using discrete event simulation was seen before in Fioroni et al. (2007).

3 METHODOLOGY

The process concept was based on Minas-Rio Project, funded by Anglo American – Iron Ore Brazil Business Unit. It is located in the states of Minas Gerais and Rio de Janeiro.

The focus is in the beneficiation plant, which is the process step responsible to treat the raw material (friable itabirite) extracted from the mines, and adjust the granulometry and solids content to be transported in a pipeline towards the port for exporting. The beneficiation plant was designed to produce 3.040 tph of pellet feed, with an overall efficiency of 92,0%.

The complete production chain of the ore can be visualized in the following scheme (Figure 1).

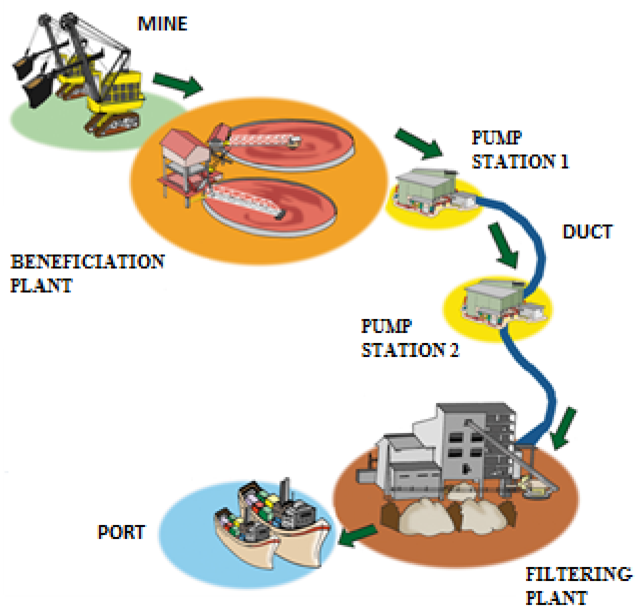

Figure 1: Ore production chain (provided by Anglo American – Iron Ore Brazil Business Unit)

The components of the beneficiation plant form a complex maintenance system that needs to be improved for increasing the uptime and avoiding losses. A model with the state control logic was created to simulate the maintenance shutdowns and the consequences of those shutdowns in terms of physical availability.

The simulation of the maintenance system allows input of the data of maintenance program into the model to identify the bottleneck and identify which is the best strategy of maintenance to improve productivity and save money.

3.1 Problem Description

The Minas Rio Project is situated in Minas Gerais and Rio de Janeiro states, in Brazil. Its operations include an open pit mine, primary crushing and conveying, high pressure grinding rolls, ball mill and vertimill, flotation, tailings disposal, concentrate and tailings thickening, slurry pipeline, filtration and the seaport. The beneficiation plant is responsible to concentrate the mined ore and then adjust granulometry and the solids content of the slurry to transport through a 525 kilometers pipeline.

This plant includes a crushing installation where the ore from the mine is crushed, screened and then goes to the stockpile. After that the ore goes to the concentrator where it is grinded using HPGR (high pressure grinding rolls) and ball mills, deslimed by hydrocyclones, floated in mechanical flotation cells to remove the main contaminants, re-grinded using vertical mills to adjust the granulometry and finally the slurry (pellet feed and water) goes to the concentrate thickener where solids content is adjusted to be transported through a pipeline.

Under the production perspective, the maintenance of the plant is vital because the hostile processes lead the system into constant breakdowns. Since all equipment is susceptible to a breakdown, three types of events were considered:

- Corrective Maintenance Stop: due to equipment or equipment component breakdown
- Operational Stop: due to equipment failure caused by operational reasons
- Preventive Maintenance Stop: due to maintenance to prevent breakdown

The corrective and operational stops are caused by unexpected failures from the damage of a machine, operational stresses and weather conditions. This type of maintenance is treated in the model as MTBF (Mean time Between Failures) and MTTR (Mean Time to Repair). Because they are not expected, we had to use historical data to provide trends regarding to its frequency and duration.

On the other hand, preventive maintenance stops are scheduled by the maintenance department, which tries to predict the machine life-cycle or an opportunity window to replace the equipment and prevent corrective stops.

When a stop occurs, it immediately causes consequences in the production chain as a whole, because the equipment upstream to the broken one should be stopped as well (in the blocked state) because it has no buffer to store its production. In addition, the downstream equipment also stops (in the non feeding conditions) because it has no input to produce.

Over time, the whole chain stops until the maintenance is completed. Figure 2 illustrates the chain of events provoked by a stop.

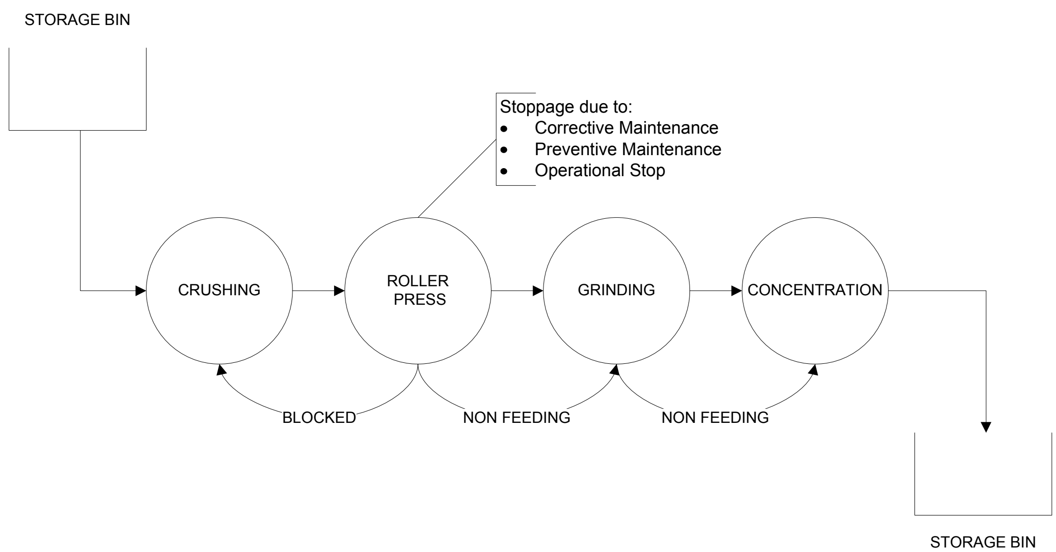

Figure 2: Stoppages due to a failure

Hence, the complex system can be divided as a set of small chains, where the storage bin are buffers that connect one system to another and provide the system a safety stock preventing the whole system to stop. Consider a stoppage in the grinding process. This event could occur given a corrective maintenance (situations), preventive maintenance (situations), or an operational stop (situations).

Under the concept perspective, the complete system is divided into sub-models which consider the particle of ore flowing between two storage bins. None of the processing steps is allowed to hold the material. So, a continuous flow between the bins is necessary. When the roller press process stops, it immediately provokes the next step "grinding" to be non feeding (no input available to it). Consequently, the "concentration" remains non feeding as well. On the other hand, the crushing process, which is situated before the stopped equipment, becomes blocked.

This communication between the processes needs to be updated in a short period of time, otherwise an unbalance is generated and the system would crash due to lack of buffers in between the line.

If a sub-model has a storage bin completely full given a blocked equipment, it stops the previous sub-model to push material into it, on the other hand, if the bin is completely empty, the next sub-model becomes without feed.

To address this problem, a state control for each equipment was created, in accordance with the consequences of a possible stop. Thus, the plant can work with different states simultaneously, because each equipment has its own state, as listed in the table below (Table 1).

Table 1: Status of the equipment

State	*Description*
Running	busy, processing material;
Non feeding	idle due shortage of raw material in the system;
Blocked	for not being able to receive material from the previous equipment due its maintenance stop or for not being able to send material for the next equipment;
Waiting	stopped due to shortage of process material to be added to the main raw material;
Operational stop	due to a failure in the equipment caused by operational reasons;
Preventive stop	when there is a scheduled maintenance stop;
Corrective stop	when there is an equipment breakdown.

Therefore, each equipment is an intelligent agent that can be provoked by a stop to make the state change and communicate its impact upstream and downstream.

Finally, if the system automatically responds to a state change, it was necessary to model the interactions that may occur in case of simultaneous changes. In some cases, the maintenance needs to be rescheduled or it is just ignored as can be seen in Figure 3.

	Individual Preventive Maintenance Stop running	Individual Corrective Maintenance Stop running	Individual Operational Maintenance Stop running	Group Maintenance Stop running
Beginning of Individual Preventive Maintenance Stop		**In parallel**	**In parallel**	**Cancelled**
Beginning of Individual Corrective Maintenance Stop	**Postponed**		**Postponed**	**Postponed**
Beginning of Individual Operational Maintenance Stop	**Postponed**	**Postponed**		**Postponed**
Group Maintenance Stop	**In parallel**	**In parallel**	**In parallel**	

Figure 3: Consequences of simultaneous disruption

The concept used in this section enables the development of a simulation model to mimic the complete production plan, schedule preventive schedules, represent corrective and operational stops, measure their impact on the overall production rate, hence evaluating if the strategy tested is acceptable or if new components should be introduced in the system to deliver better results.

3.2 Model

The production process defined in the model can be visualized in Figure 4.

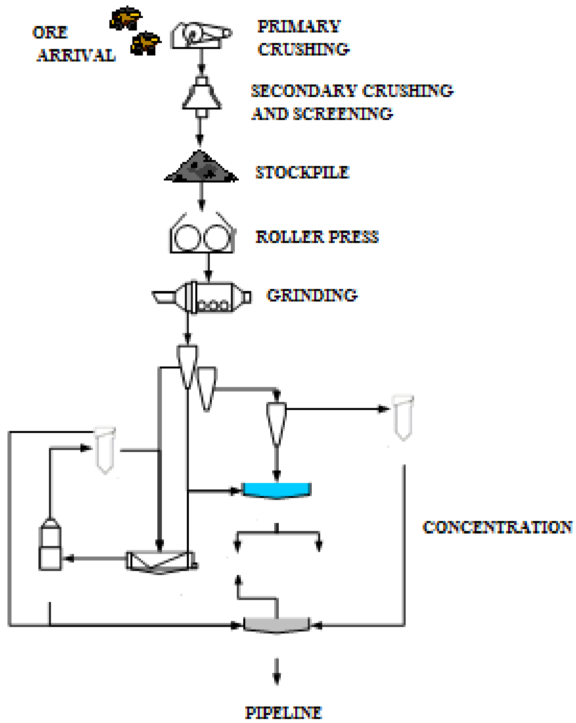

Figure 4: Process flow in Minas-Rio system

The material and information flow can be visualized in the following scheme (Figure 5).

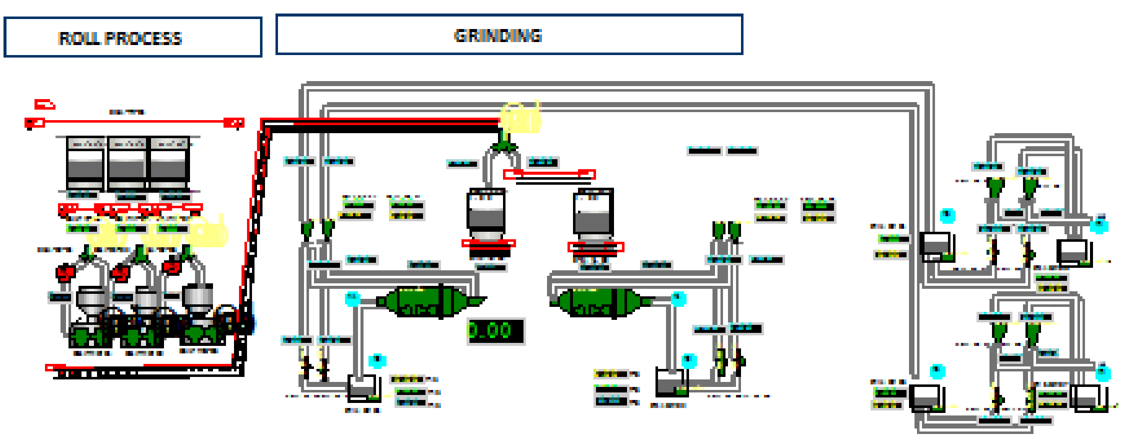

Figure 5: Model Snapshot

The parameterization of the maintenance activities in the system can be summarized into two sectors: (1) corrective and operational stops; and (2) Preventive maintenance.

The first type occurs in random intervals. These intervals are based on the MTBF and MTTR (defined in Section 3.1). The simulation model should be flexible enough to assume any random distribution for both parameters for each instance of equipment assigned for the production. This flexibility allows individually replacing an equipment with another more reliable one in the simulation and check the overall impact caused by this change. Figure 6 illustrates the MTBF definition of each component in a crushing set.

MTBF				Distribution	Parameter a	Parameter b	Parameter c
Crushing	PRIMARY CRUSHING	01	0111-AP-01	Exponential Dist. Prob.: Average "a"	1500		
			0111-BR-01	Exponential Dist. Prob.: Average "a"	2000		
			0111-GR-01	Exponential Dist. Prob.: Average "a"	1000		
			0111-SL-01	Constant: Equal to "a"	0		
			0111-TR-01	Exponential Dist. Prob.: Average "a"	600		
		02	0111-AP-02	Exponential Dist. Prob.: Average "a"	1500		
			0111-BR-02	Exponential Dist. Prob.: Average "a"	2000		
			0111-GR-02	Exponential Dist. Prob.: Average "a"	1000		
			0111-SL-02	Constant: Equal to "a"	0		
			0111-TR-02	Exponential Dist. Prob.: Average "a"	600		
		GENERAL	0111-TR-03	Exponential Dist. Prob.: Average "a"	600		
			0111-TR-04	Exponential Dist. Prob.: Average "a"	600		

Figure 6: Input information for corrective and operational failures

In order to have a productive material flow, it is desired to have the "unexpected" stops minimized. Some policies can affect the reliability of the equipment to achieve this goal.

The preventive maintenance activities are not modeled under the MTBF and MTTR parameters, since they need to be scheduled when there is an operational window to make a stop. So, the input of the preventive maintenance has to be scheduled by the production or maintenance manager. In this case it is important to know when it is going to occur and how long it is going to take.

Figure 7 illustrates the user interface to register the maintenance of a specific equipment (identified by its tag).

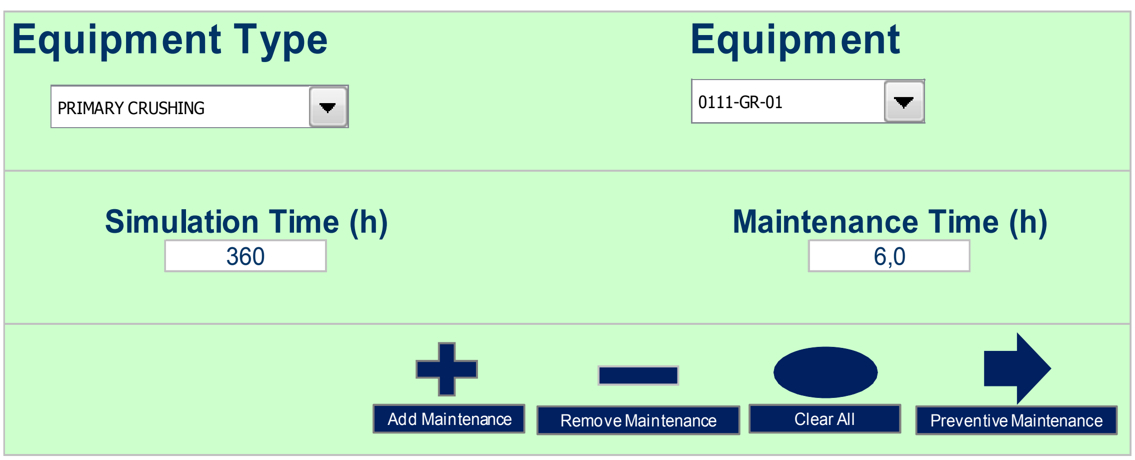

Figure 7: Input form for preventive failures

Once all the preventive maintenance are scheduled, it can be checked by the maintenance book (Figure 8).

The output of the model is basically the calculation of the time the system remains in each state described in Table 1. Based on those times, KPIs are calculated. The concept adopted for the simulation output is shown in Figure 9.

Simulation Time (days)	Simulation Time (h)	Maintenance Time (h)												
		Primary Crushing												
		0111-AP-01	0111-BR-01	0111-GR-01	0111-SL-01	0111-TR-01	0111-AP-02	0111-BR-02	0111-GR-02	0111-SL-02	0111-TR-02	0111-TR-03	0111-TR-04	0111-TR-05
0.4	10													
15.0	360	6	6	6	6								6	6
20.0	480						8		8		8			
30.0	720													
35.0	840	6	6	6	6								6	6
40.0	960						8		8		8			
45.0	1,080													
50.0	1,200	6	6	6	6								6	6
60.0	1,320						8		8		8			
65.0	1,480													
70.0	1,680	6	6	6	6								6	6
75.0	1,800						8		8		8			
80.0	1,940	6	6	6	6								6	6
90.0	2,160													

Figure 8: Input information for preventive failures

Available Time(AT)					Maintenance Time(MT)	
Productive Time(PT)	Unproductive Time(UT)					
Working	Non Feeding	Blocked	Waiting	Operational Stop	Preventive Maintenance Stop	Corrective Maintenance Stop
1	2	3	4	5	6	7
WT	NFUT	BUT	WUT	OSUT	PMST	CMST

Figure 9: Equipment states and its indicators

The following information is collected in the model (standard unit is hour).

- Simulated time (ST) is the total time of simulation
- Available time (AT) is the total time that the equipment was not in maintenance
- Productive time (PT) or Running time (RT) is the total time that the equipment kept running
- Unproductive time (UT) is the total time that the equipment is in stopped state for any reason other than maintenance
- Non Feeding Time (NFUT)
- Blocked unproductive time (BUT) is the unproductive total time that the equipment is in stopped state due to unavailability upstream or downstream
- Waiting unproductive time (WUT) is the unproductive total time that the equipment is in stopped state waiting for process material
- Operational stop unproductive time (OSUT) is the unproductive total time that the equipment is stopped due to an operational failure
- Maintenance time (MT) is the total time that the equipment is in maintenance stop (all kinds of maintenance)
- Preventive maintenance stop time (PMST) is the total time that the equipment is in preventive maintenance stop
- Corrective maintenance stop time (CMST) is the total time that the equipment is in corrective maintenance

Two KPIs are used for evaluating the scenario run by the simulation. The first is the physical availability (PA), which is the percentage of the time that the plant or equipment was available to produce. It is calculated by the following formula (1):

$$PA = 100 \times \frac{AT}{ST} \tag{1}$$

The second KPI is the utilization of a equipment (UT). The utilization is the percentage of the time that the equipment was producing in the available time. The utilization indicator is calculated by the formula (2):

$$UT = 100 \times \frac{PT}{AT} \tag{2}$$

4 EXPERIMENTS

In order to realize an exploratory analysis of the system two distinct scenarios were studied: (1) Pessimist and, (2) Optimist to analyze all equipment times and the influence of the maintenance in the performance of the system.

The scenario parameters were based on production information provided by Anglo American – Iron Ore Brazil Business Unit. Based on its production plan, it was possible to investigate the PA and UT (Section 3.2) of Pessimist and Optimist strategies described above.

A summary of the results can be seen in Figure 10. The results seen in the figure show the indicators of each equipment time. With the computation of these times the physical availability and the utilization were calculated. Thus we could identify the equipment with high or low utilization, and those with high or low physical availability.

AngloAmerican **Equipments Results** Menu paragon

Equipments	Simulated Time(ST)						
	Available Time(AT)					Maintenance Time(MT)	
	Productive Time(PT)	Unproductive Time(UT)					
	Working(WT)	Non Feedinf(NFUT)	Blocked(BUT)	Waiting(WUT)	Operational Stop(OSUT)	Preventive Maintenance Stop(PMST)	Corrective Maintenance Stop(CMST)
	1	2	3	4	5	6	7
0111-AP-01	6,806.12	0.00	1,641.57	0.00	4.98	152.00	16.04
0111-BR-01	6,813.51	38.83	1,597.44	0.00	2.25	152.00	16.68
0111-GR-01	6,807.57	17.62	1,620.12	0.00	4.05	152.00	19.36
0111-SL-01	3,383.95	0.02	5,221.14	0.00	0.00	14.00	0.00
0111-TR-01	6,827.61	38.25	1,494.29	0.00	16.53	158.00	88.60
0111-AP-02	6,751.44	0.00	1,671.28	0.00	3.83	170.00	24.24
0111-BR-02	6,758.53	63.97	1,593.58	0.00	2.84	170.00	31.22
0111-GR-02	6,752.90	22.18	1,638.45	0.00	12.58	164.00	31.00
0111-SL-02	3,095.05	0.00	5,520.06	0.00	0.00	4.00	0.00
0111-TR-02	6,758.32	94.99	1,496.24	0.00	19.75	170.00	82.22
0111-TR-03	7,052.04	2.58	1,432.80	0.00	7.99	40.00	85.71
0111-TR-04	7,052.89	81.60	1,348.19	0.00	12.00	40.00	86.42
0111-TR-05	7,191.04	25.50	1,267.59	0.00	15.17	40.00	80.86
Primary Crushing							

Figure 10: Equipment results

Each scenario has a calibration to adjust the equipment utilization and physical availability to the desired functionality of the plant. Furthermore, with these indicators the impact on the productivity, planning and costs of the mining system were analyzed. Testing several scenarios, with different schedules, and different durations, the simulation model could identify which policy could be more profitable and should be considered for the system, and which will jeopardize the operations and should be avoided.

We present in Tables 2 and 3, an example of an exploratory analysis with analysis of two specific equipment in the pessimist and optimist scenarios. Tables 2 and 3 presents the results of each indicator times of the equipments.

Table 2: Pessimist scenario parameters

Equipment	Running	Non Feeding	Blocked	Waiting	Operational Stop	Preventive Maintenance Time	Corrective Maintenance Time
0111-AP-01	4,569.05	0.00	977.53	0.00	11.18	3,071.98	37.72
0111-BR-01	4,582.88	2,705.81	1,121.05	0.00	13.53	144.00	40.80

Table 3: Optimist scenario parameters

Equipment	Running	Non Feeding	Blocked	Waiting	Operational Stop	Preventive Maintenance Time	Corrective Maintenance Time
0111-AP-01	6,806.12	0.00	1,641.57	0.00	4.98	152.00	16.04
0111-BR-01	6,813.51	38.83	1,597.44	0.00	2.25	152.00	16.68

Figures 11, 12 and 13 show the charts with analysis of the equipment by productive time, unproductive time and maintenance time. Thus, we can analyze the interaction between the different pieces of equipment. In the pessimist scenario example, we can see that due to the preventive maintenance on the equipment 0111-AP-01, the next equipment 0111-BR-01 was kept without feeding and blocked. Therefore, we can analyze distinct scenarios to identify the bottleneck and take a new strategy to the maintenance stops.

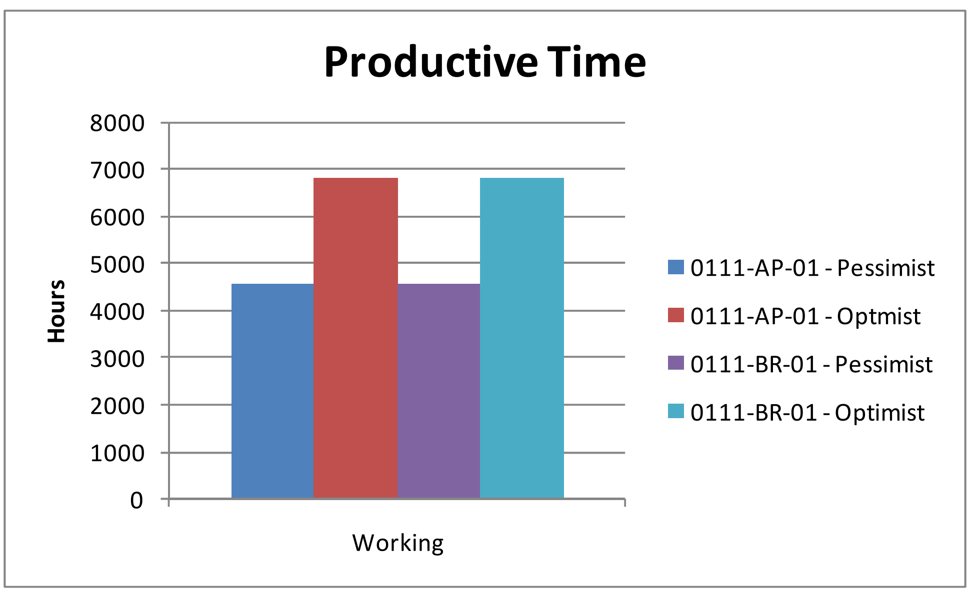

Figure 11: Productive time chart

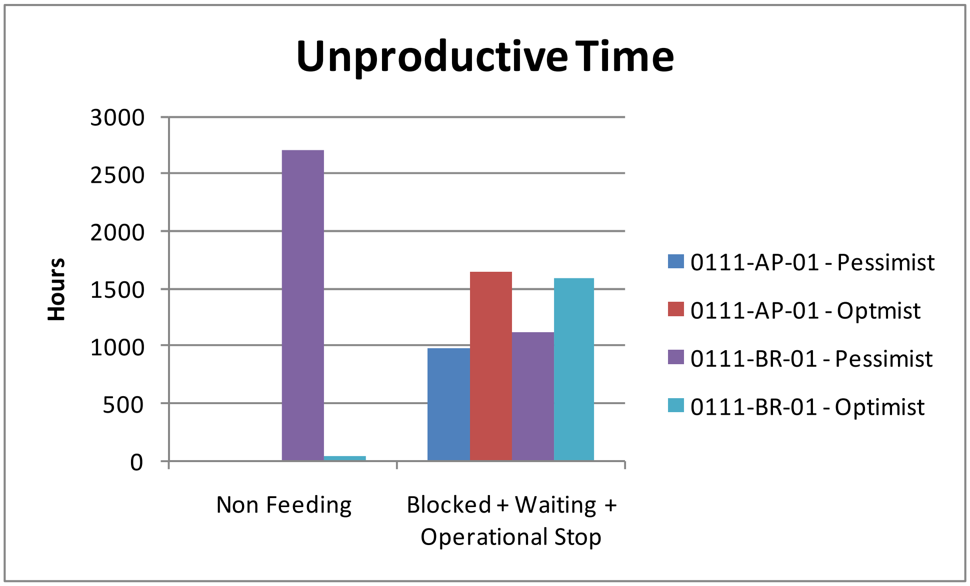

Figure 12: Unproductive time chart

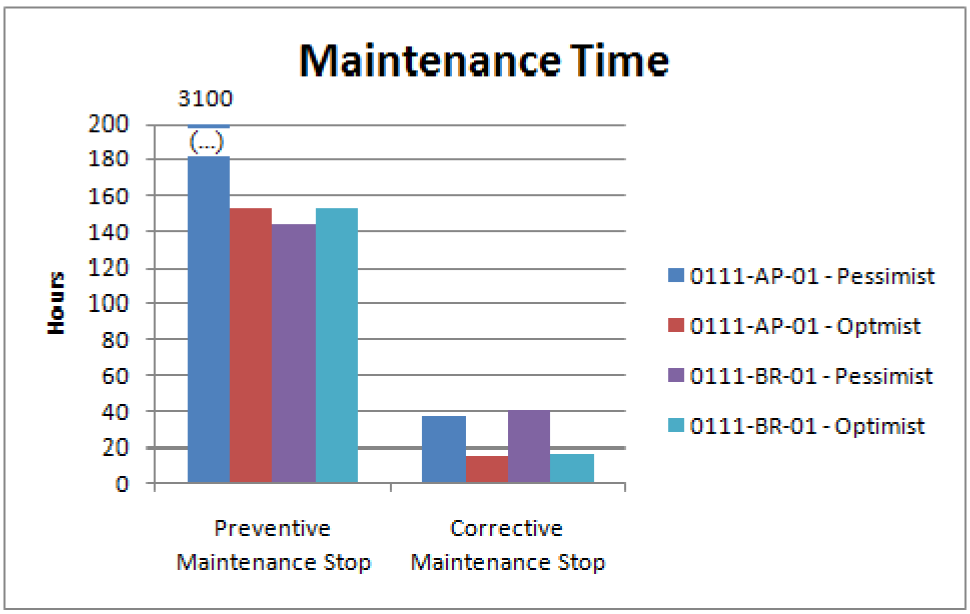

Figure 13: Maintenance time chart

5 CONCLUSION

The experimentation with the Beneficiation Plant designed by Anglo American – Iron Ore Brazil Business Unit and modeled by Paragon Technology, handling the complex interaction of a continuous flow system under the maintenance perspective brings to the operations research community a reliable technique to handle complex systems using simulation. Given the computational power, robust software available in the market and the popularity of mathematical tools to solve operations problems, it was possible to model such complex system.

With the model built for this study it was possible to prove that the proposed method is efficient for analyzing each equipment utilization and physical availability. Thus, it was possible to identify which were the bottlenecks of the system. Hence, identifying the bottleneck enabled taking decisions to change the strategy of operation, and maintenance, by modifying the maintenance schedule (preventive), or equipment reliability (corrective), measured by the results in productivity (tons per year) and costs.

The idea of managing each component's failure parameters individually, and use a model to test how it behaves jointly is one of the most important deliverable of this project according to the final user, because it can drive the decision maker toward a more accurate decision.

6 FUTURE WORK

Despite all the work described by this document, the beneficiation plant is part of a bigger project aimed to model the complete supply chain of the ore. The other steps, such as the port, pipeline, filtering and mine are under development and should be integrated to this in order to have other factors, such as shipment rate, berth utilization, and machines allocation performance to be analyzed.

Beyond the modeling future work, there is the managerial future work, as well. The set of scenarios analyzed by this document dispatched a primary identification of desired equipment specifications and probable bottlenecks of the system. The next steps are to discuss those specifications with the suppliers to analyze cost and benefit of the production target.

ACKNOWLEDGMENTS

The authors thanks the Anglo American – Iron Ore Brazil Business Unit for supporting this project and authorizing the use of its information.

REFERENCES

Contador, J. C. 1997. *Gestão de operações: a engenharia de produção a serviço da modernização da empresa*. São Paulo: Edgard Blücher.

Dekker, R. 1996. "Applications of Maintenance Optimization Models: A Review and Analysis." *Reliability Engineering & System Safety* 51(3):229-240.

Fioroni, M. M., L. A. G. Franzese, C. E. Zanin, J. Furia, L.T. Perfetti, D. Leonardo, and N. L. Silva. 2007. "Simulation of Continuous Behavior Using Discrete Tools: Ore Conveyor Transport." In *Proceedings of the 2007 Winter Simulation Conference*, edited by S. G. Henderson, B. Biller, M.-H Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, 1655-1662. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Sherif, Y. S. 1982. "Reliability Analysis: Optimal Inspection and Maintenance Schedules of Failing Systems." *Microelectronics and Reliability* 22(1):59-115.

AUTHOR BIOGRAPHIES

LUIZ AUGUSTO G. FRANZESE is a simulation consultant with a degree in Production Engineering and an MSc. in Logistics and has completed 250 successful projects with simulation. He founded PARAGON Tecnologia in 1992, the pioneer and leading consulting company in simulation in South America. He has trained more than 1,200 professionals in simulation. He can be contacted by email at augusto@paragon.com.br.

DANIEL DE OLIVEIRA MOTA is a project manager at Paragon Tecnologia Inc. (Rockwell Automation affiliate). He graduated in 2009 with an M.S. in Management Science and Operations Research from North Carolina Agricultural and Technical State University, USA. He developed and managed over 20 projects as a consultant at Paragon using Arena in humanitarian logistics, health care, supply chain, mining, and steel company. He also researches modeling techniques of stochastic systems: simulation, queueing theory, and Markov decision process. His email is daniel@paragon.com.br.

MARCELO MORETTI FIORONI is a simulation consultant with an Electrical Engineering degree, an MSc. in Manufacturing and a PhD in Logistics from the University of Sao Paulo (USP). He has participated in 250 successful projects involving simulation. He is a consultant with PARAGON Tecnologia, leading consulting company in simulation in South America. He teaches Simulation at Faculdades Metropolitanas Unidas (FMU) in Sao Paulo, Brazil. He has trained more than 1,200 professionals in simulation. He can be contacted by email at marcelo@paragon.com.br.

YURI AMARAL C. L. MOURÃO is a risk analyst at Paragon Tecnologia Inc. (Rockwell Automation affiliate), with a degree in petroleum engineering. He developed over 5 projects involving reliability engineering and risk analysis, using techniques of simulation, Markov Chain, Bayesian Models, Fault Tree Analysis and Event Sequence Diagram. His email is yuri@paragon.com.br.

FARLEY SANTOS RIBEIRO is a Process Coordinator at Anglo American – Iron Ore Brazil Business Unit. He has Mine Engineering degree from Universidade Federal de Minas Gerais, MBA in Project Management from Fundação Getulio Vargas, and has been working in the mining industry since year 2000. At Anglo American he is leading in the biggest mining simulation study ever undertaken in Brazil. His email is farley.ribeiro@angloferrous.com.br.

MARCELO NAZARO SILVA is a Process Engineer at Anglo American – Iron Ore Brazil Business Unit. He has Industrial Engineering degree from Faculdade Espírito-santense de Administração, technical metallurgical from Centro Federal de Ensino Tecnológico do Espírito Santo and has been working in the mining industry since year 1996. His email is marcelo.nazaro@angloferrous.com.br.

FERNANDO A. LAGE GONÇALVES is a Plant Manager at Anglo American – Iron Ore Brazil Business Unit. He has MBA in Business Management from Fundação Dom Cabral and has been working in the mining industry since year 1985. His email is fernando.lage@angloferrous.com.br.

THIAGO A. M. BRANDÃO DINIZ is a Mine Operation Engineer at Anglo American – Iron Ore Brazil Business Unit. He has Industrial Engineering degree from Universidade Federal de Ouro Preto and has been working in the mining industry since year 2007. His email is thiago.diniz@angloferrous.com.br.

MARCELO BARCELOS GOMES is a Maintenance Manager at Anglo American – Iron Ore Brazil Business Unit. He has MBA in Business Management at Fundação Dom Cabral and has been working in the mining industry since year 1992. His email is marcelo.gomes@angloferrous.com.br.

DOUGLAS JOSÉ DA SILVA is a simulation consultant. With an Industrial Engineering degree, he has participated in almost 10 successful projects with simulation and teaches simulation at Paragon. He can be contacted by email at douglas@paragon.com.br.

ISAC REIS DE SANTANA is a simulation consultant. With Technical Degree, he has participated in almost 20 successful projects with simulation and teaches simulation in Paragon. He can be contacted by email at isac@paragon.com.br.

JOHANNA GÓMEZ QUEVEDO is a simulation consultant with a Production Engineering degree, an MSc. in Production Management from the Pontificia Universidade Católica do Rio de Janeiro (PUC). She has participated in different projects involving simulation. She is a Consultant with PARAGON Tecnologia, a leading consulting company in simulation in South America. She has trained professionals in simulation. She can be contacted by email at johanna@paragon.com.br.