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SIMULATION TOOLS TO COMPLEMENT CAST HOUSE DESIGN AND DAILY OPERATION

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Abstract

In this paper, cast house operation is considered as a true example of a Flexible Manufacturing System (FMS), where a target product mix is achieved by adapting both process parameters and production plans, respectively. The examples presented here were initiated by challenging cast house operation situations. The results derived from the simulation scenarios were used to propose mitigating measures and to corroborate suggested solutions. From the components of the simulation tool-set, further models are built. As is often required, these models can be configured and applied to, among others, cast house design, production planning and operations decision support. Moreover, they can be used for operator training.

In-depth knowledge of cast house operations and dynamic process modeling has been turned to a practical engineering tool which is regularly used by Bechtel's Mining & Metals "Center of Excellence" (COE) group to deliver recommendations and results to clients in global aluminum smelter projects.

Introduction

There is a recurring need at Bechtel M&M for modeling and simulation activities to complement various pre-feasibility and feasibility studies, design alternatives as well as plant demolition, construction and operation activities. Concerning aluminium production, all major sectors of a modern smelter have already been addressed in one way or the other. Modeling works were done on:

- Movement of people, product and material in and out of a smelter
- Internal movements between smelter sectors (e.g. Carbon, Reduction, Cast house, Port etc.)
- Operation of particular sectors (with their key units, internal movements, applicable schedules, operational logic and material balance calculation)
- Operation of coupled sectors.

Most of the raised questions turned to be logistic-type problems; discrete event models (DEM) and process simulation were used to address the issues.

During the years, special interest articulated around modeling and simulation of cast house operation. Some of the reasons are:

- While other sectors of a smelter are characterized as "single product" lines, cast house should be capable of producing ingots of various types, sizes and compositions
- While other sectors' production lines take benefit of "storage" facilities to damp temporary imbalances between production and demand, a cast house is directly exposed to variations in liquid metal arrivals
- When cast house operation is biased, correction and continuation of the operation often require activating/deactivating key unit or complete production lines, adjusting product mix or significantly changing the casting plan – in "real time".

In critical situations, equally in design and plant operation, the flexibility present in cast house operation might quickly turn into complex problems, challenging or even exceeding the skills available for decision making required. DEM process modeling, complemented with decision support tools could be of great benefit [1,2]. The available cast house simulation tools, their applications and their ongoing development are presented below.

Model Components

Recently, the ever-growing COE Aluminium Smelter Model Library has been extended with cast house-related model components. Systematic process modeling activities addressed all important metal handling and casting equipment used in a typical, generalized cast house. Modules are shown in Figure 1.

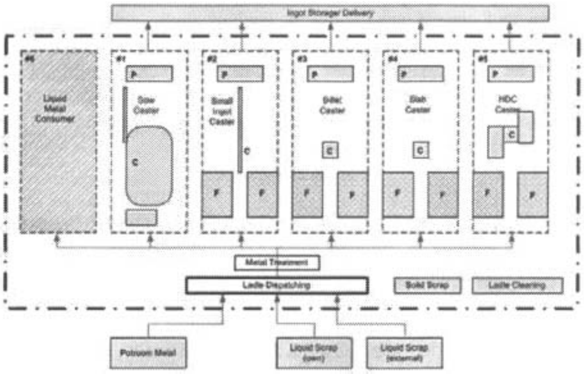

Figure 1 Generalized Cast House Modules

The generalized cast house activities cover:

- Ladle handling (transporters, stands, ladles, scales)
- Liquid metal treatment (TAC/SKIM stations)
- Crucible cleaning (cleaner, pre-heaters)
- Dross handling (bins, coolers, forklifts)

- Solid scrap and alloying material handling (bins, bags, forklifts)
- Furnaces (casting furnaces, melter-holder furnaces)
- Casting lines (of small ingots, billets, slabs, rough wire, HDC, sows)
- Ingot treatment (homogenizing furnaces)
- Ingot handling (cranes, down-enders, saws, packaging robots, conveyors, forklifts, etc.)
- Ingot storage and shipping (conveyors, pallets, floats, trucks)

The modeled equipments became parts (items) of a toolset. These items could be used individually, but for efficiency, most of them are functionally grouped, forming specific "modules" and "sub-models" (e.g. a "furnace" module incorporates all items needed to perform tasks of a generalized furnace). Model building starts with choosing a casthouse layout for model background, then populating the layout with modules, sub-models and individual items. Defining access points, routes, staging zones and assigning transporters to services complete the skeleton of the casthouse model. Figure 2 shows a model component, available as a library "module".

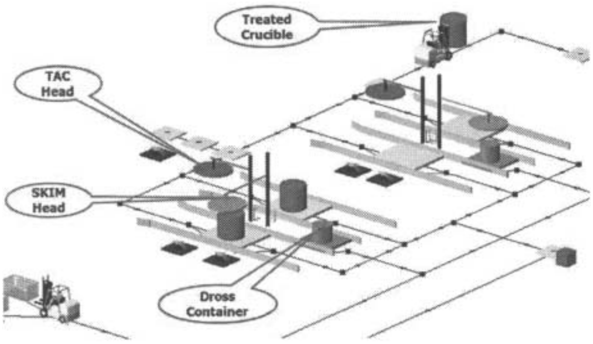

Figure 2 TAC/Skim modules

Then, the parameters of the model components are tuned to design values and simple scheduling is applied (ladle arrival, furnace filling, triggering casting, etc.). Also, 3D shapes of default items could be changed for better visual resemblance to equipments applied in a particular plant. At this stage, the model starts to "work", and step-by-step model verification could begin.

Process Simulation

Meaningful dynamic process simulation requires realistic boundary conditions between the model and its environment, and proper operational logic.

Boundary Conditions

As a cast house is - typically - a stand-alone entity, its blueprint suggests natural battery limits:

- Entry points where metal ladles arrive to cast house
- Exit points where ingots are removed

Ingot removals hardly influence internal cast house operation, thus a relative freedom in modeling "exit" points is given. However, ladle arrivals have great impacts on cast house operation. Correct implementation of a particular cast house – potlines co-operation is fundamental.

After several studies on stand-alone potroom operations and coupled cast house - potrooms operations, it was concluded that a specific module for the arriving ladles is to be created. The completed module now is part of the cast house simulation toolset. The module is adjustable to a specific smelter and generates stream of arriving ladles and is derived from potroom models. It is implemented on a cast house – potrooms layout. Metal delivery paths, travelling distances and entry/exit points at potrooms are all respected. Ladle filling follows metal tapping schedules. Figure 3 shows a cast house model for billet casting, assembled from the modules introduced above.

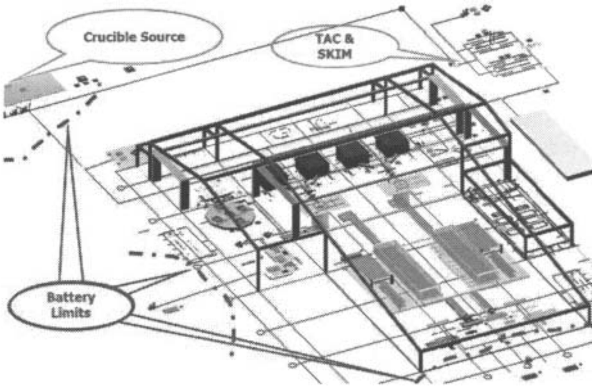

Figure 3 A billet casting & homogenizing model

Operation Logic

Operation control logics are routinely implemented to discrete event models. Those are mainly "level controls", monitoring a generalized inventory (i.e. difference between supply and demand) and acting on reaching limit values. In cast house operation, the fields where control logics have to be implemented are:

- Furnace operation
- Casting line operation
- Cast house traffic
- Ladle cleaning
- Ladle dispatching

Furnace operation logics are typically provided in the form of schedules (drop preparation sequence) to follow. A furnace goes through phases of cleaning, checking, scrap receiving, liquid metal receiving, skimming, alloying, stirring, settling, temperature adjustment while it is declared "ready to cast" a certain type of alloy.

Casting line logics are to control casting rate of a casting unit as well as to synchronize casting operation with statuses of furnaces assigned to the casting line. Logic is often specified in the form of logic diagrams and coded as "if-then" rules.

Traffic management handles utilization of access points, routes, intersections, staging areas, and controls movement of metal haulers and ladles. Traffic logic is specified in the form of dedicated routes, capacity of staging areas, allowed number of vehicles in buildings or in the vicinity of a furnace and such.

Ladle cleaning covers both monitoring dross accumulation and performing ladle cleaning operation. A "Ladle Cleaning" module has been developed for the operation, while assigning a particular ladle for cleaning could be based on dross accumulation, number of delivery cycles or other conditions.

Modules for these operation control tasks have been developed and grouped in a toolset. The modules are available for rapid implementation of specific logics. An application, a model developed for a complex cast house, is shown in Figure 4.

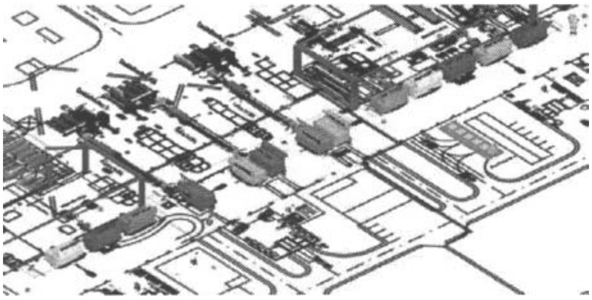

Figure 4 A detailed cast house model

Ladle dispatching logic, however, may require significant effort to capture and implement it. Ladle dispatching logic is usually provided in the form of a "casting plan" plus a "logic diagram" to assign individual ladles to furnaces. It was found that implementation of such "plan" and "logic" allows rather short simulations sessions:

- The simulation starts well and progresses correctly
- After a while, the natural deviations coming from all parts of the casting process (e.g. variations in liquid metal arrivals, variations in furnace operation) develop situations that exceed the scope of the applied logic
- The simulation runs into gridlocks (no furnace is available for arriving ladles, furnaces compete for metal, leaving vehicles wait for empty ladle, traffic jam occurs, etc.)
- The simulation session terminates as the executions turn to be unrealistic.

Similar situations were observed several times, in various studies, even when well-developed plans and detailed logics were implemented. It was concluded that the complexity of arising problems exceeds the capacity that a "plan & logic" approach could handle. Indeed, in real operation, area experts (foreman, dispatcher, casting planner) are often required to intervene to find a solution. Mitigation may require finding alternative operation modes, blocking/ mobilizing resources, adjusting unit parameters, or even significantly altering the casting plan. Difficulties experienced with ladle dispatching initiated further modeling works towards advanced decision support: reviewing available cast house manufacturing execution systems (MES), approaching cast house operation as a flexible manufacturing system (FMS) and considering the use of expert (knowledge processing) tools.

Manufacturing Execution Systems

Day-to-day aluminium smelter operation is heavily dependent on ME Systems. MES perform data collection, data analysis, archiving, production and maintenance planning and many more tasks, resulting in integrated supply chain management. MES are commercially available [3,4]. In the scope of the present article, the planning and projecting features of MES are of interest.

MES are definitive in matching orders (market demands) and production in cast house operation. Outcomes from production scheduling are translated to "casting plans", operation targets for days and shifts.

From literature review, it was concluded that industrial ME Systems are typically short of projecting/predicting features. It is a well-founded comment, that MES-generated casting plans could be corroborated by applying them to cast house models and observing the simulated outcomes. Also, a broader set of cast house operation knowledge could be put into use for managerial decision support.

Flexible Manufacturing Systems

Cast house operation falls into the definition of FM Systems:

- With possible alternative production routes
- Capable of being performed by different/redundant equipments
- Capable of activating different processes
- Achieving the same results via a combination of the above.

The performance of an FM System is highly dependent on the scheduling policy [5,6]. Scheduling problems are known to be hard. Different techniques are available in quest of acceptable solutions (e.g. schedule optimization, dynamic dispatching rule selection, application of learning algorithms, neural nets, etc.). Experience suggests that performance of a schedule ("casting plan") could efficiently be evaluated by applying it to a simulation model. A structure and a mechanism are proposed below for an adaptive cast house scheduling (casting plan development) system; see Figure 5.

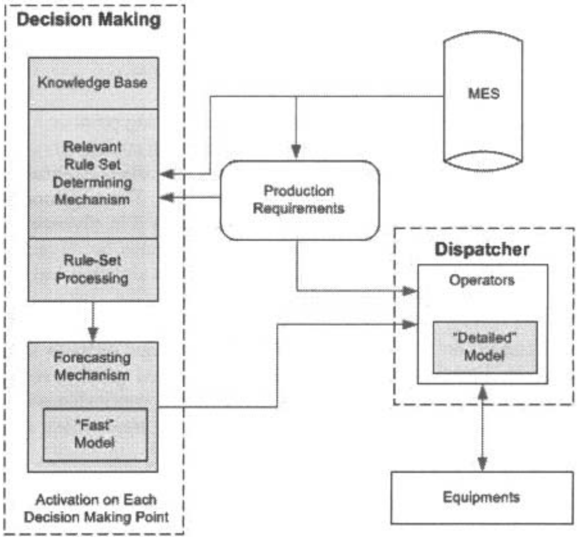

Figure 5 Suggested structure for cast house scheduling
(after Shnits [6])

This multi-level system, complementing an MES, suggests a *"Decision making"* block and a *"Detailed model"* module for *"Dispatcher"*. Indeed, it suggests another, *"Fast model"*, embedded to the *"Forecasting mechanism"* block.

From the cast house simulation tools, in addition to the regularly used, proven cast house operation models, various prototype-models have been developed. Examples are:

- Enhanced process representation and 3D graphic could lead towards *Virtual Cast House* applications (not in the scope of the present article)
- Removed ladle dispatching logic - taking direct orders only (from casting plan or from MES)
- User interface extended with a "Dispatcher Consol", allowing order modification or full "manual" dispatching regime
- Fast, strip-down models, calculating short-range projections

In general, model execution is fast. It could be 10-100 times faster than real time, depending on model granularity as well as animation and reporting overload. It was found, that results for a projected cast house shift could be generated within minutes, i.e. still in real-time with the ongoing process. It means that in critical situations, a "Dispatcher", weighing options, first could apply the possible changes to a model, then run the model and compare the outcomes. It is proposed to deploy a model-based "calculator" to the cast house office and leave it for testing and evaluations.

Decision Making Tools

The decision making toolset in Figure 5 aspires to put in use the "best corporate knowledge" in casting plan development. This knowledge is often available in form of reports, comments, and recommendations. Its use requires coding the knowledge to rules first, then applying the rule-set to a specific situation. However, there are differences between applying traditional algorithms and rule sets:

- Processing algorithms start from a defined point and follow a programmed sequence of execution (progressing linearly or selecting alternatives, according to conditions)
- Processing rules do not have a set starting point or foreseen order of execution, either. An additional algorithm is called on to decide if any rule is applicable at all for a certain group of conditions. The sequence of execution of the rules is not programmed in advance. Particular conclusion of a rule may or may not trigger further rules to become relevant in that situation and thus require execution.

An example for the differences: following a logic chart to fix a particular problem (going through a tree-shaped graph), versus reading a report and trying to find if anything is applicable within it to fix a particular problem (searching for trajectories in a complex graph with loops).

Steps of knowledge application are shown in Figure 6. Comments on cast house operation were turned to *"If-Then"* rules. Each rule is viewed as a piece of knowledge; new knowledge could be added or existing knowledge can be easily changed. A mini knowledgebase was built for test purposes. For rule processing, the simulation tools were complemented with a search algorithm, implemented in C++. An abstract data type was defined to represent the graph structure. Rules were built to nodes and a list structure was used to represent references (connections) between nodes [7,8].

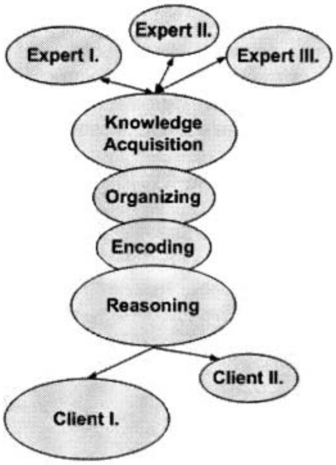

Figure 6 Knowledge Application

The generalized structure, graph with loops, looks as shown in Figure 7. The edges demonstrate possible connections as some of the rule-variables present in the connected rules. A simple search algorithms was built (capable of breadth-first and depth-first processing) to travel the graph, i.e. to process the rule set and try to derive relevant information on the given parameter set.

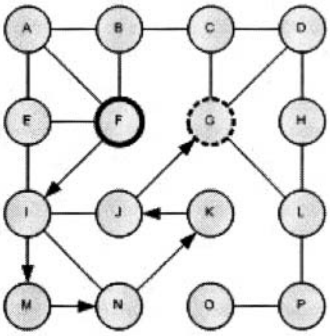

Figure 7 Reasoning Process
(after Goodrich [7])

In general, a reasoning process starts from a node (rule) that is evaluated on available data. Then, conclusion(s) from this rule may or may not lead to other rule(s). As of the search algorithm, a subsequent rule is triggered and the roaming over the graph progresses. In Figure 7, the search starts from node F (rule in node F), progresses through nodes I, M, N, K, J. As seen, it is a depth-first type search, and G is considered now as a goal (result). Conclusions from G will be applied to the model.

The test rule set was kept minimal in size (started with 10 rules, then extended gradually). The search algorithm performed correctly during the tests. A "Fast model" was added to the module, as well. The suggested decision making module now is available as a prototype to be used in knowledge application forecasting plan development.

Conclusions

A basic toolset, containing all major equipment of a generalized cast house is presented. Several cast house models have been built from it, supporting study and design works at Bechtel COE. During the years, the modeling toolset has been systematically developed. Now, boundary condition modules and control logic modules are available for easy model development.

"Dispatcher" interface modules are added to the models to provide plant-like data, usually available through a Manufacturing Execution System and to receive dispatcher orders in a direct manner. These interface modules provide the means for eventual coupling models to MES systems, if found beneficial.

Resulting from background development works, a structure is suggested for casting plan development. Then roles of specific models are discussed. Finally, a rule-processing decision support tool is proposed for complementing scheduling.

The proposed tools were assigned to various test arrangements:

- Prototypes of "Dispatcher" interfaces were tuned and tested for certain plant applications.
- "Detailed" and "Fast" models were tested for selected plants.
- A knowledge base was compiled and processed in laboratory.
- Reasoning algorithms were tested in laboratory.

Preliminary results indicated that the proposed modeling tools are capable of mitigating variations in casthouse performance.

Extending and improving the modeling toolset is ongoing. Works are in progress on casting plan development and related decision support. Results are expected to be published at coming TMS conferences.

Trademarks

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Acknowledgements

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