

# Modeling of Aluminum Tapping Operational Management to Enhance Smelter Productivity

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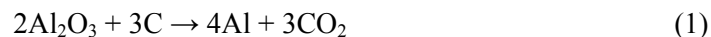
## Abstract

A good planning and control of the operations involved in a smelter is crucial for achieving a high-level of performance and productivity for the plant. Given the large number of processes involved in a smelter, as well as their complexity and interrelationships, it is far from trivial to evaluate the actual operational impacts of changes to the cell amperage, work organization and schedules, equipment capacities and replacement, the layout, etc. In the present work, a simulation model based on the discrete event method is developed to analyze the operations management related to the tapping of aluminum from the electrolysis cells. The inputs to the model are the plant layout, the work schedule, the travel and process times, the availability and the capacity of the equipment such as crucibles, cranes, etc., and the list of required cells to be tapped, based on the cast house requirements. The model was validated with plant data. Results of the simulation include the details of all operations performed within a 24 hour period and the time at which they were completed. The simulation also provides information such as the idle times of equipment and workers, and the operational incapacity to respect the planning, if applicable. The simulation model proposed can therefore be viewed as a powerful tool to test different scenarios and guide towards profitable short-term and long-term planning decisions.

**Keywords:** Planning and control of operations; aluminum electrolysis cell tapping; discrete event simulation; amperage creep.

## 1. Introduction

Primary production of aluminum is a highly competitive sector. One of the main issues for this industry is to constantly increase its production. Smelters have been relying for over a century on the Hall-Héroult process to transform alumina into aluminum according to the well-known overall reaction in Equation (1):



This reaction takes place in the electrolysis cells and requires an important electric current. In order to increase their production, smelters need to creep the current.

However, changing the production rate from the electrolysis cells affects all related operations. For example, carbon anodes are consumed faster and therefore, need to be replaced more

frequently. Similarly, operations such as aluminum tapping, beam lifting, and addition of bath and  $\text{AlF}_3$  may be needed at a different frequency. As these tasks involve several workers and pieces of equipment with different requirements and constraints, the modification to the planning and control of operations can become difficult to evaluate. Therefore, before implementing amperage creeping in a smelter, it becomes interesting to study its impacts on all the operations.

In fact, whenever smelters modify their technologies, face significant changes from their suppliers or deal with variable demands, they typically need to adapt the planning and control of their operations. There is thus a need to develop and exploit systematic simulation tools to better support operational management.

Among the first published analytical models for planning and management of technical and economic changes in the aluminum industry was that of Nicholls *et al.* [1] which was implemented in a Portland smelter. Later, Tuck [2] proposed an optimization approach of the aluminum tapping. He applied the cell batching problem to the New Zealand Aluminium Smelter (NZAS) at Tiwai Point. Ryan [3] and Piehl [4] mentioned that this problem could be solved more easily by a set partitioning problem (SPP) approach. Voorhis *et al.* developed a software based on the Branch-and-Bound method to generate the optimal casting planning in smelter's cast house [5]. However, they concluded that without a simulation program, it was impossible to make a decision while considering all applicable constraints. Finally, again for optimizing production, Duman *et al.* developed a multiobjective ant colony optimization metaheuristics in order to schedule the continuous production of aluminum [6].

This body of work on mathematical modeling of operations management adapted to primary aluminum production has paved the way to the development and exploitation of systematic tools for operational management. However, as mentioned by Harton, up to now, *“these models have not been able to model the complex real world constraints. The only way to truly do this is through an aluminium smelter simulation. [7]”*

Harton simulated metal flows in a smelter [7]. He claimed that improving the management of metal fluxes provides an opportunity to increase revenues without altering the main production process. The objective in his approach was to use more efficiently the available resources in order to produce the most profitable metal grade for the smelter. His simulations showed how the decisions affect the overall efficiency of the system and their impacts in the smelter.

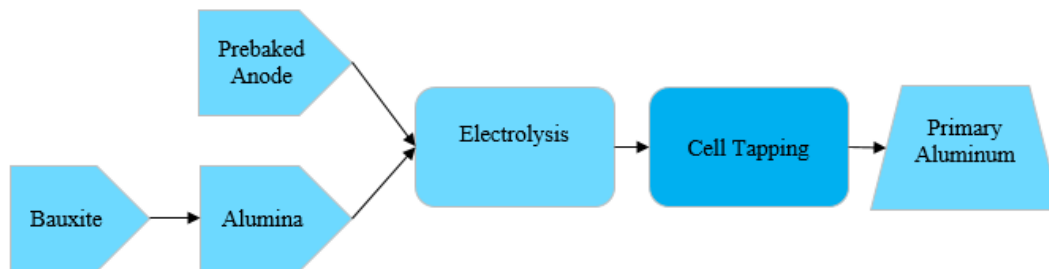
Given the advent of the lean manufacturing concept, Meijer explained that the development of simulation models adapted for operations management in smelters should be given more attention, because it represents an important solution to reducing costs: *“Combining discrete modeling with the advanced models of cell simulation open up a new area of research in which the material flow can be optimized, towards the need of the individual cell. Since anode changing and metal tapping are important parameters that influence the stability of a cell, such an attempt can create a more efficient use of assets and higher productivity of the smelter”* [8].

Recently, Eick *et al.* [9] used a dynamic logistic simulation model to aid the planning of potroom activities, traffic flows, and logistic equipment needed for a smelter expansion project. They used the software POSES++, a modeling and simulation environment for discrete event systems with applications in the fields of logistics, communication systems, hardware design, and algorithms validation. He concluded that the simulation is a visual tool that can predict the reality with reasonable accuracy.

The work presented in this paper is in line with that of Eick *et al* [9]. Simulation is used to observe operational changes brought by amperage creeping on the tapping. In particular, with the help of the software Simio, a discrete event model is proposed to simulate the tapping operation in a specific smelter. The model being validated with real data from the smelter, it was then used to simulate different scenarios.

## 2. Simulation Modeling

Several steps are required in the primary aluminum production as summarized in Figure 1. This paper is oriented on one of the crucial operations, namely the tapping. Tapping needs to be carefully planned and executed so as to provide the right amount and grade of aluminum at the right time.



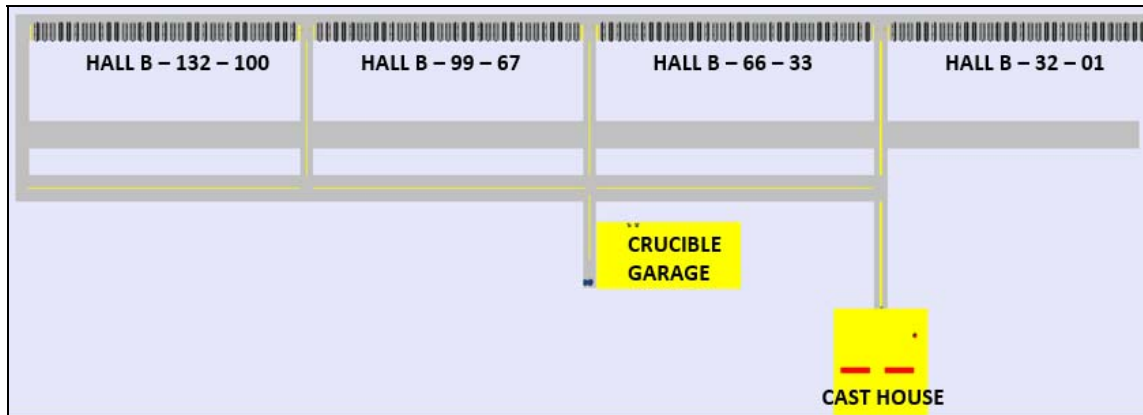
**Figure 1. Schematic representation of the main steps for primary production of aluminum.**

### 2.1 Discrete event simulation model

In order to take all the significant elements required to represent the current reality into account, a dynamic simulation tool was used to analyze the production system. In fact, simulation allows replicating reliably the operations performed on a real system. It can then be used as an analysis and prediction tool.

Since the system studied in this paper is constantly changing in time, one needs to use a dynamic simulation approach. The software Simio (*Simulation modeling framework based on intelligent objects*) was used because it is a tool for building and executing dynamic models of systems so that one can see how they perform [10]. This technique allows changing the model to test ideas without disrupting the real system. It relies on the discrete-event method. With this technique, the simulation engine advances from one event to the next, and recalculates the state of the system after each event. In the context of a smelter, the events are the different operations that have been included in the model. In the present work, the focus is on the different operations related to aluminum tapping, i.e. preparation of the crucible, transport and filling of crucibles and the casting of aluminum.

It is important to delineate the environment and boundaries of the system under study to support the assumptions on which the model relies. The test case that was considered is the Alcoa Deschambault (ADQ) smelter (Quebec, Canada). In order to focus on the tapping operation, the layout of the smelter was reproduced. Only one potroom with its 132 pots was included in the model, with the proper transportation pathways for crucibles, as shown in Figure 2.



**Figure 2. Layout of the potroom in the model.**

The simulation begins with a transporter who brings an empty crucible from the crucible garage to a waiting station (A) in the potroom. Based on the purchase order forms from the cast house, an employee picks up the empty crucible from the waiting station with a crane, and brings it successively in front of the different pots included in the order forms to tap a specified amount of aluminum. The employee then transports the filled crucible to another waiting station (B). The transporter brings a new empty crucible to the waiting zone (A) and brings the filled crucible from the waiting station (B) to the cast house.

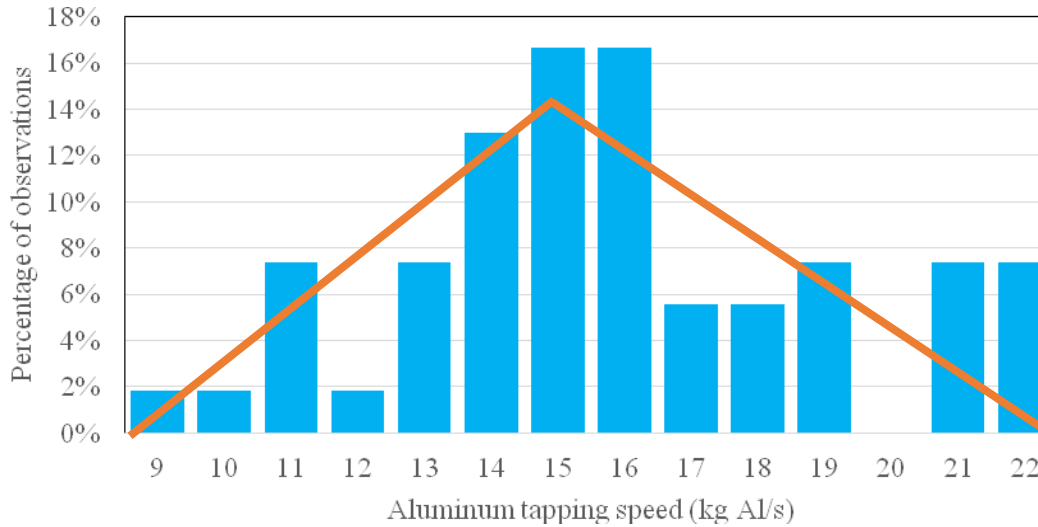
As described below, probabilistic laws were used to characterize some operations. As a result, running two simulations with the same setting can lead to two different sets of results. Therefore, for each case studied, the model was run 25 times with a confidence level of 95% to achieve a good estimate of the average scenario and relevant statistical data. It should be noted that a warm up period of 1 day, over which the results are not considered, was used. This creates realistic initial conditions for the model in the context of a dynamic environment. After the warm-up, the model was run for 1 day.

In the end, the simulation can provide the detailed information regarding the time required to perform each operation in the different scenarios, the idle times for employees and equipment, etc.

## **2.2 Observations and probability distributions**

A series of observations in the plant concerning the tapping operation was carried out. It consisted in measuring the time required to perform each operation. The following times were measured: (i) transportation time of the crucible by the potroom crane from one point to the next, (ii) set-up time required to install the empty crucible from the waiting zone (A) to the crane, (iii) tapping time required to extract the specified amount of aluminum, (iv) set-up time required to remove the crucible from the crane and put it in the waiting zone (B).

It is important to note that several sources of variability can affect these times in the smelter (e.g., experience of operators, obstruction in the crucible, orders from the cast house, etc.). Based on the observations, statistical laws were used to include the variance of the measured times in the simulation. Triangular laws were chosen to represent the collected observations. An example of observed times is presented in Figure 3 and compared with the triangular law that was used.



**Figure 3. Probability of occurrence for the different tapping rates (kg Al/s) during the observation period versus the triangular probabilistic law in the model.**

At this point, the model considers an ideal environment, and does not include any equipment failure rate. Also, the speed and the movement logic of the transporter provided by the smelter are considered constant.

### 2.3 Validation

The model was validated by simulating situations observed in the plant. Table 1 shows the simulated times required to process different crucibles and the actual times that were observed in the plant. It can be seen that the differences between the two times are smaller than 3.83 minutes, which was considered as acceptable by the smelter.

**Table 1. Simulated and observed times to process different crucibles.**

Crucible	A	B	C	D	E	F	G	H
Average simulated time (minutes)	27.15	26.83	23.98	20.59	21.15	24.26	27.03	24.30
Observed time (minutes)	30	23	21	19	24	24	26	25
Difference (minutes)	2.85	3.83	2.98	1.59	2.85	0.26	1.03	0.7

## 3. Scenarios and Results

### 3.1 Scenario 1

In order to obtain reference values against which the next scenarios would be compared, the first scenario consisted in replicating the tapping operations during a 24 hour period at ADQ. This scenario was similar to the one used for the validation (Section 2.3). However, the simulated period was longer, and most importantly, the work schedules were included in the model. As a result, no aluminum was tapped during changes of shift and during breaks, which is closer to the reality experienced in the smelter.

For this simulation, the real tapping planning of a typical day was used as an input to the model. Currently, the smelter performs its planning to achieve a selective casting, i.e. aluminum is tapped as a function of the grade desired at the cast house. As a result, even though all cells will eventually be tapped, the order in which each cell is tapped can be quite variable. For the simulation, this order was given beforehand for each crucible. The model then executed the tasks that were requested while respecting constraints such as the work schedules, and kept track of all resulting operations/events. Again, the model was run 25 times to achieve a good estimate of the average scenario and relevant statistical data.

Results showed that all the tapping orders planned were executed successfully within a 24 hour period. This was expected since the orders corresponded to the current plant situation. The model indicated that the daily tapping was performed in 18h20 on average, see Figure 4. This left an approximate time of 5:40 h (excluding break times) to face real-life problems that the model does not take into account. For example, it should be noted that the model does not include constraints related to the cast house or the time required for the maintenance of equipment. However, the results of this first scenario provide a good reference for the next scenarios discussed below.

### **3.2 Scenario 2**

In the second scenario, the smelter wanted to study the overall impact in terms of planning and control of operations of a sequential tapping compared to a selective one as considered in Scenario 1 (Section 3.1). In this case, the order in which the cells are tapped would therefore be that of the cell numbers. In other words, the operator taps cells as a function of their position in the potroom rather than as a function of aluminum grades.

For this simulation, the inputs to the model were modified compared to scenario 1. The cells were tapped in the ascending order of their position, i.e.: 001, 002, ..., 132. However, it must be verified that the amount of aluminum in the crucible never becomes superior to its maximal capacity. This rule determines the number of cells to tap per crucible. Again, the model was run 25 times with a confidence level of 95 %.

With this approach, the total traveled distance of the crucibles diminished significantly. As a result, the total time required to perform the requested operations also decreased. As shown in Figure 4, the simulation revealed that the required time to fulfil the sequential planning was approximately 16:30 h, i.e. 9.8 % less than in the first scenario.

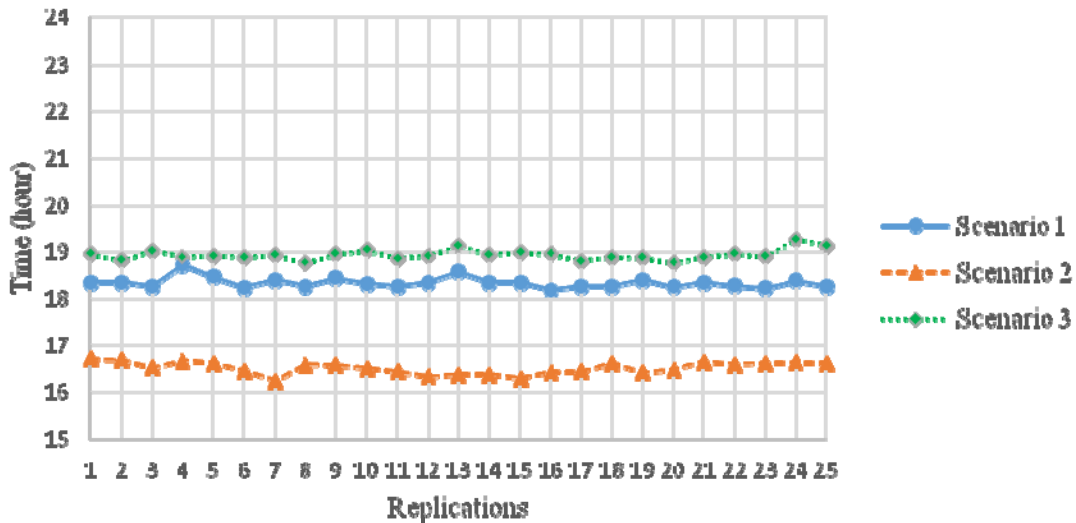
This scenario quantifies the effort added to the tapping to function under a selective planning versus a sequential planning. Nevertheless, scenario 2 would probably move the effort burden to the cast house. Specifically, to produce the desired grades, the cast house would need to perform more operations and potentially use more pieces of equipment. Nevertheless, scenarios 1 and 2 can help to evaluate the current tapping planning. The smaller the difference between the two scenarios the better the selective tapping planning. Scenario 2 can thus be seen as a tool to evaluate the planning efficiency.

### **3.3 Scenario 3**

The third scenario studied evaluated the consequences of a 5 % increase of the production rate (i.e. amperage creep). Therefore, more aluminum needed to be collected in each cell, which had a direct impact on the operations.

The inputs of the model were again modified to simulate this scenario properly. The selective planning of scenario 1 was used, but the amount of aluminum to be tapped in each cell was increased by 5 %. Furthermore, to respect the maximal capacity of the crucibles, more of them were required. Again, the model was run 25 times with a confidence level of 95 %.

One of the most important issues in this scenario was whether the plant could actually support the amperage creep with its current equipment from an operational standpoint. The simulation showed that it was possible to execute all requested tapping operations within the allocated time. The required time to perform the tapping was approximately 19 h, as shown in Figure 4. This represents an increase of 40 minutes compared to scenario 1.



**Figure 4. Ending time of the 25 replications for scenarios 1, 2 and 3.**

#### 4 Conclusions

In this article, a simulation model was developed under Simio to analyze the tapping operations at the Alcoa Deschambault smelter. The simulation includes the operations required to perform the daily tapping of a potroom of 132 cells. The simulation model developed allowed analyzing the impacts of different changes to the planning and control of the tapping, such as amperage creep, new working schedules, or equipment capacities.

Future work will focus on including in the model other operations in the potroom, such as anode change, while investigating the impact of equipment failure.

#### 5 Acknowledgements

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