Prove Your Process:

Practical Simulation of Plant Dynamics

A dynamic model has been developed for analysing and predicting the performance of metallurgical process plants. The model takes into account the factors that influence production on a dynamic basis, including ore grades, throughput capacity, equipment reliability and surge capacity.

The model has been applied to several hydrometallurgical flowsheets for design verification, surge optimisation and identification of production bottlenecks. This paper tracks the development of the model, describes its operation and proposes future applications.

Introduction

Complex metallurgical processes can be analysed quickly and effectively using simulation models. Recent innovations provide a powerful tool for evaluating flowsheets, taking into account the key economic drivers over the whole operating life of a project. Mine plans, metallurgical characteristic models, equipment reliability statistics and surge capacities are all considered in an integrated plant dynamic model. The result is lower risk and greater confidence in engineering decision making.

Plant designs are commonly based on a steady state mass and energy balance model of the flowsheet. These give a simplistic ‘perfect world’ snapshot. Real world fluctuations are conveniently ignored, creating the illusion of a stable, steady process. Dynamic models bring the mass and energy balance to life with real plant limitations and instabilities.

Simulus first developed a dynamic transfer model to meet a client’s specific needs. The client, operating a complex nickel hydrometallurgical process, was embarking on expansion and optimisation studies and needed a tool to evaluate the various alternatives. The plant was characterised by:

- Poor equipment reliability in some areas
- Mismatched area throughput capacities
- Limited inter-stage surge capacity
- Parallel production trains (existing and proposed)
- Complex interactions between plant stages (multiple recycles)
- Utility and reagent supply constraints

The dynamic interactions of throughput capacity, equipment reliability, and surge capacity caused the production bottleneck to shift from point to point. The impact of capital projects could not be accurately predicted by steady state modelling. In some cases throughput improvements were rendered inconsequential by the quite daunting reliability issues. These problems were overcome by developing a whole-plant simulation tool.

The Simulus Dynamic Model overlays the mass and energy balance with real equipment characteristics and dynamic fluctuations. The simulated plant can be run for a period of several years, with all major economic drivers considered on a dynamic basis:

- Ore grades
- Area by area throughput capacity
- Equipment failure statistics
- Planned maintenance schedules
- Surge capacity
- Utility and reagent supply

The resulting models give a far more realistic simulation of plant operation and are becoming a fundamental tool in design and optimisation of process facilities.

Dealing with Complexity

Consider the simple process shown in Figure 1. With an unlimited ore supply, the only downtime is due to equipment failures and scheduled maintenance. There is no waiting for upstream or downstream processes.
The rate of production can be expressed in simple terms as:

Production (t/h) = Throughput (Instantaneous capacity) (t/h) x Grade (%) x Recovery (%) x Availability (%)

Where: Availability = Running time / Time required to run

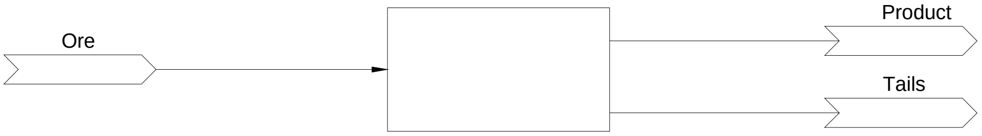

Figure 1 – Single Stage Process

The situation becomes more complex when two units operate in series, as shown in Figure 2. A utilisation term must be added to the equation.

Area 1 Production (t/h) = Throughput (Instantaneous capacity) (t/h) x Grade (%) x Recovery (%) x Availability (%) x Utilisation (%)

Area 2 Production (t/h) = Throughput (Instantaneous capacity) (t/h) x Grade (%) x Recovery (%) x Availability (%) x Utilisation (%)

Where: Utilisation = Running time / Time available to run

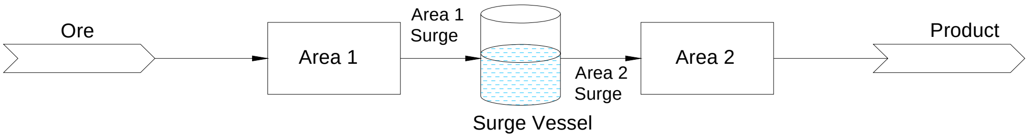

Figure 2 – Two Stage Process

Ideally the instantaneous throughput and availability should be closely matched across the plant areas. A high maintenance area needs catch-up capacity while a more reliable area could get away with a lower instantaneous rate.

Predicting the utilisation is not straightforward. It depends on the inter-stage surge capacity in relation to the instantaneous throughput and equipment availability. In the case of zero surge capacity, instantaneous production is constrained at the lower of the two area rates. An equipment failure in either area stops production entirely, and area utilisation is limited by the availability of the upstream or downstream area.

In the case of excess surge capacity, Area 1 can operate at full rates for the longest shutdown in Area 2. Similarly, Area 2 has enough feed to continue operating while Area 1 undergoes any required maintenance. There should be no process delays and so utilisation equals 100%.

Surge capacity has a different meaning depending on perspective. The operator of Area 1 wants enough empty space in case Area 2 goes down. The Area 2 operators want a high tank level in case Area 1 goes down. Thus the true surge capacity may be less than half the tank volume, depending on the control philosophy.

For scheduled maintenance, the tank level can be set in anticipation of requirements. Setting the level to deal with random failures may require some judgement. If Area 2 is prone to unplanned maintenance, the tank should be run at a lower level. Conversely, if Area 1 fails more often, the tank should be run high to avoid shutting Area 2 down.

Parallel production trains should also be considered, as shown in Figure 3.

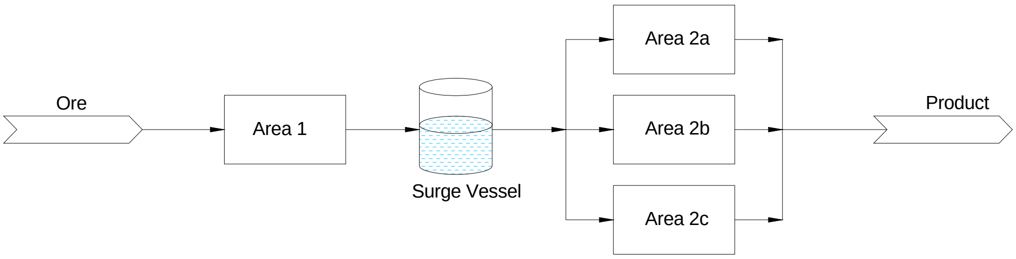

Figure 3 – Parallel Trains Included

Parallel trains compensate for low availability, but add complication to the relationship between surge capacity and throughput.

The level of complexity mushrooms with multiple production stages, recycle streams, reagent and utility requirements. The throughput, surge and availability of every reagent and utility further impact the overall production rate.

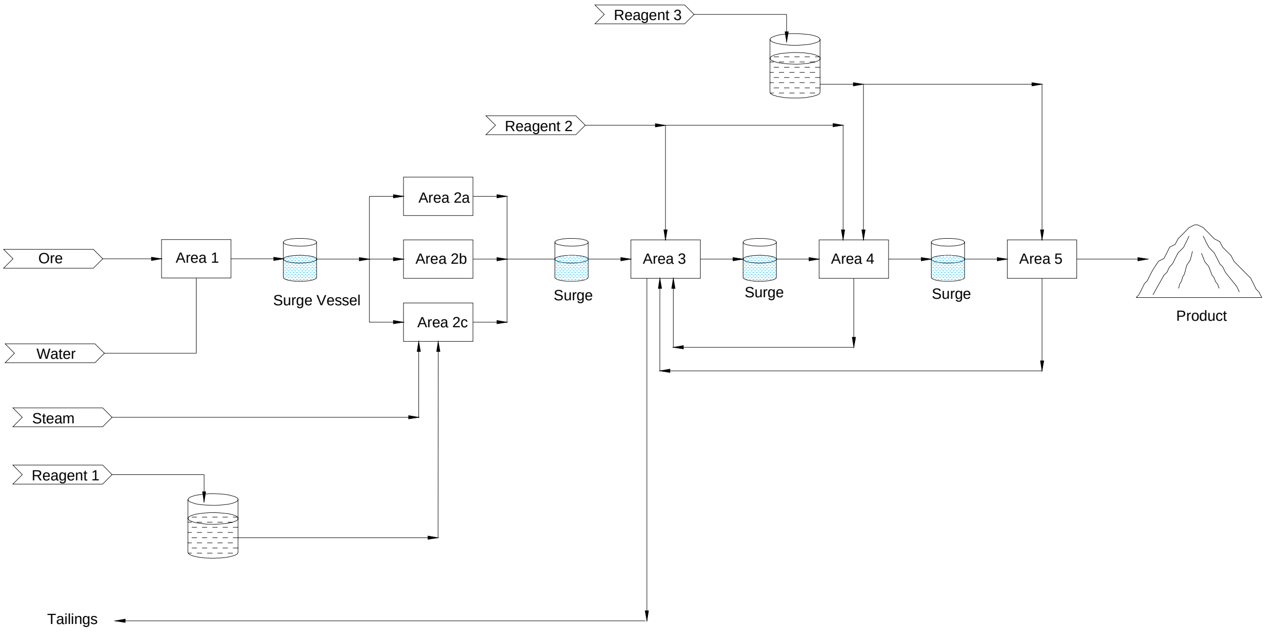

Figure 4 – Complex Process

Additional complicating factors include:

- Transient processes such as heap leaching
- Incremental plant expansion projects
- Turndown ratios
- Catch-up capacity

- Maintenance resource limitations
- Multiple reagent demands

The best way to analyse complex flowsheets is through simulation. The process of setting up the model and gathering the data in itself raises important questions and identifies knowledge gaps. The designer is forced to take a rigorous, logical approach and to explicitly define assumptions and inputs used in the model. Errors in reasoning usually become apparent when concepts must be translated to computer code.

Model Structure and Operation

The Simulus Dynamic Model was developed using the SysCAD simulation platform, developed by KWA Kenwalt Australia Pty Ltd. SysCAD is widely used in the minerals industry is well suited to complex hydrometallurgical flowsheets. The open architecture gives great flexibility and transparency of model operation. All model input and output data can be readily presented on an Excel spreadsheet.

The following data is input to the model for each plant area, including utility and reagent plants:

- Throughput rates, key process criteria and volumes of surge vessels
- Volumetric capacity of inter-stage tanks, ponds, bins and stockpiles
- Scheduled maintenance times, including the first planned shut, the shutdown duration and the time to next shutdown.
- Unplanned shutdowns, specified in terms of mean time to fail and repair

Downtime statistics can be separated into major and minor, depending on the nature of the distributions. Unplanned maintenance is controlled by a random generator function. The average and standard deviation durations are input, and the distribution function generates actual fail and repair times.

The model is configured to use run time, not calendar time. A plant area will only go into scheduled maintenance when it has actually been running for the required time. Similarly, the failure distributions are based on actual running time. A long process delay will thus postpone the next scheduled downtime or failure.

The result is a time trend of the process conditions such as flow rates and tank levels. Over an extended period of months or years, the area by area utilisation can be determined, as can the final product amount. The step size can be varied. Smaller steps give a more accurate simulation but directly lower the speed of solving. The step size must be longer than the shortest event time. Each area of the process is controlled by a program file, which turns flows on and off according to the maintenance and process requirements. The following modes and status definitions are used:

Table 1 – Area Mode Times

	Status	Mode
Running	Maximum rate	10
	Reduced rate	11
Plant-wide shutdown	Power off	21
	General shutdown	22
Process Delay	Upstream 1	31
	Upstream 2	32
	Downstream 1	33
	Downstream 2	34
Scheduled Maintenance	Minor	41
	Major	42
	Unclassified	43
Failed	Minor	51
	Major	52
	Unclassified	53
Await Reagent	Reagent 1	61
	Reagent 2	62
Await Utility	Utility 1	71
	Utility 2	72

Reliability Data

Any model is only as good as its inputs. The Simulus dynamic model requires process information to build the mass and energy balance, but it also needs equipment capacity and reliability data. Reliability engineers are called upon to develop key input information:

- Mean time to fail
- Mean time to repair
- Type of distribution
- Modality of distribution

Failure distributions in metallurgical plants normally follow an exponential curve. Bimodal distributions are common, with failures being either 'major' or 'minor'. Repair times normally reflect this modality. The level of detail in the model should not exceed the level of detail of the reliability statistics. This can be either the plant area level, or by individual equipment items.

Simulation Results

Final results are transferred to an excel spreadsheet as one of two types of report. A static report can give a snapshot of the whole process at any point in time. It can also give totals and averages of flows, levels and other process parameters over the model run time. A trend report gives a time profile of the desired parameters, and is very useful for detailed examination of plant behaviour.

The main outputs of interest are:

- ♦ Major process flow rates (average and total)
- ♦ Metal mass flow in each major stream (average and total)
- ♦ Surge tank levels (average and maximum)
- ♦ Area by area mode time - e.g. % running, % planned maintenance, % awaiting downstream etc.

This information is selected to describe plant performance and reveal where the bottlenecks occur.

Some sample output results from a hypothetical project are shown in Table 2 and Table 3 below. The data shows the impact of a project to increase throughput rates in Areas 2 – 4, the parallel leach trains.

Table 2 – Area Mode Times

State	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7
Maximum rate	64%	42%	42%	42%	91%	82%	86%
Reduced rate	0%	27%	27%	28%	0%	0%	0%
General shutdown	3%	3%	3%	3%	3%	4%	4%
Await Upstream	0%	1%	1%	1%	1%	0%	0%
Await Downstream	22%	4%	4%	4%	4%	9%	0%
Planned Shut	2%	10%	10%	10%	0%	0%	3%
Failure	8%	12%	12%	13%	1%	2%	6%
Await Reagent	0%	0%	1%	0%	0%	2%	0%
Await Utility	0%	0%	0%	0%	0%	1%	1%
Total	100%	100%	100%	100%	100%	100%	100%

The low proportion of time running a full rates shows that the project creates a process bottleneck downstream. Even though severe equipment failures are evident, there is little to be gained from increasing either throughput or availability in this area. The greater priorities in this case are reagent, utility and downtime issues in areas 6 and 7.

Overall tonnages are presented on an area by area basis in Table 3. This shows average conditions over the period in question.

Table 3 – Area Production Rates

Final tonnes	Dry tonnes			Metal		Recovery
	Average t/h	Maximum t/h	Total Mtpa	Average t/h	Total tpa	% leach feed
Ore feed	393.0	630.0	3.44	5.43	47,549	
Ore rejects	23.6	37.8	0.21	0.33	2,853	
Leach feed	369.5	592.2	3.24	5.10	44,696	
leach train 1	114.4	187.2	1.00	1.58	13,849	
leach train 2	114.4	187.2	1.00	1.58	13,849	
leach train 3	114.4	187.2	1.00	1.58	13,849	
Leach discharge	343.3	561.5	3.01	4.74	41,546	93.0%
Tails	498.1	826.3	4.36	0.92	8,100	18.1%
Precipitation feed				4.49	39,342	88.1%
Final product	4.0	8.2	0.0352	4.02	**35,203**	78.8%
Final circuit inventory					352	

The model shows how well surge tanks are utilised over an extended period of time. Presenting the tank level distribution readily shows whether tanks are regularly filling up or are rarely used. The outputs can be used to identify where extra capacity is needed, or where costs could be cut by eliminating unnecessary surge.

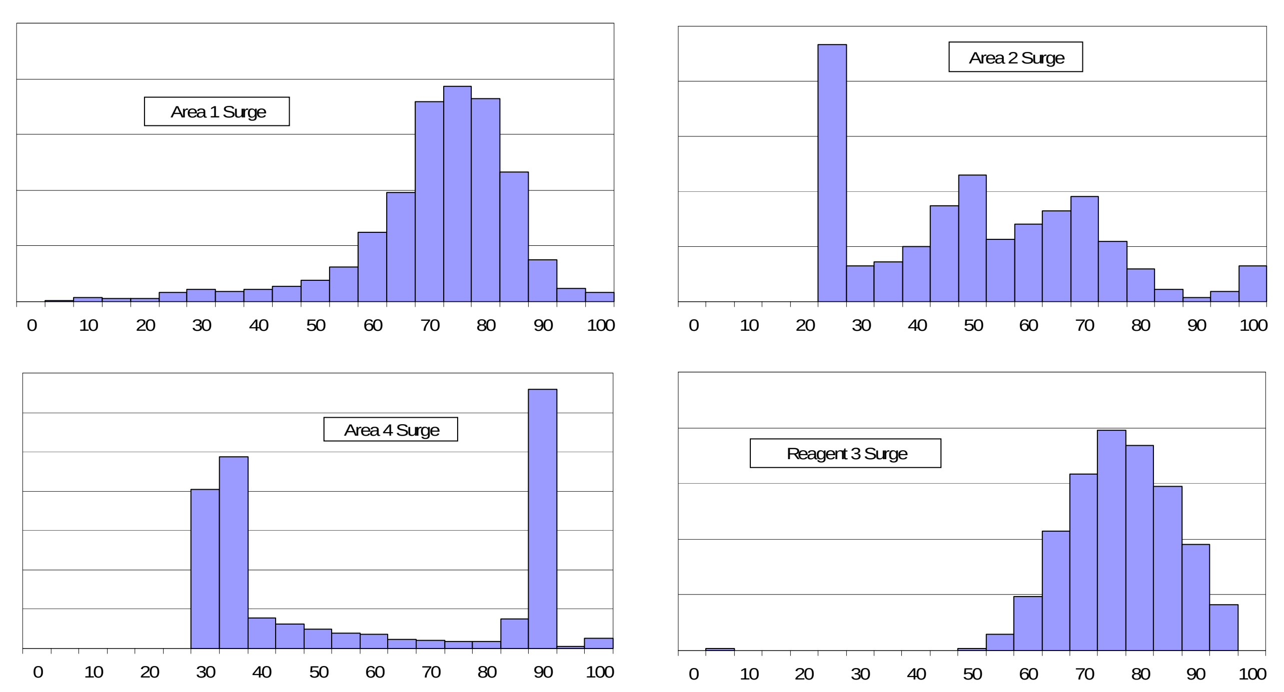

Figure 5 – Tank Level Distribution

Figure 5 shows the level distribution plots for four tanks. The horizontal axis represents the tank level, and the vertical axis shows the proportion of time at each level.

Area 1 and area 2 surge tanks appear to be well sized for their application. They are both occasionally filled to full capacity, but show a wide range of levels over time.

Area 4 surge is not well utilised. It is normally near empty, but when it is needed, the level shoots up to 90%, forcing area 4 into standby downstream more. During normal operation it is three times larger than it needs to be, and during downstream shutdowns it is too small to be of any use.

Reagent 3 surge is also not well utilised. The reagent is normally produced faster than it is consumed, and the supply is reliable enough to always keep the tank at least 50% full. A tank half the size would do just as good a job.

Practical Applications

Results from the dynamic model are usually fed into an economic model, to calculate the production and operating cost profile. Multiple scenarios are run to determine the Net Present Value (NPV) response of capital projects or operating changes. The Simulus model has been applied to a range of major projects, including existing and new plants. Some notable case studies are briefly described below.

Murrin Murrin – Nickel laterite high pressure acid leach process

A dynamic transfer model was developed incorporating the entire integrated process plant including key utility and reagent supplies. As part of the development phase, the model was rigorously validated against historical plant data before being applied to future scenarios. The model has been used to evaluate a variety of major capital projects

In each case the model was used to generate realistic estimates of nickel and cobalt production under future scenarios. Expansion plans are thus optimised by focussing on scenarios giving the greatest production benefit from the least spending.

Goldsworthy Iron Ore

A model was developed incorporating iron ore stockpiles, reclaimers, feeders and rail system. Scenarios were run to optimise the equipment sizing and configuration to align with train loading schedules. The simulation demonstrated that the system could be designed with less feeders without lowering the overall system capacity, thus saving significant capital.

Avalon Project – Sulphide Leach Project

An integrated plant dynamic model was developed for a feasibility study involving an innovative sulphide leach process. The project involved major process modification and expansion of an existing plant.

The model was used for surge and availability analysis and to verify the nameplate capacity of the design. The results helped identify process risks and optimise the area by area throughput to achieve the required metal output.

Niquel do Vermelho - Nickel laterite high pressure acid leach process

As part of the final feasibility for a greenfields laterite project, a dynamic model was built to verify the nameplate production capacity. The results proved the design and helped lower the overall project risk

The model will be used and developed on an ongoing basis as the project moves into detailed design.

Queensland Alumina Refinery – Bayer Process

A mature operation with an in-house simulation team engaged Simulus to develop a dynamic model for the entire alumina refinery. The model will be applied to ongoing de-bottlenecking and expansion projects, and will also be used for planning and optimisation of routine operations.

Conclusions

Complex metallurgical flowsheets are best analysed by use of dynamic modelling. Process chemistry, equipment capacity and reliability, surge capacities and ore blend profiles all affect the project outcome and should all be considered in the model.

Many projects have failed to consider the inter-relationship between equipment reliability, surge capacity and instantaneous throughput, and not realised the impact on production. The results have been over-inflated production forecasts and mismatched area capacities. A dynamic simulation could have identified the optimum flowsheet configuration, surge requirements and equipment size.

Ever increasing computer power and improvements in simulation software are making dynamic simulations far more accessible to the minerals industry.

Innovative hydrometallurgical processes are often seen as risky investments, particularly when the flowsheets are complex and conditions are aggressive. Dynamic modelling can mitigate risk firstly by identifying any deficiencies in knowledge and assumptions, and then by providing reliable, realistic estimates of future production profiles.