DOI: 10.1515/orga-2015-0014

DE GRUYTER OPEN

A Statistical Model for Shutdowns due to Air Quality Control for a Copper Production Decision Support System

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Background: In the mid-1990s, a decision support system for copper production was developed for one of the largest mining companies in Australia. The research was conducted by scientists from the largest Australian research center and involved the use of simulation to analyze options to increase production of a copper production facility.
Objectives: We describe a statistical model for shutdowns due to air quality control and some of the data analysis conducted during the simulation project. We point to the fact that the simulation was a sophisticated exercise that consisted of many modules and the statistical model for shutdowns was essential for valid simulation runs.
Method: The statistical model made use of a full year of data on daily downtimes and used a combination of techniques to generate replications of the data.
Results: The study was conducted with a high level of cooperation between the scientists and the mining company. This contributed to the development of accurate estimates for input into a support system with an EXCEL based interface.
Conclusion: The environmental conditions affected greatly the operations of the production facility. A good statistical model was essential for the successful simulation and the high budget expansion decision that ensued.

Keywords: *decision support system, simulation, statistical modelling*

1 Introduction

Welgama et al. (1996a) describe a major study conducted for Mount Isa Mines Pty. Ltd. Mount Isa Mines is one of the biggest mining operations in Australia (Mount Isa Mines, 2015). The study involved the use of simulation to analyze options to increase production of a copper production facility. Mount Isa Mines is one of Australia largest underground mines. Mount Isa Mines Limited (MIM) operates the Mount Isa copper, lead, zinc and silver mines near Mount Isa, Queensland, Australia as part of the Glencore Xstrata group of companies. For a brief period in 1980, MIM was Australia's largest company (Wikipedia, 2015). In 1992, MIM commissioned an ISASMELT™ furnace in the Mount Isa copper smelter to treat 104 tons/hour of concentrate containing 180,000 tons/year of copper (Arthur and Hunt, 2005). The throughput was initially constrained because MIM chose to keep one of the two reverberatory furnaces operating and the converters became a bottleneck. The ISASMELT™ plant's throughput had to be restrained to allow enough material to flow through the reverberatory furnace to prevent the matte freezing in the bottom of the furnace.

It was decided in 1997 to shut down the fluidized bed roaster and the reverberatory furnace, and the ISASMELT™ furnace throughput was boosted to more than 160 tons/hour of concentrates by the addition of a fourth Peirce-Smith converter (Player, 1998) and a second oxygen plant (Arthur and Hunt, 2005). The simulation described in Welgama et al. (1996a) provided support for the major expansion decision of MIM. The simulation study involved a detailed and accurate model capturing the factors affecting production and material handling. A decision support system with an Excel interface was developed (Welgama

Received: March 12, 2015; revised: June 22, 2015; accepted; July 2, 2015

et al., 1995). The analysis using the developed software resulted in supporting a decision for a $92M investment to achieve the increase in throughput.

2 The Simulation Model

Welgama et al. (1995), Welgama et al. (1996a) and Welgama et al. (1996b) describe in details the simulation study jointly conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Mount Isa Mines Limited. A detailed and accurate simulation model was developed capturing the factors affecting copper production and materials handling. The study resulted in a SIMAN/ARENA based software support system with an Excel interface (Welgama et al., 1995). About 40 different parameters were included in the Excel spreadsheet which provides a user interface to the simulation model. The user can change these parameter values and conduct experiments. Validation was carried out using known scenarios. The production process modeled can be summarized as follows. In the first phase, ore is processed to produce chalcopyrite concentrate ('cons') which contains about 26% of copper. The second phase process this 'cons' further to produce anode copper, in a copper smelter aisle. The study focused on the second phase. Figure 1 shows the MIM copper production process in this second phase.

The copper smelter aisle consists of two primary smelters, called ISASMELT and fluo-solids roaster (FSR), three converters, two anode furnaces and a casting wheel. ISASMELT and FSR produce matte which contains about 56% of copper from cons. Converters produce blister copper which contains about 97% copper, from matte. Anode furnaces produce anode copper from blister copper. Casting wheel produces anodes, which are copper plates weighing 350kg, from anode copper. Smelters, converters and anode furnaces produce exhaust gas, which contains sulphur dioxide, and slag which contains iron, silica and lime. Material transfer between processing units is done by two overhead bridge cranes operating on the aisle. The production system runs 24 hours a day. Primary smelters operate continuously. Each smelter has a matte storage facility attached to it. Converters and anode furnaces operate in batch modes and have operating cycles. Converters are the key element in this copper production system. They pull matte from primary smelters and push blister copper to anode furnaces.

The objective of the study was to evaluate various options to increase copper production by developing a simulation model of the current operations of the copper smelter aisle, considering the uncertainties of the system, such as breakdowns and other forms of shutdowns.

A number of simulation modules covering matte production by primary smelters through to the production of anodes were developed. Modelling was done using the SIMAN simulation language (Pegden et al., 1990; System Modelling Corporation, 1993). Converter operations were modelled in great detail. The full converter cycle was modelled using the rules actually followed in the plant. Converter blow times were calculated using a formula derived by MIM from historical data. Considerable effort was spent in modelling the movements of the two overhead cranes which operate on the same aisle performing all the materials handling tasks.

The special routings available in SIMAN to model automatic guided vehicles were used to model these crane movements accurately avoiding collisions. Both full and empty pot movements were modelled. Crane speeds, distances, loading and unloading times, waiting times and speed changes when travelling across the aisle were also considered. The situation where only one crane is operating while the other crane undergoes repairs or maintenance was also modelled (Welgama et al., 1996a). All downtimes were analyzed and modelled. In addition to downtimes of various processes, matte grades contribute to randomness in the model output. The output values of primary interest are the throughput, copper removal time per converter charge, crane utilization and the percentage stack time, which indicates the time contributed to the production. Animation screens were developed for the purpose of debugging and verification, validation and final presentation. About 40 different parameters were included in an EXCEL spreadsheet which provides a user interface to the simulation model. The user can change these parameter values and conduct experiments.

During the study, vast amounts of failure and maintenance data were collected. Information on time between failures and durations of downtimes was extracted from the data and fitted to probability distributions. Expert opinions were used to improve the estimates of parameters. Expert opinions and past data were also used to represent planned maintenance activities of each process. Plant shutdowns due to environmental considerations were modelled using statistical analysis. The statistical work was described in Welgama et al. (1996b) for most processes involved in the production of copper. In this article, we describe in more

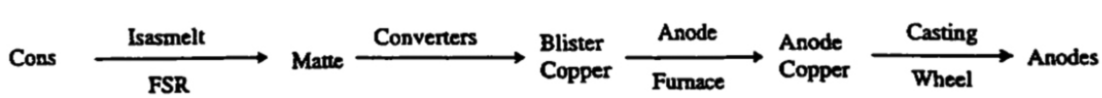

Figure 1: Production process of copper anodes (Welgama et al., 1996b)

details the statistical model built to reproduce shutdowns due to air quality control. The model made use of a full year of data on daily downtimes and used a combination of techniques to generate replications of the data. We also show how an adequate use of expert opinion solved a maintenance data problem and allowed a successful simulation.

3 Statistical Model for Air Quality Shutdowns

Downtimes were caused by planned maintenance shutdowns, breakdowns and environmental effects called air quality control (AQC). When the wind direction changed towards the nearby city, the primary smelters and converters had to be shut down because their exhaust gas contained sulphur dioxide and other air pollutants. A statistical model for AQC Shutdowns was used as an input in the simulation study that generated all related shutdowns which basically amounted to the shutdown of the plant. In this section, we reproduce the statistical model and illustrate with some figures.

As seen in Figure 2, the shutdowns due to AQC followed each other in a random pattern and had durations that followed a seasonal pattern. The ticks on the x-axis of Figure 2 show some pattern of days in the year when there is an AQC shutdown. In essence, they form an arrival process. In one of the days of AQC shutdown in Figure 2, the duration of the shutdown is shown with a vertical line. The curve in the figure shows an approximately sketched theoretical average daily duration. That theoretical average is clearly showing a seasonal effect as the AQC daily shutdown duration grows during the year then diminishes. The data provided estimates of the maximum daily shutdown durations in minutes, along with minimums, illustrated in Figure 2 by a width window.

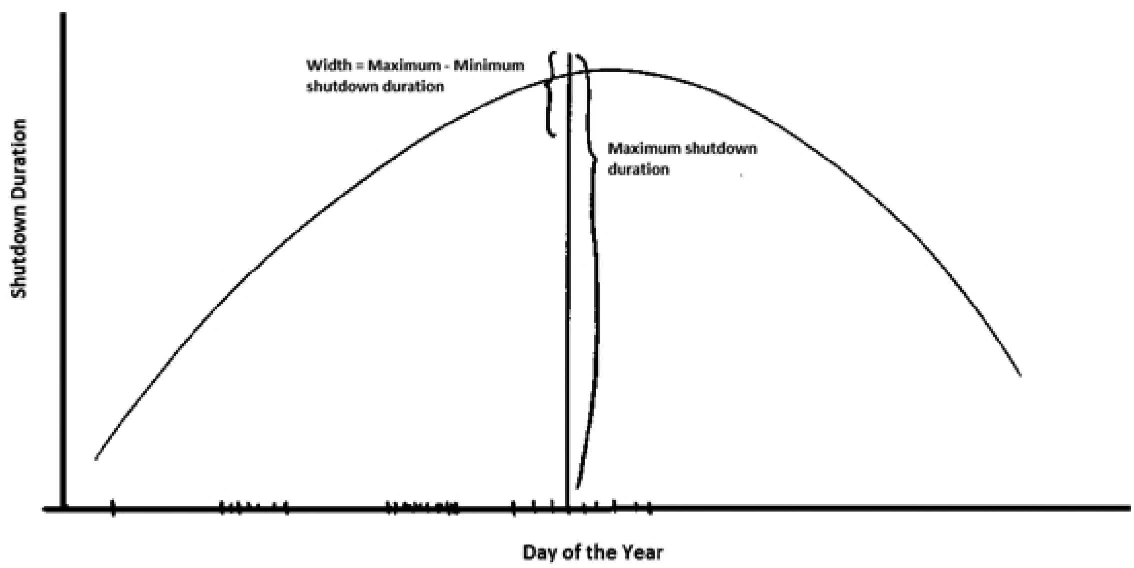

Figure 2: Statistical model for shutdowns due to air quality control

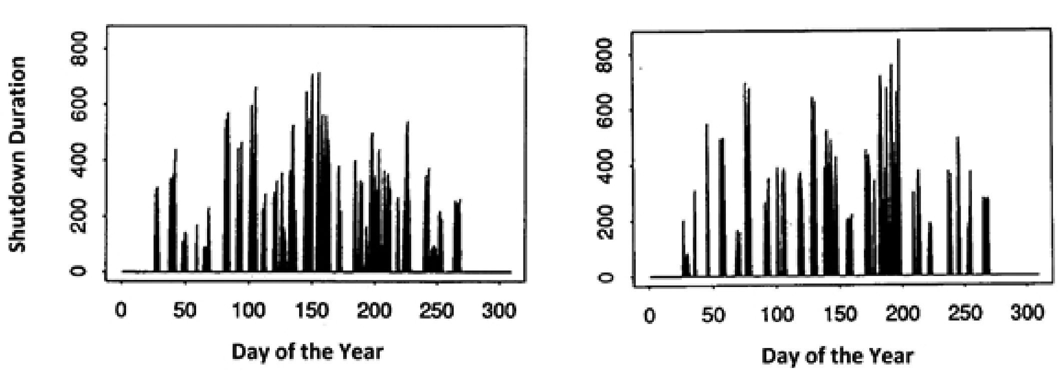

Figure 3: Two independent reproduced shutdowns durations (in minutes) due to AQC for each day of the year

The statistical model used a combined linear regression model using a quadratic mean compounded on the arrival process to generate replications of the data. The arrival process of shutdowns was studied using the data and modeled. Then, upon the occurrence of a shutdown, a magnitude was modeled using a maximum and a minimum value that were regressed on the time of the year using a quadratic formulation. The full statistical model was validated using standard techniques. Figure 3 shows two independent simulation run of replicated data of shutdowns durations (in minutes) due to Air Quality Control for each day of the year. They displayed a strong statistical resemblance to the original data.

Although seemingly simple, the model managed to reproduce the AQC shutdowns. In each run of the simulation, a new AQC set of data was generated that statistically resembled the real scenario. This part of the study was essential as the shutdowns of the plant affected greatly the output. From a simulation point of view, considerable time and effort was spent to establish the model's validity. In the process of validation some of the following techniques discussed in Sargent (1984) were used. The model was used initially to generate and compare several scenarios. Further experiments were made for one scenario with different values of parameters. In all cases the throughput, converter holding times, times that anode furnaces were waiting on blister copper, and times that converters were waiting on matte were recorded and compared. But it remained to run the model under realistic condition of shutdowns due to Air Quality Control. The above statistical model provided an adequate input to the simulation model therefore validating the simulation results.

4 Expert Opinion in Maintenance

In the simulation study, a set of twenty-seven computer data files were provided by MIM. The data files were large and contained information for a one-year period about the sequencing of operations, the downtimes of the various processes, the durations of downtimes, shutdowns due to air quality control and the maintenance of some processes. The first job was to extract information from the maintenance records for input into the simulation model. At first, the records seemed to indicate patterns of maintenance suitable for use in the model. However, a closer look at the data revealed that a change of maintenance policy had taken place for one particular process. The purpose of the simulation was to optimize return on future investment. Therefore the maintenance policies used in the simulation needed to reflect likely future maintenance strategies. It would not have been adequate to make the simulation perform like the data provided if that was not indicative of the future.

At the next meeting with the company, the scientists discussed the maintenance policy for the process in question. It turned out that the maintenance policy had been changed during the period of data collection. Following some renovation, a cautious strategy of preventive maintenance shutdowns had been followed. The maintenance intensity had been gradually relaxed to more steady campaign intervals. In order to make their simulation relevant to the future, the analysts asked the company's technical staff to indicate what maintenance strategy they planned to use in the future. Details of the intended maintenance strategy were used in the simulation model rather than using that derived from the data. Had they not queried the relevance and consistency of the data, the estimates from the simulation model would not have reflected the intended maintenance strategy.

The simulation project involved a large number of daily operational details. A pragmatic approach to the availability of data was essential for completing the simulation study on time. However, even having been provided with masses of data, the analysts still found it necessary to sit down with technical staff and extract further information. In this example, the data were telling only part of the story and, for some purposes, that was enough. But in some cases, the data are telling only part of the story. Confronted with masses of data, many tend to forget to ask themselves whether they have enough or even the right kind of information.

For some purposes, it may be necessary to seek further information from knowledgeable operators and it may be necessary to ignore certain parts of the data. This part of the project was also an essential contribution. Simulation studies usually tackle complex systems that are hard to understand on an intuitive level. If an important input to the simulation model is mishandled, the model may still be validated if the runs ignore the effect of the mishandled input. This can lead to erroneous results when more runs are made in different scenarios. It is imperative that great care be given to the modeling of all inputs to the simulation. As described in this section, this potential fault was avoided because of the close collaboration between the CSIRO analysts and the MIM clients.

5 Conclusions

The Process Development Manager of the company MIM stated that "The SIMAN model of the copper smelter aisle has been used extensively for comparing options for expanding the aisle throughput, and identifying bottlenecks. This is the first model of the aisle with which we feel confident of extrapolating aisle performance". MIM investigated a large number of scenarios. A presentation of the model was made and the animation was shown to the MIM personnel including crane drivers, foremen, engineers and managers. The presentation generated a wide acceptance of the validity and usefulness of the model. The simulation model was used successfully to expand the plant through a major financial investment. The study clearly demonstrated the usefulness of a detailed simulation model for making facilities planning decisions in modern complex manufacturing systems. The stochastic aspect of a real-world large scale simulation using discrete events is very important. Without proper modelling of all random processes, the simulation results can be erroneous.

We mentioned two models, one for environmental modelling which was vital to the simulation and the other an expert opinion elicitation procedure that corrected some maintenance records essential to the validity of the simulation model. A lot of effort was devoted to the simulation programming by Welgama et al. (1996). The authors welcomed the statistical model for AQC shutdowns with enthusiasm, realizing fully that the simulation model would not be effective without a validated AQC shutdowns input into the model. All validations were done in joint work with the MIM managers.

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