Simulative Study of Aluminium Die Casting Operations Using Models with Varying Degrees of Detail

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Abstract. Aluminium die casting plants offer great potential for optimisation in terms of production and energy efficiency, which can be demonstrated by simulation. However, real companies often have a poor data basis for complex simulation. Based on a complex model, simplified simulation models are designed that are compatible with a low amount of data acquisition. These are described in this paper and tested on different scenarios. One scenario is the variation of downtimes of production machines. Considerable savings in computing time can be reached with still plausible results in terms of material and energy consumption.

Introduction

Simulation-supported methods are increasingly used in production and logistics companies to demonstrate operational optimisation measures [1]. The simulation models often aim to accurately represent the real operating processes. This usually requires a high level of detail, but is also associated with a high modelling effort, a need for detailed operational and production data, and a long computing time. For models with little need for measurement data and computing time, new areas of application arise, such as model predictive control (MPC). In addition, the use in companies with a low data acquisition rate is possible. Especially in the non-ferrous industry, the data basis is often insufficient for the application of a complex simulation model.

Energy-intensive companies are particularly suitable for simulation of optimisation measures or predictions of material and energy consumption. Within the scope of a preliminary study, simulation models with varying degrees of detail of an aluminium die casting plant were set up and compared under certain scenarios [2]. The highly detailed simulation model was validated by the data of two real facilities and can, thus, serve as a reference for the simplified models. As the results reveal a lower level of detail, a massive saving of computing time and data acquisition effort can be achieved. However, there are deviations in the results, such as the output of processed mass and the specific energy consumption.

A weakness of the models with a low level of detail lies in the exclusive consideration of the liquid aluminium storage tanks. By adding the melting shaft with the solid-liquid phase transition, the quality of the models is improved without significantly increasing the calculation effort and the scope of the required operating data. In the present work, the considered melting die casting operation as well as the simulation models of different levels of detail are described. Based on the models, different operating scenarios are examined and the models are compared.

1 Aluminium Die Casting Company

The present study is based on a large aluminium die casting facility. The typical structure of such a plant is shown in Figure 1. The operating sequence includes both continuous (e.g., melting) and discrete (e.g., forklift transport) process steps.

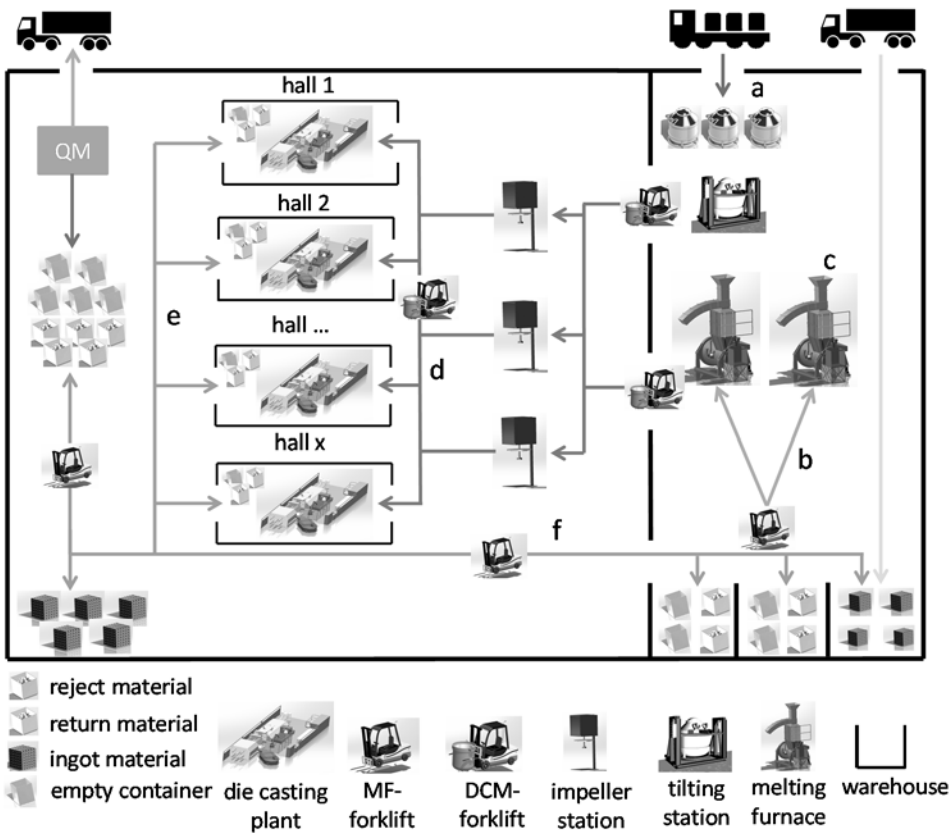

Figure 1: Scheme of an aluminium die casting plant with its process steps [3].

The underlying processes are (Figure 1):

1. delivery of molten aluminium
2. feeding the gas-operated shaft melting furnaces via forklift trucks with metal ingots, return, or reject material
3. heating, melting and overheating, or keeping the metal warm
4. distribution of the liquid aluminium with forklift trucks to the dosing furnaces of the die casting machines
5. production of cast parts in the die casting machines and quality control
6. transport of material containers from the die casting machines or ingot packages from the warehouse to the melting division

The plant can be supplied with liquid aluminium in two ways. On the one hand, the melting furnaces are supplied with solid aluminium in the form of ingots, return, or reject material by forklift trucks. In the furnaces the aluminium is melted and kept warm in the holding area until it is removed.

Alternatively, the liquid aluminium can be delivered directly from external smelters and stored in a tilting station until removal. Once per shift the furnaces must be melted free and cleaned. The melting and holding processes in the furnaces are particularly energy-intensive processes and are, therefore, decisive for the energy efficiency of the facility. The melting division requires about 50 % of the total energy consumption of the company.

For this reason, the melting and holding process is in the main focus in terms of calculating energy consumption. This process is displayed in an energy flow model.

For the material flow, all process steps are relevant. For example, after the melting process, the liquid aluminium is removed from the trough of the melting furnace and transported to the die casting machines by forklift trucks. The forklift trucks operate according to predefined rules: Die casting machines that have a little liquid aluminium available for production are supplied with priority. In the die casting machines, the actual production of the parts takes place. Depending on the machine, different components are casted, which leads to a machine-specific consumption of liquid aluminium.

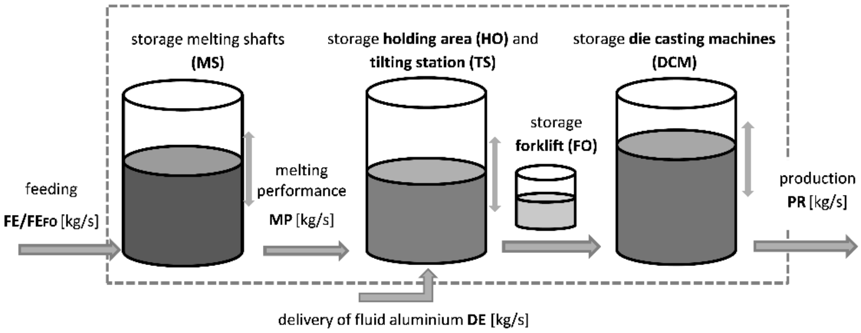

Figure 2: Scheme of the simplified model.

2 Simulation Models

In a previous study, different simulation models were developed depending on the level of detail, which simulate the aluminium die casting operation shown in Figure 1 [2]. The highly detailed model is used as a reference model to evaluate the models of lower levels of detail. In the further development of the simplified and detailed model, importance is attached to ensure that the models remain mathematically describable using hybrid automata that take into account both continuous and discrete event elements [4]. The models are constructed and simulated with the software tools Matlab, Simulink, and Stateflow.

2.1 Simplified Model

In the simplified model (Figure 2), entire machine groups are considered as liquid aluminium storages. The machine groups – such as melting shafts, furnace tanks with tilting station, and die casting machines – are combined to form a material storage. The material flow between the reservoirs is described by continuous and discrete event elements. The energy flow is determined by the continuous variable melting performance.

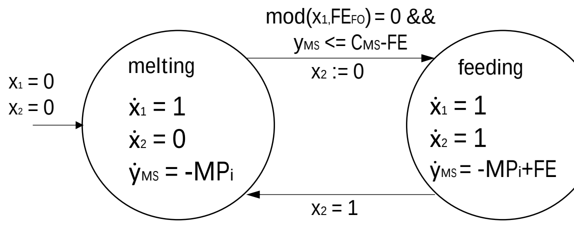

Figure 3: Hybrid automat for the melting shafts in the simplified model (x_1 time for determining the feeding, x_2 time for determining the feeding duration, y_{MS} total filling level of the melting shafts, C_{MS} total capacity of the melting shafts, MP melting performance of the melting shafts, FE feeding quantity, FE_{FO} duration for the renewed feeding process).

The individual storages are described as hybrid automata and as such are implemented in Stateflow. Figure 3 shows an example of the hybrid automaton, which describes the melting shafts. The machine has two states to switch in between and in which continuous processes are included. The change from melting to feeding takes place after a certain time if the melting shaft still has the necessary capacity.

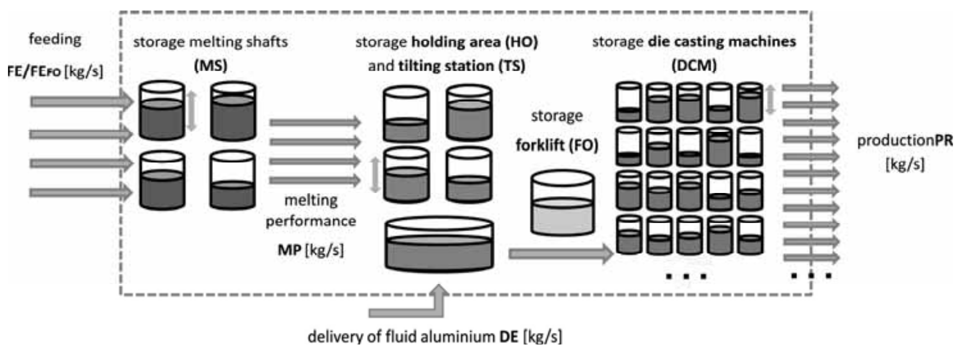

Figure 4: Scheme of the detailed model.

In addition to the previous investigations [2], the model was extended by the charging process, the observation of the melting shaft and an own energy model. The model is characterised by low computing time and low complexity. Due to the combination of the storages, no intelligent forklift control is required. Also, it was not possible to model individual machine failures due to a lack of aluminium.

2.2 Detailed Model

In the detailed model (Figure 4), the machines are each considered as separate material storages, which allows for depicting the aluminium shortage of individual machines.

An individual energy model is implemented for each melting furnace. As there are several material sources and sinks in the detailed model, a forklift control is required to determine which material source to take and which sink to supply. This control of the forklifts is steered by the filling levels of the machines. The control logic specifies that the tilting station is used as a material source with priority. If the tilting station has no aluminium in stock, the furnace with the maximum level of aluminium is chosen.

The die casting machine with the lowest relative filling level is supplied. For the feeding of the melting shafts, a control is also implemented that prioritises the melting shaft with the lowest relative filling level. The storages in Figure 4 are modelled as hybrid machines, too. Figure 5 shows an example of the hybrid automaton of a melting shaft including the states free melting, melting, and feeding. The states melting and feeding correspond to the states of the same name in the simplified model. In the state of free melting, the furnace cannot be charged during the time of the cleaning period.

Besides, a control system is implemented in the automatic machine, which determines whether a certain melting shaft is to be charged. The logic is outsourced in an external control module. Considering the feeding processes and the individual melting shafts, the detailed model offers the advantage that machine- and filling-level-dependent melting capacities and energy consumptions can be implemented for the melting shafts.

2.3 Highly-detailed Model

In the highly detailed model (Figure 6), all process steps from Figure 1 are represented except for warehousing. The highly detailed model, which is validated by the data of two facilities, serves as a reference model for the following study. The simulation model focuses especially on the melting shaft, the melting process, and the associated energy model.

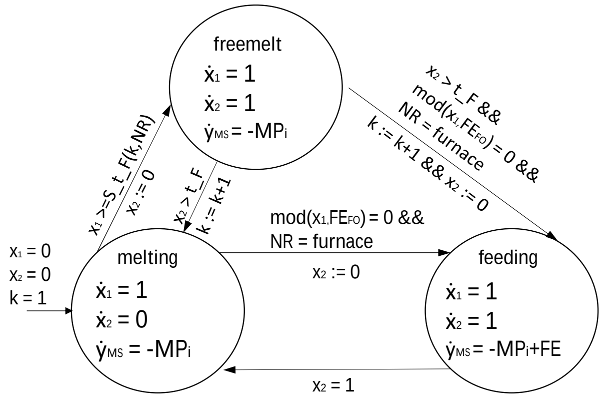

Figure 5: Hybrid automat of a melting shaft in the detailed model (S_t_F array with free melting times, k position in array S_t_F, NR number of the melting furnace, t_F duration of the free melting and cleaning process, furnace furnace to be charged; determined by control).

The material flow model includes the complete material flow within the plant, while the energy flow model captures the thermodynamic processes within the melting furnaces. The synchronisation is done in each time step using an interface object, which realises data exchange between both models. To control operating sequences, orders for the forklifts and the melting furnaces are generated in a control module based on plant and process parameters as well as the defined control strategies.

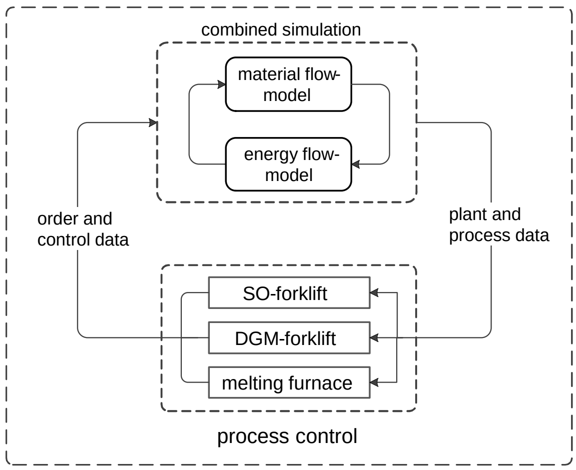

Figure 6: Components of the highly detailed operational simulation [5].

The highly detailed simulation model includes further functionalities such as the consideration of different alloys and the mapping of the impeller stations. Buswell et al. describe the model in detail [5, 6].

3 Results

The quality of the simplified models is analysed by using the highly detailed model. In particular, factors such as the output of the die casting machines, the molten mass, and the energy consumption of the melting furnaces are considered. Various applications for the models of varying levels of detail are analysed. For the simulation, a large plant with four melting furnaces, 31 die casting machines, and additional delivery of liquid aluminium is displayed.

3.1 Calculation Time and Data Volume of the Models

The primary goal of the model simplification is to save computing time and the amount of necessary data acquisition. The evaluation is shown in Table 1.

	Simplified model	Detailed model	Highly detailed model
Simulation duration in minutes	1	4	132
Required operating parameters	30	157	275

Table 1: Calculation time and data scope of the models.

A considerable reduction of the simulation time is gained by minimizing the level of details. When using the detailed or simplified model, the calculation time is reduced by a factor of 33 in the detailed model and 132 in the simplified model. The amount of data decreases with the reduction of the level of detail, too.

The number of required operating parameters using the detailed model is lowered by 43 % compared to the highly detailed model. Only 11 % of the operating parameters are required for the simplified model.

3.2 Scenario A: Operation Procedure Under Real Conditions

To compare the models, the first step is to simulate the operation based on the operating data of a working week. The comparison is based on the determined material consumption of the die casting machines, the molten mass, and the specific energy consumption of the melting furnaces.

The specific energy consumption is determined by the molten mass and gas consumption. The results are shown in Table 2.

	Simplified model	Detailed model	Highly detailed model
Molten mass [t]	937	912	920
Cast mass [t]	1198	1198	1200
Specific energy consumption [kWh/t]	851	968	972

Table 2: Comparison of the models.

In terms of material consumption, the simplified models were able to reproduce accurately the mass melted by the furnaces and the mass cast by the die casting machines. Only the molten mass shows significant differences of 1.9 % in the simplified model and 0.9 % in the detailed model. These differences result from the different feeding strategies of the models.

The simplified model shows considerable weaknesses in specific energy consumption. While the detailed model mirrors the energy situation well with a deviation of 0.4 %, the simplified model deviates by 12.5 %.

The deviations can be explained by the fact that different furnace types are used in operation under real conditions, whereas the simplified model considers the furnaces in an aluminium storage tank as one all together.

3.3 Scenario B: Variation of Downtimes at Die Casting Machines

In Scenario B, the downtimes of die casting machines vary. In the highly detailed model a reduction in downtimes increases the efficiency of the melting furnaces, as they are consequently utilised to a higher degree.

The study investigates whether this effect can also be displayed in the simplified models. The downtimes were reduced by 50 % and 75 % in the course of the study. The results are shown in Figure 7.

The simplified as well as the detailed model illustrates the effect. Especially the detailed model and the highly detailed model are very close together in their behavior. The deviation of the simplified model results in the combination of the different furnace types to one aluminium storage tank, as described in Section 3.2.

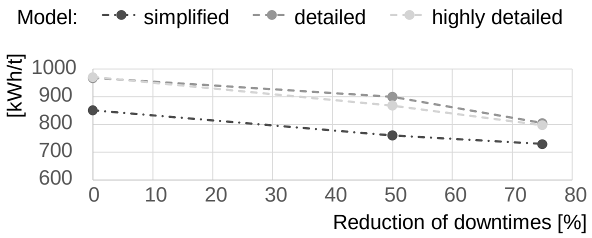

Figure 7: Specific energy consumption in the models with a variation of downtimes at die casting machines.

4 Summary and Outlook

Within the scope of this study, two simplified simulation models of an already existing highly detailed simulation model have been created and described. The simplified models enable a massive reduction of computing time and required operating data. Only small deviations from the highly detailed model could be observed in the mapping of material and specific energy consumption.

However, the simplified model shows significant deviations in the energy calculations, since a single storage does not sufficiently describe the different furnace types. Therefore, the detailed model is particularly suitable for quick use to make predictions about energy and material consumption.

In order to enable a real application of the simulation models, the models should be tested and optimised on further real scenarios. A final goal is the use of the models in smart services, such as intelligent forklift truck control up to model-predictive control of the operation.

References

[1] März L, Krug W, Rose O, Weigert G. *Simulation und Optimierung in Produktion und Logistik, Praxisorientierter Leitfaden mit Fallbeispielen*. Berlin; Springer VDI; 2011.

[2] Dettelbacher J. Simulative Untersuchung von Betriebserweiterungen in einem Aluminium-Schmelz- und Druckgussbetrieb anhand von Modellen mit unterschiedlichen Detaillierungsgrad. *ASIM-Treffen STS/GMMS*; 2019 February; Braunschweig. 53–58.

[3] Jeckle D. Dokumentation der Software zur Simulation des Materialflusses und Untersuchung der Energieeffizienz eines Schmelz- und Druckgussbetriebes. Ansbach: Ansbach University of Applied Sciences; 2015.

[4] Atterer R. Hybride Automaten. Munich: Technical University of Munich; 2001.

[5] Buswell A, Schlüter W. E|Melt: Erweiterung einer unternehmensspezifischen Materialfluss- und Energiesimulation zur Abbildung variabler Betriebsstrukturen der Nichteisen-Schmelz- und Druckgussindustrie. In: Loose T, editor. *Tagungsband Workshop 2018 ASIM/GI-Fachgruppen; 2018 March;* Heilbronn. 33–38.

[6] Buswell A, Schlüter W. E|Melt: A flexible material flow and energy simulation in the context of Industry 4.0. In: Deatcu C, Schramm T, Zobel K, editors. *ASIM 2018 – 24. Symposium Simulationstechnik*; 2018 October; Hamburg. 42–47.