SIMULATION MODELLING OF IRON ORE PRODUCTION SYSTEM AND QUALITY MANAGEMENT

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Abstract: Iron ore is railed several hundred kilometres from open-cut mines inland, to port facilities, then processed to lump and fines products, blended and the lump product re-screened ready for shipment, mainly to Asia. Customers use the ore as principal feed in steel production. Increasing demand and price, especially from China, requires expansion of existing mines and planning of new operations. Expansion planning of the operational logistics, maintaining acceptable product quality, has been greatly helped by simulation modelling described in this paper.

1 INTRODUCTION

Ore from open-cut mines in the Pilbara region of Western Australia is railed a few hundred kilometres to a port where the ore is processed and blended for shipment, mainly to Asia. Customers use the ore as feed in steel production. Figure 1 shows a simplified ore flow, although many operational variations exist.

Increased iron ore demand has required a review of capacity. To increase tonnage safely, at minimum cost and acceptable quality, processes need to be upgraded, existing mines and infrastructure expanded, and new mines brought on line. Assessment requires informed choices between operation and infrastructure development options that differ in capital and operating costs. Many alternatives exist for mining, ore processing, stockpiling, railing and ship loading operations.

Expansion options must be assessed for their effect on product quality. Customers assess quality by cargo grade, and inter-cargo grade variability. As well as iron, several impurities, principally phosphorus, silica, and alumina are important. Simulation models of expansion options enable mining and handling alternatives to be compared. They consider tonnage capabilities and the variation in product quality, a vector of iron, phosphorus, silica, and alumina grades. These grades shows complex serial and cross correlations, so synthetic data cannot readily be constructed. Production was simulated from historic data of geologically similar ore, statistically adjusted to match potential operations.

The models were written in Excel™, with Visual Basic (VBA) macros, making full use of the graphical capabilities. Simulations described here have been used to evaluate expansion and development options. The results have helped assess the effect on product quality for many processing and equipment options for capacity expansion.

2 THE PRODUCTION SYSTEM

The Pilbara produces about 200 million tones of iron ore per year, sold as two product types; lump (6 to 31mm) and fines (under 6mm). Increased demand for iron ore, mainly by China, requires producers to increase tonnage, by upgrading existing mines and opening new mines. Assessment requires informed choices between alternative modes of operation and development, which differ greatly in expected capital and operating costs. Reviewing the many options that exist is complex, and greatly aided by simulation. This paper describes simulations carried out to assess product grade quality for potential expansion developments. Simulations were based on proposed infrastructure and capacity options identified from engineering studies. They were set up so the impact of changes to operating practices on product grade quality could also be assessed.

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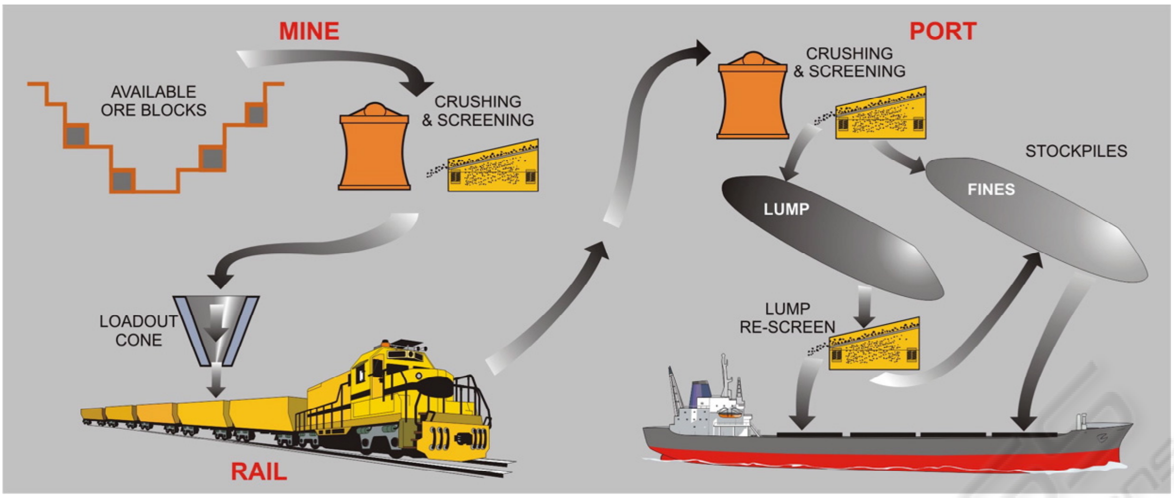


Figure 1: A Typical Iron Ore Production System.

2.1 Production Flow

At the mine, monthly mine plans are designed for cost efficient use of the resource. Ore blocks are blasted and assigned into floor stocks of consistent geology and composition using analysis from samples taken during the drilling of the blast holes. Each day, ore to mine is selected from floor stocks, based on target grade, current deviation from target, and cost efficient mine development. In our example, ore from four mines goes 400 kilometres to the port to be crushed, screened into lump and fines products and blended by stacking onto 150 kilotonne stockpiles. Ore from completed stockpiles is reclaimed, loaded onto ships, and transported to customers. Everett (1996, 2001) discusses iron ore quality control. Kamperman et al (2002) describe application of the methods to a Pilbara operation.

2.2 The Cost of Quality

The objective is to deliver the required ore tonnage, at minimum total cost and of quality acceptable to the customer. Quality is based on iron content and the percentage of impurities such as phosphorus, silica and alumina. There are two key criteria: cargo grade and inter-cargo variability. Customers require each shipment to be close to target composition. Agreed tolerances are used to guide decisions, throughout the production process. Excessive inter-cargo variation potentially affects price and sales tonnages. This cost, containing an element of risk, is hard to evaluate quantitatively. Blending and re-handling to improve uniformity adds to operating cost, a potential trade off against quality.

3 SIMULATION METHODS

Expansion options were developed, for alternative production and handling concepts from mine to ship loading. Their quality implications were evaluated by simulation. Long-term grade variability (> one month) is controlled by the mine plan. Short-term inter-cargo variability is controlled by the operational process, and is the assessment metric.

3.1 Data Preparation

Production data show complex serial and cross correlation (for iron, silica, alumina and phosphorus) that is ascribed to the orderly mining of blast blocks and the daily decisions to control grade.

Historic data were used to generate the required input data for modelling future mining production in the simulations, so that the existing serial and cross correlations were maintained. However, historic data contained long-term variation that could mask any incremental improvements identified in the simulations; planned new mines lacked historic data, and had expected means grades differing from existing mines.

Synthetic data for new mines were created from existing mines of similar geology. Long-term trends were filtered out using Fourier analysis. Means and standard deviations were then adjusted to create synthetic data matching planned production. The data preparation model allowed the standard deviation to be reduced, simulating increased effort within the mine to control short-term variability, through such activities as selective mining and pre-crusher stockpiling.

4 SIMULATION MODELS

Dedicated simulation packages need specialists to run and interpret the results, usually with cost and licensing restrictions. They represent a barrier to practitioners who must learn a new package if they are to run the models independently.

Developing the system in Excel^{TM} allowed mining engineers and operators to explore alternative policies and scenarios, using domain knowledge unavailable to the designer of the simulation model. Graphing and analysing of results was built in, so minimal ongoing assistance was required from the simulation provider.

Constructing a simulation model in a spreadsheet workbook, run by VBA macros, is as easy as in a dedicated simulation package. The spreadsheet's data input and output reporting and graphing capabilities are fuller than are generally found in a simulation package. The industry user, familiar with spreadsheets and their potential, can suggest improvements to the simulation model. The VBA macro coding is hidden from the practitioner, who can use it by means of inbuilt buttons and menus.

The simulation model comprised three VBA macros: reading in parameters to set up the simulation; running the simulation the required number of time periods, and finally using Excel's statistical and graphing power to report the results.

The models were used to study the effects of controllable variables (such as stockpile sizes and stockpiling methods) and uncontrollable variables (such as cargo sizes). The worksheets specified parameters and policy choices, displayed simulation progress, and reported and graphed a performance summary for any simulation run. For reproducible results, a year or more of production had to be simulated.

The simulation was time-sliced (at six hour intervals) rather than event-driven. In each time interval, ore is mined and trains loaded, while at the port trains arrive and are unloaded, crushed and stacked to stockpiles, ships can arrive, commence being loaded from an available stockpile (or wait if none are available) continue being loaded, and depart when full. Simulations were run to explore the effect of steadily changing the values of a particular parameter, or a set of parameters.

Separate workbook models were written to simulate the Mine and Port operations. They could be run individually, or be run together by a Master model, for a sequence of scenarios. Space limitation limits discussion here to the Port model.

5 PORT MODEL EXAMPLE

The Port model has six worksheets, simulating stack and reclaim of ore from train to ship.

The "Input Rakes" sheet imports a set of 2,048 train rakes from the "Output" sheet of the Mine model file. Incoming trains are from either of two pits that have systematically different mean grade, to reflect planned trends in mining.

Figure 2 shows the Port "Specify" sheet. Settable parameters are in yellow cells. In the example, the ore arrives at 40 million tonnes per year, with a train every six hours (generated in the Mine model). This model explores a plan of up to four ship berths, with each berth fed from a stockpile of nominated capacity. Stockpiles can be fully Blended in Blended Out (BIBO) or built First In First Out (FIFO). Stockpile sizes are here set 240kt and 360kt. Train and ship arrivals be equally spaced or random. The cargo capacities distribution is specified. Each incoming train can be direct loaded (with chosen probability) to a ship, or sent to a stockpile, chosen by a weighted composite of four criteria.

A "Progress" worksheet allows the system to be tracked, at a chosen multiple of 6 hours, for a chosen time range. This is useful for debugging, and also for better understanding the system behaviour.

For each mineral, the "Cargoes" worksheet graphs the cargo compositions varying around target. For example, Figure 2 shows that the "Process Capability" (the Tolerance divided by twice the Standard Deviation) for Fe is 1.15.

The "Audit" worksheet reports the full simulation history, with product flows and stockpile and ship berth states for each time interval. Tonnage aspects of the simulation history are plotted to aid interpretation, and validate the parameter values selected on a particular run.

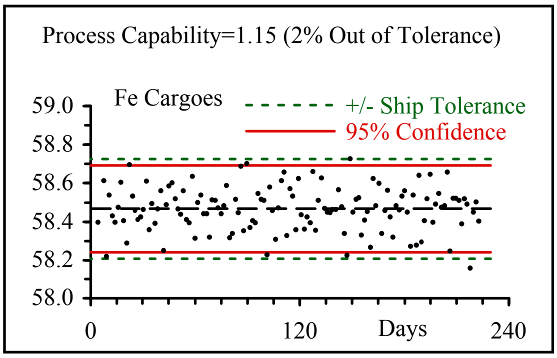
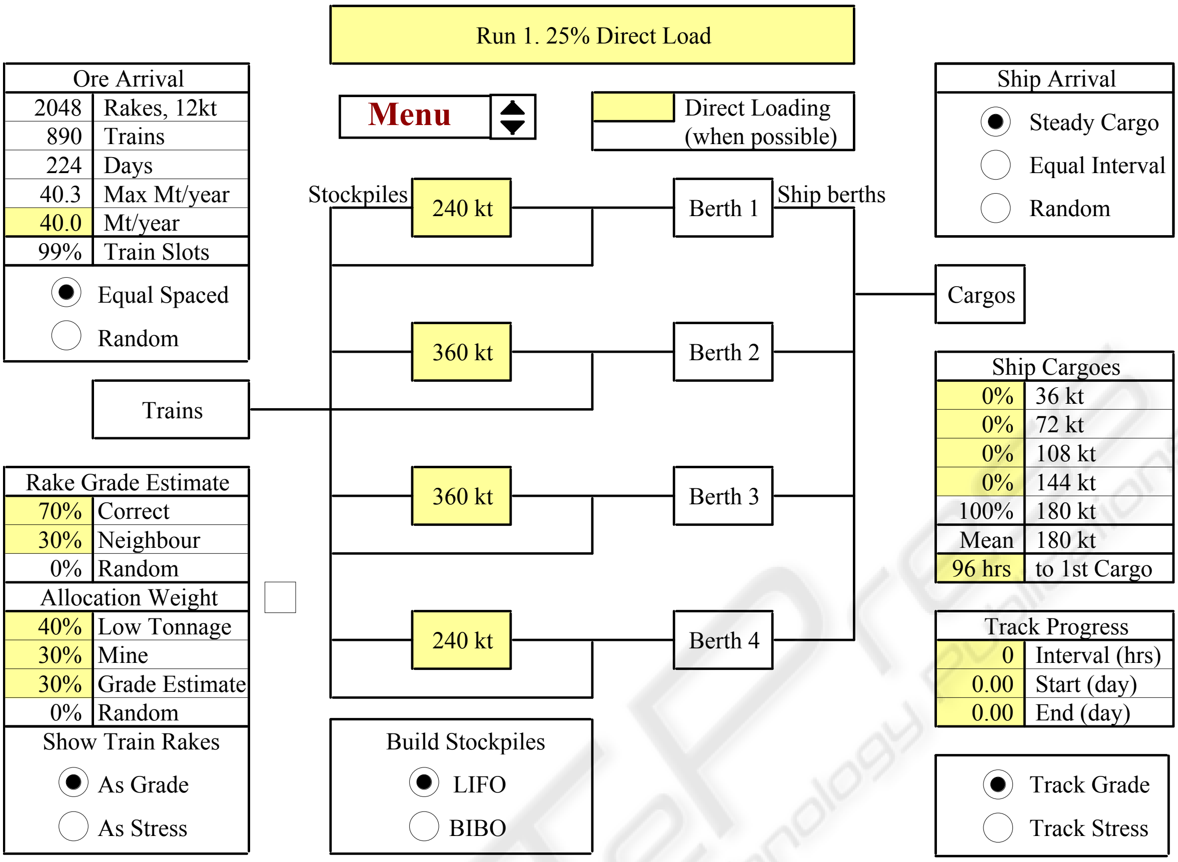


Figure 2: The "Cargoes" Report.



Run 1. 25% Direct Load

Ore Arrival	
2048	Rakes, 12kt
890	Trains
224	Days
40.3	Max Mt/year
40.0	Mt/year
99%	Train Slots

● Equal Spaced
○ Random

Rake Grade Estimate	
70%	Correct
30%	Neighbour
0%	Random
Allocation Weight	
40%	Low Tonnage
30%	Mine
30%	Grade Estimate
0%	Random

Show Train Rakes
● As Grade
○ As Stress

Build Stockpiles
● LIFO
○ BIBO

Ship Arrival
● Steady Cargo
○ Equal Interval
○ Random

Ship Cargoes	
0%	36 kt
0%	72 kt
0%	108 kt
0%	144 kt
100%	180 kt
Mean	180 kt
96 hrs	to 1st Cargo

Track Progress	
0	Interval (hrs)
0.00	Start (day)
0.00	End (day)

● Track Grade
○ Track Stress

Figure 3: The Port Model "Specify" Worksheet.

6 CONCLUSIONS

As an example of the results, one simulation run showed that to ship ore of acceptable quality at the planned production rate required
1) 10% reduction of Mine short-term variability by selective mining or pre-crusher stockpiling.
2) 30% priority to the use of Intelligent Stacking.
3) More accurate train composition estimates.

This solution was compared to installing blending stockpiles at the mine and a cost/quality risk analysis carried out. Without the simulation studies, many capacity-related options such as this would have been virtually impossible to evaluate.

The simulation models described are a valuable aid to examine the effect on product chemical quality of alternative potential development options, to meet the potential capacity expansion required for the rapidly increasing iron ore market.

The particular benefit in using Excel™ based VBA simulation models is that it provides a familiar mode of working for the company personnel, enabling them efficiently to contribute domain knowledge during running of the simulations, without the assistance of the simulation developer. In addition, the use of ExcelTM allows easy interrogation of data and generation of reports.

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