DYNAMIC SIMULATION IN IRON ORE PELLETIZING PLANTS[1]

Philippe Lavoie[2]
Pietro Navarra[2]
Robert Kuhne[3]

Abstract

Dynamic simulation (discrete event simulation) is the preferred methodology to evaluate the impact of dynamic aspects of processing plants on the overall plant capacity. This tool can be used to: 1) identify bottlenecks in the plant, 2) justify upgrade and expansion projects by evaluating their impact, or 3) optimize maintenance and operating practices without disrupting the operation. Iron Ore Company of Canada's (IOC) pelletizing plant is a complex operation because of multiple products, varying equipment capacity and shifting bottlenecks. Furthermore, with extensive capital requirements for projects and long leadtimes, a high level of confidence in project outcome is required. Therefore, a model of IOC's pelletizing plant in Labrador City was constructed in 2007 by a joint IOC and Hatch team. The model includes both operational and metallurgical aspects in order to better capture the complexity of IOC operation. In this paper, the justification, boundaries, and functionality of the model are described. A comparison of simulation results to historical plant operation is given. It is observed that projects have interactions and that the benefits of combined projects are not equal to the combined benefits of the individual projects. Projects can have synergies that result in greater benefits when combined or can have overlapping benefits that result in lower benefits when combined. The power of the proposed modelling exercise lies in the ability to assess the impact of projects on overall performance.

Key words: Pelletizing; Iron ore; Simulation.

SIMULAÇÃO DINÂMICA EM PLANTAS DE PELETIZAÇÃO DE MINÉRIO DE FERRO

Resumo

A simulação dinâmica (simulação de eventos discretos), é a metodologia preferida para avaliar o impacto dos aspectos dinâmicos das plantas de processamento sobre a capacidade total da usina. Esta ferramenta pode ser usada para 1) identificar gargalos na planta, 2) justificar projetos de expansão e modernização avaliando o impacto dos mesmos, ou 3) otimizar as práticas de manutenção e operação sem interromper a operação. A planta de peletização da Iron Ore Company of Canada (IOC) possui uma operação complexa devido a diversos produtos, capacidade variável de equipamento e gargalos de turnos. Além disso, com grandes necessidades de capital para projetos e long lead, é necessário um alto nível de confiança no resultado do projeto. Por isso, um modelo de planta de peletização da IOC foi construído em Labrador City em 2007 por uma equipe conjunta da IOC e Hatch. O modelo inclui os dois aspectos operacionais e metalúrgicos para captar melhor a complexidade da operação da IOC. Neste documento são descritos a justificativa, limites, e a funcionalidade do modelo. É fornecida uma comparação dos resultados da simulação em relação ao histórico de operações da planta. Observa-se que o benefícios dos projetos combinados não são iguais aos benefícios combinados de projetos individuais. Os projetos podem ter sinergias que resultem em maiores benefícios quando combinados ou podem ter benefícios sobrepostos que resultem em benefícios menores quando combinados. O poder que o modelo proposto exerce, está na capacidade de avaliar o impacto dos projetos no desempenho total.

Palavras-chave: Peletização; Minério de ferro; Simulação.

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[2] *Hatch, 5 Place Ville-Marie, Suite 200, Montréal, Québec, H3B 2G2, Canada, PLavoie@Hatch.ca*
[3] *Iron Ore Company of Canada, P.O. Box 1000, Labrador City, Newfoundland, A2V 2L8, Canada*

1 INTRODUCTION

1.1 Background

The Iron Ore Company of Canada (IOC) is one of the largest iron ore producers in Canada. IOC has been in operation since 1954 and is owned by Rio Tinto, Mitsubishi Corp. and the Labrador Iron Ore Royalty Income Fund and its head office is located in Montreal. The open pit mining operations take place outside of Labrador City, province of Newfoundland and Labrador, and the ore is transported by automated train to the Carol Lake facilities in Labrador City. The ore is then concentrated and most of the concentrate is used by the pelletizing plant while the remaining concentrate is sold. The concentrate for sale and the pellet product are transported by train to Sept-Îles, in the province of Quebec, where IOC has its main product storage and port facilities from which the product is shipped to various clients. This paper will focus on IOC's pelletizing plant.
With the increasing demand on steel products resulting from phenomenal economic growth rates and infrastructure development in countries like India and China, the price of iron ore has seen a drastic price increase in recent years. Figure 1 shows the evolution of iron ore prices between 1999 and 2008. The estimated price for iron ore fines has more than tripled between 2004 and 2008.(1) To take advantage of the favourable market conditions, IOC has recently announced over 500 million dollars (CAD) in expansion projects aimed at increasing iron ore concentrate production from 17 Mtpa to 22 Mtpa and iron ore pellet production from 13 Mtpa to 14.5 Mtpa. However, because of the size of processing equipment combined with their high demand and the increase in raw material prices, the required capital expenses for these expansion programs are important. Furthermore, the high demand for process equipment has resulted in lead times of several years for some of the key components. This results in a need to estimate the benefits of proposed projects with a high level of confidence.

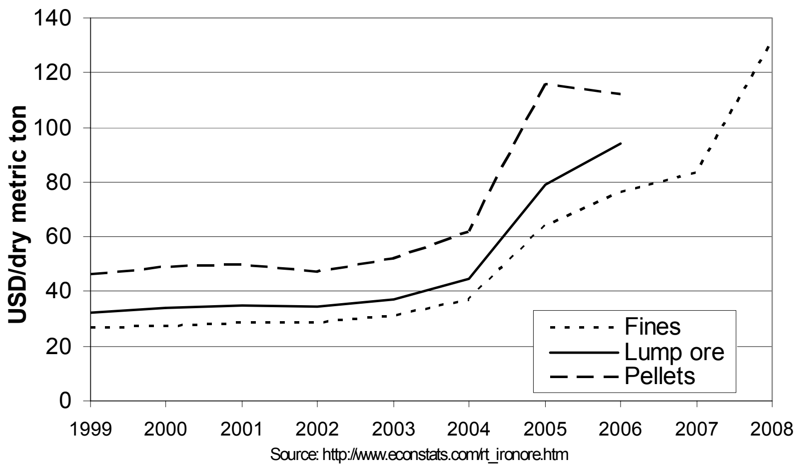

Figure 1: Evolution of iron ore prices between 1999 and 2008

1.2 The Challenge: the Complexity of the Operation

Brownfield projects have some advantages over greenfield projects: in-house expertise, knowledge of the operation and ore characteristics, steady revenues, operating permits and already existing infrastructure. Production increases can often be achieved by identifying and targeting specific areas of the operation. Gains can normally be achieved in much shorter time spans than required for greenfield projects by reducing the amount of required test work, equipment requirements and delays for obtaining permits. However, because of the complexity of these systems, their inherent variability and the high degree of interrelatedness of the different parts of the operation, estimating benefits of projects in existing operations is not a simple task. Figure 2 illustrates potential causes of variation in the output of an industrial operation. Adding to this complexity is the fact that IOC produces five (5) different types of pellets. The pellet types differ from one another mainly based on composition. This implies changing solicitation and capacity of the plant areas depending to the pellet type in production. When adding the effect of equipment reliability and maintenance schedules, the result is a shifting bottleneck that is dependent on the type of pellet in production. The cumulative effect of these sources of variability makes it excessively difficult to accurately estimate the benefits of the proposed projects based on the current product mix and even more so when considering a product mix that will be changing over time.

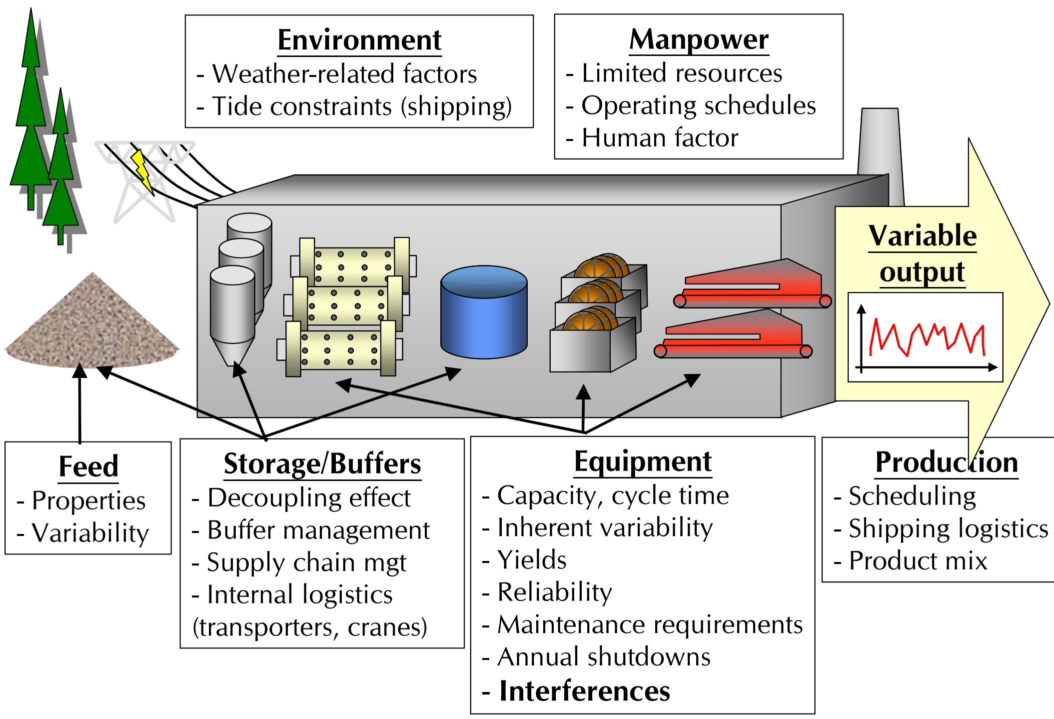

Figure 2 : Potential causes of output variability in an industrial operation

1.3 Review of Available Tools

1.3.1 Steady state calculations

Traditional equipment capacity calculations are based on the average or steady state operation of the operation. Although quick, these static calculations fail to capture all of the inherent variability of pelletizing plant operations. In the best case, interferences between upstream and downstream operations in the plant are accounted for with estimated factors based on experience and are sometimes disregarded altogether. Equipment uptime and downtime is aggregated in an overall operating time without distinction between short interruptions, that can be offset by internal buffers in the system and long-term interruptions that propagate by blocking upstream operations and starving downstream operations.

1.3.2 Analytical models and decomposition techniques

Analytical methods such as Markov chain-based models and decomposition methods, both well described in Gershwin[2] are interesting from an academic perspective and may eventually become useful for industrial applications. However, analytical models require strong mathematical skills and most of the time require simplifications of the real-world problem beyond the point where they are useful. As the complexity of the formulated problem grows, it becomes unsolvable with today's knowledge and tools. Decomposition techniques are simpler in application and can be used in the design of transfer line type systems for example, but Bonvik[3] shows that their accuracy decreases when moving away from the simple transfer line problem. In both the analytical and decomposition methods, the types of system performance statistics that can be estimated are very limited.

1.3.3 Monte Carlo simulation

Monte Carlo type simulation is a more interesting approach to capacity evaluation than the traditional steady-state calculations. Less restrictive assumptions are required as compared to mathematical models. They allow the practitioner to include variability in the system parameters by modeling them as statistical distributions. By sampling from the proposed distributions, a number of steady state "snapshots" of the operation can be taken to evaluate the average performance and the estimated variability of the system. However, Monte Carlo simulation becomes much less user-friendly when it is required to model the dynamic evolution of the system over time, to account for decision-making schemes, the use of transporters, competition for resources or the effect of scheduled events such as maintenance. When the consideration of all these factors is required, dynamic simulation (also known in the literature as 'discrete event' or 'combined discrete/continuous simulation') is the tool of choice.

1.3.4 Dynamic simulation

Dynamic simulation is the most effective and comprehensive methodology to date to evaluate the production performance of complex systems while considering the variability in the process and the interactions between the various parts of the operation. In the model, the system is represented by a series of logical operations and decisions that mimic the behaviour of the operation over time. The random elements of the system can be reproduced using representative statistical distributions. The simulation model is executed over an appropriate period of time, depending on the time scale of the events. During the simulation run, statistics are collected on the performance of the simulated plant. "What-if" analyses are done by changing the parameters of the system so that the impact of each element on the overall performance can be estimated. Many different scenarios can be investigated without disrupting the operation. This facilitates the selection of the most beneficial projects.

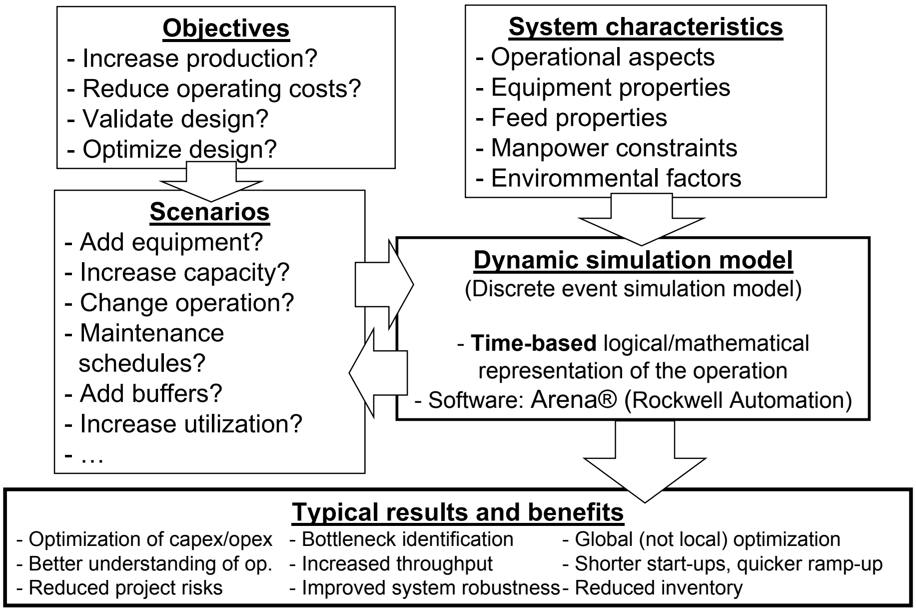

Figure 4: Dynamic simulation modelling

Figure 4 illustrates how the dynamic simulation model can result in benefits (optimization of capex/opex, bottleneck identification etc.) by bridging the gap between management objectives (increase production, reduce operating costs, etc.) and the complexity arising from the characteristics of the system. Over the course of the simulation exercise, a better knowledge of the operation is acquired. Therefore, it is usually an iterative process. As the understanding of the system grows, new scenarios are proposed, some of which require modifications to the model.
The remainder of this paper is organized as follows: material and methods are discussed in Section 2, key results are given and discussed in Section 3 and conclusions are given in Section 4.

2 MATERIAL AND METHODS

2.1 Material

The simulation software used for this work is Arena® from Rockwell Automation. It is the most widely used general-purpose discrete event simulation software. Its applications range from mining to manufacturing and services. Computer hardware required is a simple PC.

2.2 Methods

Musselman(4) defines 8 steps for the execution of a simulation project: problem formulation, model conceptualization, data collection, model building, verification and validation, analysis, documentation and implementation.

2.2.1 Problem formulation

Refer to Section 1.2 of this paper.

2.2.2 Model conceptualization

The objective of this step is to define the functionalities that will be included in the model and the required level of detail. The conceptualization should be closely tied to the problem formulation and the model objectives. In the current case, the objectives of the model were to (1) help identify the bottlenecks of the plant and (2) help rank projects in terms of costs vs expected benefits. The process steps that required modeling to achieve these objectives were outlined. Figure 3 gives an overview of these process steps. The availability of feed material was modeled using statistical functions and it was assumed that the pellet load-out was never a bottleneck.

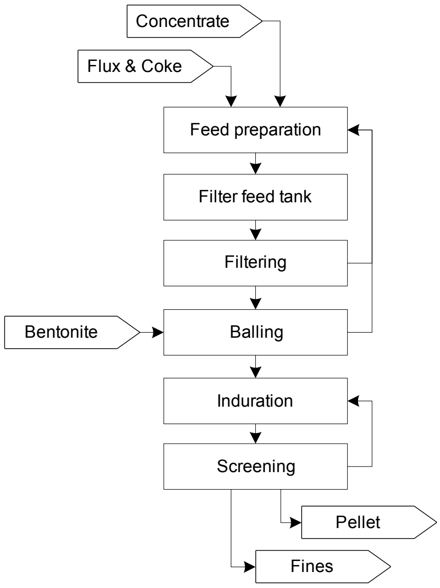

Figure 3: General block flow diagram of the pelletizing plant process

All of the major process equipment found inside the plant were modeled each with its own equipment capacity, scheduled and unscheduled (random) downtime function logic and process variations. The list of modeled equipment included:

- 14 ball mill feed silos for feed availability;
- 3 variable feed ball mills (flux, coke or concentrate);
- 9 dedicated concentrate ball mills;
- 1 dedicated coke ball mill;
- Magnetite concentrate slurry feed;
- 3 thickeners;
- 1 flotation plant;
- 5 slurry tanks;
- 1 bentonite plant;
- 1 bentonite day bin;
- 26 disc filter modules;
- 26 balling drums;
- 6 straight grate type induration furnaces;
- 2 product loadout conveyors.

99 pieces of major equipment were modeled in total.

2.2.3 Data collection

In the case of the model of IOC's pelletizing plant, data was extracted from 3 main sources: historical process data servers, the equipment downtime logging system and the IOC staff. Historical process data servers contain useful information about the past performance of the system. The analyst must, however, make sure he understands what is measured, when and how. An equipment downtime logging system can also contain valuable information to analyze the causes and durations of downtime when the data is entered with care. Finally, because of their involvement with the system on a daily basis, operators and maintenance personnel also contributed to the modeling exercise by adding value to the interpretation of the available data. Several model definition and review meetings were held to ensure the model was sufficiently representative of the operation given the project time frame.

2.2.4 Model building

Model building represents the actual coding of the model. In order for this step to move forward efficiently, the previous steps must be conducted rigorously. Ideally, the programmer has all of the necessary data at this step to develop the model. However, because all of the information is not always readily available, it is often not the case. The model building can still move forward using assumptions and the remaining data collection can be executed in parallel. By doing this, the overall duration of the project can be shortened.

2.2.5 Verification and validation

Verification and validation was executed in two steps: the first step was aimed at verifying the model calculations against an existing static model (yields, throughput, mass balance, etc.), while the second step aimed at validating the dynamics of the model.

The objective of the first step was to verify that on a steady state basis, the model results were similar to the plant's mass balance calculations. In order to do this, disrupting events like scheduled and unscheduled downtime were turned off and a simulation was run for each product type. In the current case, the results were identical and thus the calculations were validated.

The second step aimed at validating the dynamic behaviour of the model. In this step, the average model results for 5 replications were compared with historical plant performance. A reference period of 1 full year was chosen. Simulated average plant throughput was within 0.2% of the actual measured plant performance for the reference period. Although the total yearly throughput was the main performance indicator of the simulation, it was important to verify that the product mix was respected since the bottleneck is dependent on the type of product. For all products, the difference between the actual and the simulated product mix was within 0.4%. The next item that was verified was the distribution of production rates. The distribution of the simulated production rates of the induration furnaces and the entire plant for each product type were compared to the historical data. Figure 5 illustrates the distribution of measured and simulated overall plant production rates. It is observed that the distributions of the production rates are very similar. The small difference between the two distributions was considered to be within measurement uncertainty.

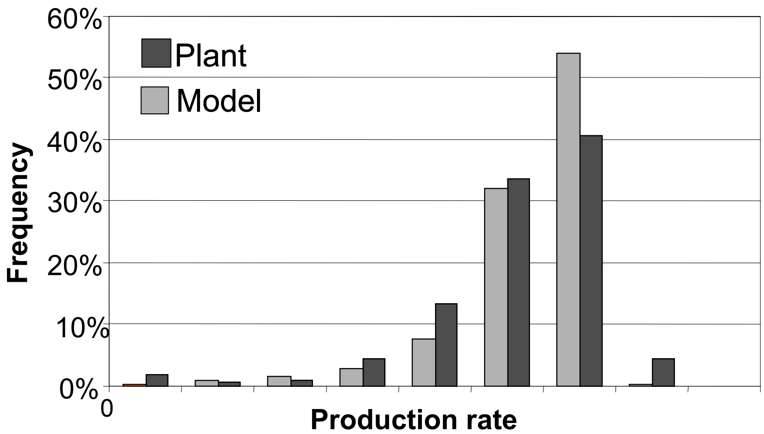

Figure 5: Plant production rate vs simulated production rate for fluxed pellets

Another item that was investigated during the validation process is the composition of the filter cake. The objective was to verify that the requirements from each part of the plant are respected in order to produce the specified chemistry. This item was important to ensure that the solicitation of each area in the model was comparable to the solicitation of the corresponding areas in the plant to avoid errors on the evaluation of the bottleneck. Figure 6 illustrates the simulated composition of the filter cake compared to the target for each element. It was observed that the fluctuation around the target is more important for EME and Flux than for silica. A quick comparison between the variability of the measured EME and flux in the plant showed variation similar to the variation of the simulated values. This was due to the sampling frequency and delay to obtain the results. A similar sampling pattern was used in the model. Therefore, the frequency of the sampling and the lag between the sampling and the results combined with the damping effect of the slurry tank causes the fluctuation in the composition of the filter cake in both the plant and the model.

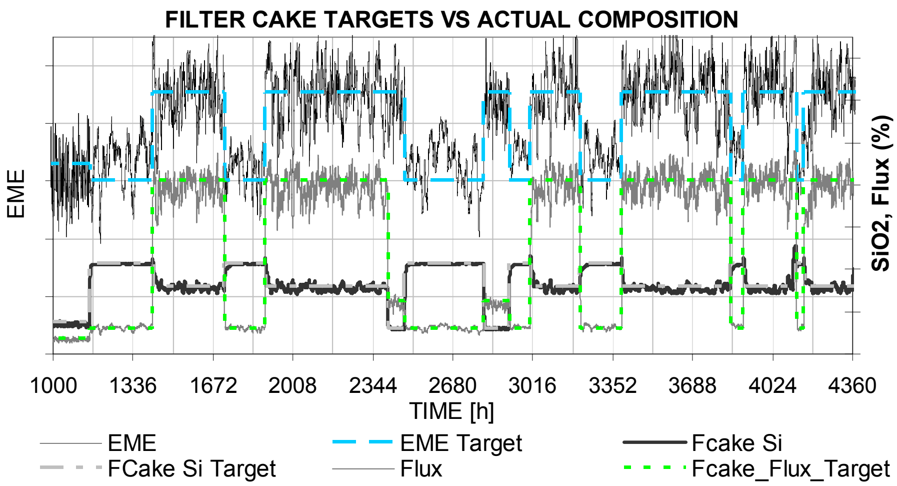

Figure 6 : Filter cake composition and targets over a portion of one replicate

Several other items were investigated during the validation process. Some of the key indicators that were investigated are shown in Table 1 along with the objective behind the verification of each element

Table 1: Key performance indicators investigated during the validation process

Performance indicator	What to look for
Equipment utilization	The utilization of the different pieces of equipment is similar to plant.
Causes of downtime	The causes of downtime are similar to the plant for the calibration case.
Time distribution of ball mill feed	A similar amount of time is spent grinding the different feed materials for the variable feed mills.

2.2.6 Analysis

For the current work, the objectives of the analysis phase were to identify the current and future limitations of the plant as well as the impact of a proposed list of projects. Some key results are discussed in Section 3.

2.2.7 Documentation

Documentation is a very important element of the modelling exercise. Having clear and detailed documentation that is understandable by the different stakeholders is crucial in succeeding. The objective of the study is not to build a simulation model, but rather to gather and improve knowledge of the operation and transfer it so it is the most useful.

2.2.8 Implementation

The last step of the simulation project is the implementation. In this step, the different decisions that were taken following the modelling exercise are put into action. In the case of IOC, the projects that have been retained were scheduled to be implemented over the course of the coming years. It is therefore not possible to compare the simulation results against the ultimate plant capacity at this time.

3 DISCUSSION

3.1 Bottleneck Identification

One of the objectives of the model is to help identify the bottlenecks of the plant. However, because the bottleneck changes depending on the type of pellet in production as well as on the state and instantaneous capacity of the equipment, there is no single bottleneck. Instead, the fraction of time each element is the bottleneck for a production line is measured. It is then possible to evaluate the limiting effect each part of the line has on the overall production. Table 2 shows an example of bottleneck identification results. It is observed that the main bottleneck is by far the filter and balling section of the plant (74.1% on average). This indicates limited gains can be expected from plant improvement initiatives focusing on feed preparation and induration. By looking at these results, one might be tempted to assign projects only in to the filter and balling section of the plant. It should be noted that these statistics do not indicate how far behind the next bottleneck lies.

Table 2: Example of bottleneck identification results

Line	Feed preparation	Filter & Balling	Induration	Total
1	8.8 %	86.0%	5.3%	100.0%
2	8.8 %	77.7%	13.5%	100.0%
3	8.8 %	64.2%	27.0%	100.0%
4	8.8 %	55.7%	35.5%	100.0%
5	8.8 %	73.2%	18.0%	100.0%
6	8.8 %	87.7%	3.5%	100.0%
Average	8.8 %	74.1%	17.1%	100.0%

3.2 Sensitivity Analysis

A sensitivity analysis can help validate a model by analyzing the response to the change in the different input variables. It also sheds light on the dynamics of the system and the interactions between the different parts of the plant. Table 3 gives the case parameters and change from the base case in annual production for a simple sensitivity analysis that was done over the course of the project. Case 1 is the base case. Cases 2-4 have an increased filter and balling capacity of 10% to 30% from the base case, Cases 5-7 have an increased ball mill capacity of 10% to 30% and cases 8-10 have a filter feed slurry tank capacity increase of 100%, 200% and 300% respectively. Figure 5 shows the results for these sensitivity cases. It is observed that the biggest production increase is obtained by increasing filter and balling capacity by 10% (Case 2). This is in line with the bottleneck identification results given at Table 2. However, further increasing the capacity of filter and balling (cases 3 and 4) gives little or no further gains. This indicates that the next bottleneck has been reached and that greater benefits would come from projects in other sections of the plant. The production increases obtained by changing the capacity of the ball mills increase much more progressively and eventually become as important as the benefits from increasing filter and balling capacity as shown by results for cases 5-7. Finally, the benefits from increasing the volume of the filter feed slurry tank are gradually increasing but modest when compared to the other cases.

Table 3: Sensitivity analysis case definition and results

			Filter and Balling			Ball mills			Filter feed tank		
Legend	●	♦	♦	♦	■	■	■	▲	▲	▲	●
Case number	Base	2	3	4	5	6	7	8	9	10	11
Filter & Balling	Base	**+10%**	**+20%**	**+30%**	Base	Base	Base	Base	Base	Base	**+10%**
Ball mills	Base	Base	Base	Base	**+10%**	**+20%**	**+30%**	Base	Base	Base	**+10%**
Filter feed tank	Base	Base	Base	Base	Base	Base	Base	**+100%**	**+200%**	**+300%**	Base
Change (ktpa)	--	360	390	390	210	250	290	60	140	180	700

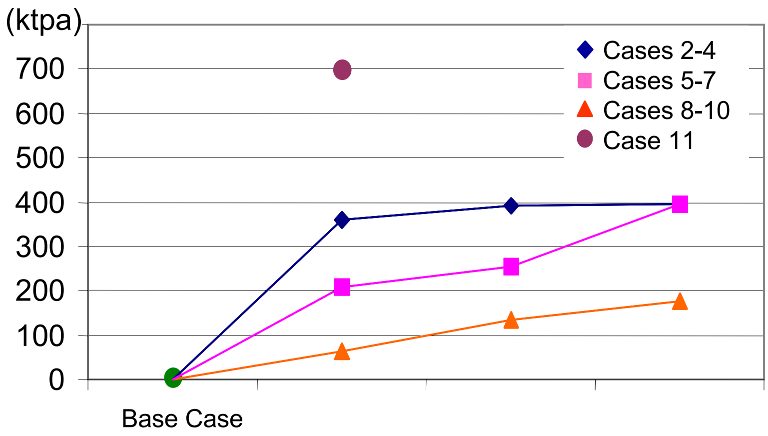

Figure 5: Production increases from base case for sensitivity analysis

An additional case was introduced. By combining the filter and balling capacity of case 2 and the ball mill capacity of case 5 to obtain case 11, the production increase of case 11 surpasses significantly the combined production increases of the individual cases. The explanation is simple but highlights the value of a dynamic simulation exercise: by increasing the filter and balling capacity, this section of the plant is no longer the bottleneck. Because of this, more pressure is put on the regrind section of the plant. Therefore, there are synergies between cases 2 and 5 that result in much greater benefits when they are combined. This is very difficult to capture using static calculations.
In the current case, the effect is positive but for other projects, the effect could be negative. For example, because increasing the both ball mill capacity and the filter feed tank capacity results in a higher availability of feed for the filter and balling area, it could be expected that the combined benefits of cases 5 and 8, for example, would be less that the combined benefits of the individual cases.

4 CONCLUSION

Being able to measure the effects of the interactions between the different parts of the plant and evaluate the performance of the system as an integrated system rather than as the sum of the parts of the system is the key benefit of a simulation exercise. The global impact of each project is therefore evaluated in consideration of dynamic interactions in the plant and potential synergies. The sensitivity analysis has highlighted an important element: the combinations of the projects as well as the sequence in which they are implemented have an impact on the time at which the benefits will be obtained and thus on the profitability of the projects. A dynamic simulation model is therefore a very effective tool to help management (1) select the projects which are the most beneficial, (2) avoid projects with little or no benefits, (3) identify which projects should be done in combination, and (4) optimize the sequence of implementation that maximises the profitability of the entire expansion program.

Acknowledgements

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