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Dynamic Simulation of Internal Logistics in Aluminum Downstream Manufacturing

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Abstract

Rolled or extruded aluminum products show an enormous variation of mechanical properties and surface qualities. Therefore, the manufacturing processes comprise a multitude of fabrication steps including forming, heat treatment and finishing that appear in arbitrary order. Accordingly this material flow includes a frequent stocking and buffering of material with process related waiting times and a corresponding number of transport and handling operations, named the internal logistics of a manufacturing plant.

Dynamic simulations based on discrete event simulation models are effective tools to support planning processes in downstream manufacturing plants. Logistics simulation models ideally accompany improvement and modernization projects and the design of new production facilities to quantify the resulting overall equipment effectiveness. This paper outlines the principles of mapping the material flow of rolling mills and extrusion plants by configuration of generic simulation models and by modeling of specific handling equipment and production facilities under consideration of process models.

Internal logistics in aluminum downstream processes

The material flow in aluminum downstream manufacturing like in rolling mills or extrusion plants starts with providing appropriate ingots. Those will pass one or more forming steps to generate the specified shape in combination with heat treatment steps to adjust defined mechanical properties of intermediates and final products. Beside these process steps there is a large variety of fabrication steps to obtain required surface qualities and coatings. Each product will be routed through the manufacturing plant according to its individual process order. All process steps need to be interlinked by material handling and transport equipment to keep up a material flow with a high utilization of the production facilities in particular in case of capital intensive equipment.

The main task of the internal logistics is to deliver the right material at the right time in the right quantity to the right location. Therefore, also adequate material buffers and storage systems need to be considered, besides the handling and transport equipment like cranes, vehicles and/or conveyor systems.

Modern manufacturing plants have automated high bay storage systems including very fast handling equipment, which should have only a moderate utilization, but these facilities increase the complexity of material flow, dramatically. Hence, modern manufacturing systems require full control of the complex material flow to keep the lead time of products on a low level and to ensure high utilization of all production facilities. The utilization of the handling equipment should not be too high to avoid bottlenecks and guarantee flexibility to enable production of a broad product mix.

For this purpose dynamic discrete event simulations facilitate logistical investigations to predict the performance of the entire manufacturing system (overall equipment effectiveness) under certain circumstances like increased production capacity or varying product mixes. The productivity of manufacturing systems is significantly depending on the logistical equipment and with dynamic simulations it is possible to show up bottlenecks caused by temporary highly utilized handling and/or transport resources.

Hydro Aluminium has extensive experiences in the use of different dynamic simulation tools as supporting tool for continuous improvement, solving planning and scheduling problems as well as for the layout design of new production facilities along the value chain of aluminum production [1, 2, 3]. In particular to guarantee the success of larger investments it is common to conduct simulations of future plant configuration and layouts [4]. Typically these simulation models are showing limitations regarding their flexibility and general applicability. Within an internal, cross-sectional strategic modeling program it was intended to take up former activities under consideration of today's simulation capabilities and to develop universal simulation models for downstream manufacturing processes.

Methodology of flow optimization

Dynamic simulation models enable demanding investigations of complex material flow with a multitude of different production routings through manufacturing processes with several process steps by using a variety of material handling equipment. Therefore a process simulation can be an effective tool to support investment decisions in an early stage of improvement or modernization measures of existing manufacturing systems and for the design of new facilities.

These investigations start ideally with an accurate description of the problem to be solved including a sufficient data base and also operating figures to demonstrate the need of improvement through quantification. A simulation model is used to map the relevant material flow as well as processes and operations to analyze the manufacturing process by providing simulation data and performance indicators as basis for generation of ideas how to improve material handling and processing.

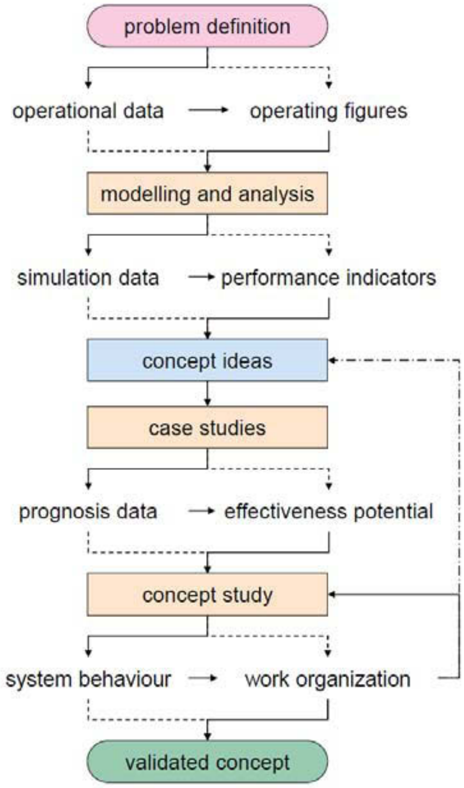

Figure 1. Flow chart methodology of logistical investigations

Figure 1 displays a methodology of logistical investigations. By means of logistic simulations case studies can be conducted to validate reasonable approaches and to check the effectiveness of different concept ideas. A detailed concept study for selected proposals, occasionally with a higher degree of detail, can deliver meaningful information about the prospective system behavior. Furthermore, the work organization often needs to be adjusted, and is to be considered relevant input to the modification measures. So after some iteration steps a fully validated concept can be prepared as a good basis for decision making.

Modeling of material flow

The simulation model is based on routing single objects representing one material unit through all process steps according to the individual process order of each product. The model comprehends all process areas of the manufacturing plant which usually starts at a primary forming step, respectively with the reception of material from sources outside the plant, and continues with the subsequent forming, heat treatment and finishing steps, while the production sequence can be principally in any order. The material balance ensures that every product will remain in the plant until it leaves through shipping and accordingly indirect effects on other process areas can be considered.

For the model development it is essential to consider the principle of material routing through the manufacturing processes [5]. In aluminum downstream processes like rolling or extrusion there can be observed mainly two different structures either star-shaped or ring-shaped.

The first modeling approach is based on the assumption that after each process step the material is always to be moved into storage before it will be routed further to the next process step. The storage does not necessarily contain centrally arrange storage yard. As shown in Figure 2 the corresponding routing principle has a star-shaped structure. The flow graph is describing a typical material flow in rolling mills starting coils at hot mill (dotted line) and firstly moved into central coil storage, continuing by moving a coil from storage to process and back to storage (solid line), ending at packing (dotted line). Alternatively material can received from external sources and/or out warded without being routed through the plant's packing area (dash-double-dotted line). Of course, for specific plant layouts there are opportunities to map bypasses from one process to another, without using the storage (dash-dotted line).

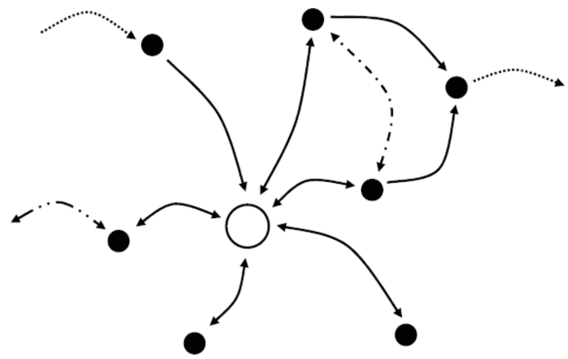

Figure 2. Routing principle with star-shaped structure

The second modeling approach highlights a material flow that is routed along a manufacturing line routing material from process to process. In many cases these process lines do not show a strict process order and, like in extrusion plants, there are containers (skips) in use for carrying the material through the plant. After the production is completed the empty containers have to be moved back to the starting point for new products. As shown in Figure 3 the according routing principle of the material flow has a ring-shaped structure.

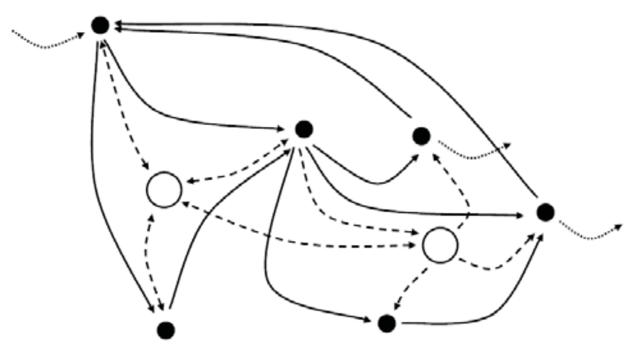

Figure 3. Routing principle with ring-shaped structure

The flow graph is describing a typical material flow of an extrusion plant, where full skips are routed from process to process (solid line). The material flow is starting at a stacker belonging to a press line and ends at packing (dotted line). After packing, the empty skips need to be moved back to the press line(s). Beside small buffers at each processing unit, typically there is a need of a buffer area before the ageing process. In this buffer area several skips containing material that need to be treated with the same ageing practice are to be batched and compiled accordingly (dashed line). Furthermore, there is another buffer area respectively after the ageing process or before skips are directed to post processing units and/or to packing.

One main goal of the model development has been to generate a plant model mapping of the entire material flow considering the material balance of the plant. Firstly, this material flow model is based on generic handling and transport processes. These generic handling operations are described by a set of parameters including buffer capacities and average handling durations. Logistical equipment that is a decisive factor for material flow needs more attention when configuring a simulation model. In this case the handling and/or transport have to be mapped by specific processes to model the concerned supply chain for the concerned process area in detail.

In dynamic discrete event simulation models the basic model objects used by the simulation software are (material) *loads*, representing a discrete material unit or single containers containing certain material in the current processing state. These loads are representing a discrete material unit and keep the relevant product information as load attributes on board and they can change their appearance (load type) to visualize the current state of the material. Loads are moved into *queues*, representing physical buffers and claim *resources*, representing manufacturing facilities and handling or transport equipment.

If there is a need of a detailed modeling of a material handling system the simulation software package provides so called movement systems to be inserted into the simulation model as sub-models carrying the material (loads) from pick-up to delivery locations. In downstream manufacturing plants, typically there is a need of floor-borne vehicles, high bay storages, conveyor systems and/or bridge cranes. Vehicles are mapped by path mover systems moving along a guide path. For the simulation of material handling within high bay storages an automated storage and retrieval systems can be configured with one or more aisles where rack feeders pick-up and retrieve loads. Conveyor systems include one or more sections each controlling speed and orientation of loads and a bridge crane is moving on a set of rails on which a crane moves over pick-up and delivery areas [7].

Logistics simulations for rolling mills

The material flow of a rolling mill comprises of all coils processed in a rolling mill during a certain period, each determined by an individual production order consisting of pass plan, intermediate and/or final annealing as well as trimming, leveling and finishing processes. According to the basic model approach the simulation of a single process step contains a coil handling and/or transport from storage to the production facility and after passing the process itself a coil handling and/or transport back to storage. This stocking is characteristic for the routing of material in rolling, because after each processing there is a need for cooling a coil, a prerequisite for providing it to the succeeding process in the right condition.

The logistical equipment of a rolling mill includes coil storages, coil transport vehicles and handling equipment to move a coil from one position into another position like cranes, coil shuttles or lifts. The coil storage plays an important role within a rolling mill, because coils stay typically longer in storage than in processing units. Accordingly, the coil storage might get significantly relevant for the productivity of a rolling mill. For this purpose, a storage module can be imported into the simulation model enabling a detailed modeling of the material handling in a general storage or in a high-bay storage in particular.

Figure 4 shows a model detail of a high-bay storage in combination with automated guided vehicles realized in the Hamburg rolling mill [7], including the coil shuttles transferring the coils between high bay storage and pick-up and drop-down stations for the vehicles.

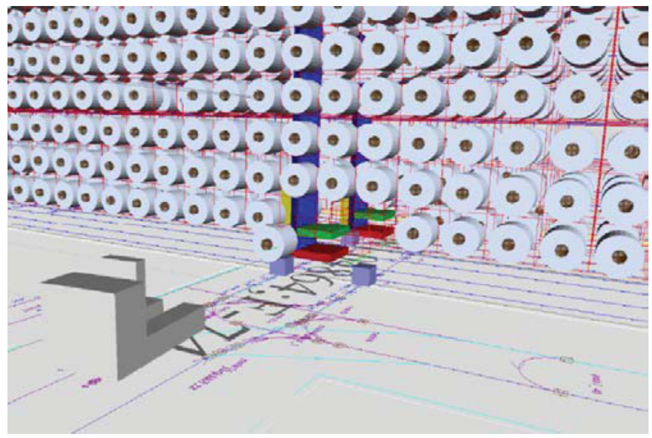

Figure 4. Detailed modeling of coils handling in high bay storage (Hamburg plant)

Especially for the annealing, the question of an efficient scheduling is such that annealing furnaces can be utilized economically regarding the compilation of annealing batches for multi coil furnaces. In particular when a rolling mill operates annealing furnaces with different batch sizes, decisions must be made to meet the often conflicting goals flexibility and productivity. Throughput and lead time of coils are directly depending on the availability of the coil handling and transport equipment. On the other hand manufacturing facilities may disturb the internal supply chains in case of downtimes, e.g. during the change of rolls. But downtime in a roll mill can have a considerable but indirect influence to other process areas due to hindered transport resources. Therefore it is necessary to analyze the mutual influence of facilities and logistical equipment.

If bottlenecks have been identified it will be a next step to investigate potential solutions how to avoid or how to compensate those bottlenecks. This results either in possible modification of the existing manufacturing system or in possible conversion measures, associated with more or less significant investments.

The given example shows the effect of a modified routing of coil transport vehicles aiming for reducing temporary high utilization on coil handling equipment, which has been considered a potential bottleneck for the production in the Hamburg rolling mill. During this investigation the entire logistical chain from high bay storage to the affected processing unit has been analyzed. This supply chain consists of a rack feeder removing coils form their storage location inside the high bay storage and transferring it to a coil shuttle which moves coils out of the high bay storage into a pick-up station from where vehicles are transporting coils to the processing unit. For this supply chain it has been found out that the coil shuttle can get utilized temporarily considerably (see Figure 5). While the average utilization shows moderate values, the more instant consideration is indicating potential bottlenecks in certain periods.

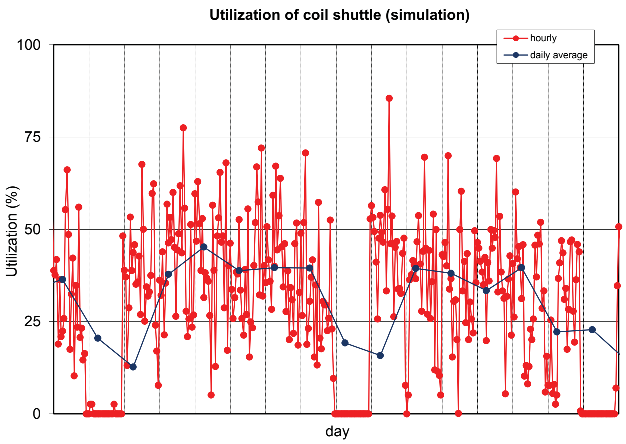

Figure 5. Simulation results: utilization of handling equipment

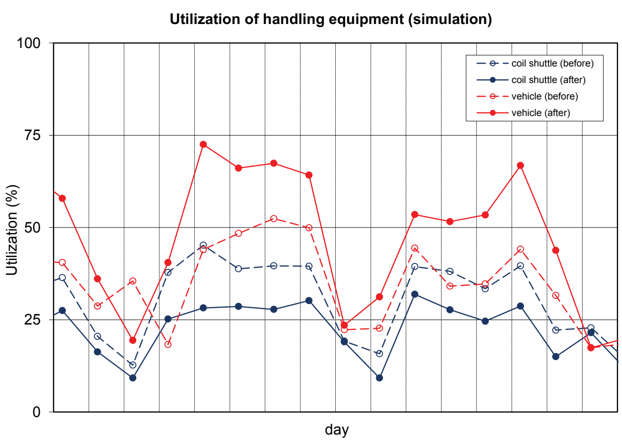

Figure 6. Simulation results: utilization of handling equipment

As a potential compensation measure an alternative routing of coils scheduled for this processing unit has been investigated. For this purpose the coils are directed to another exit of the high bay storage allocating vehicles which are usually not delivering to the concerned processing unit. As shown in Figure 6 the utilization of the previously used coil shuttle could be reduced considerably. On the other hand the transport vehicles have now a higher utilization, but this negative effect would not be that critical for the process area where these vehicles normally operate.

Logistics simulations for extrusion plants

The simulation model for extrusion is mapping the material flow represented by the routing of skips through the plant. Therefore the material flow starts at the stacker(s) where empty skips are to be filled with several layers of sections (extruded aluminum profiles). The skip flow is routed then from process to process by using dedicated handling equipment. Finally at the de-stackers of packing or fabrication units the flow of a full skip ends and there is a backflow of empty skips to the stacker(s).

A handling process starts by moving a skip into the handling territory, which may be occupied, leading to a queuing situation. This is specific for the routing of material in extrusion, so a reservation and release logic is providing a buffering of skips waiting for access to a handling resource and is ending the buffering of a skip in handling resources. Each buffer stands as well as the skip handling in combination with a resource to be used for reservation of buffer space. The reservation and release logic of a buffer is following the same principles as in the buffer reservation and release.

The ageing of skips is an essential process of an extrusion plant also regarding the skip flow. Accordingly the simulation model contains a skip batching logic to select skips out from a pool of buffered skips scheduled for heat treatment. The batch of skips will be set onto a carrier, called ageing frame. This ageing frame is represented by another load type containing the process information of all skips included. Beside the batching and de-batching the model contains also the handling process mapping the frame flow in and out of the ageing furnaces considering the available buffer locations.

As mentioned above it might be necessary to simulate dynamic behavior of the skip handling in a certain plant area on a more detailed level, for example in the area of a skip buffer before ageing. For this purpose it is needed to expand the simulation model by mapping the handling equipment in this area in detail. Figure 7 is showing this main buffer area including a bridge crane which is employed for the skip handling. Moreover, when the ageing buffer is used as one main buffer of an extrusion plant, it could be reasonable to subdivide the buffer area into sub-buffers each for a certain skip type with a specific capacity corresponding to the different process steps a skip is scheduled for the next process step. Through differentiated modeling of the material flow the rout causes of appearing bottlenecks could be identified more effectively.

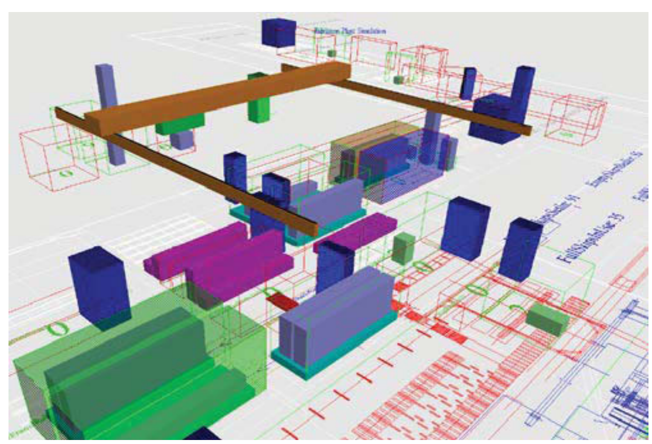

Figure 7. Detailed modeling of skip handling in main buffer area of a typical extrusion plant

The example demonstrates the potential effect of replacing an old ageing furnace, which is not directly linked to the buffer area, by two new furnaces in combination with a modernized buffer area after ageing and before fabrication and packing. In opposite to the existing remaining single-door furnaces, the new ageing furnaces are through furnaces also directly linked to this buffer area. For these furnaces the skip batches are to be compiled also in front of the furnaces, so the effective capacity of this main buffer will be reduced considerably. The focus of a first principle investigation is now the effect of this new arrangement on the productivity or the overall equipment effectiveness.

Due to the considerably higher ageing capacity of the new plant layout the throughput of the extrusion plant would be increased by approximate 15 % (see Figure 8). Figure 9 and Figure 10 are displaying the corresponding buffer levels before ageing, i.e. in the old main buffer area, and after ageing, i.e. in the new buffer area before fabrication and packing. The old plant layout consists of a potential bottleneck within the main buffer area indicated by the buffer level in Figure 9. With the new layout the buffer level is much lower, but here displayed in relation to the former buffer capacity, which will be relevantly reduced with the new layout. Accordingly this buffering before ageing needs a deeper consideration within the next steps of the investigation.

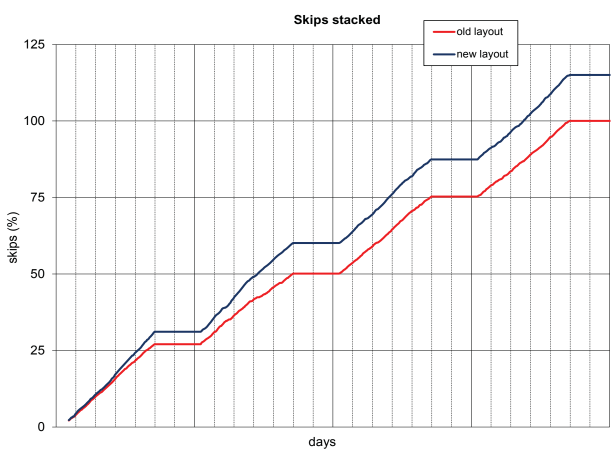

Figure 8. Simulation results: productivity

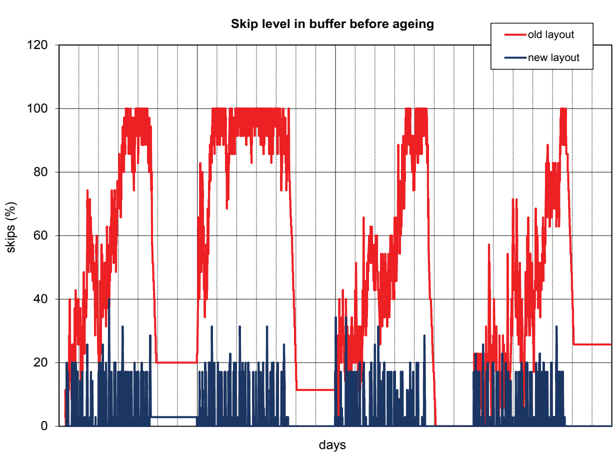

Figure 9. Simulation results: buffer levels before ageing

On the other side the higher productivity leads in principle to a higher skip level after ageing, as shown in Figure 10. This buffer includes the empty skips waiting for being routed back to the stacker. Besides the skip handling within the new buffer area, also the handling of empty skips should be analyzed within further investigations to validate the increased productivity for the whole extrusion plant.

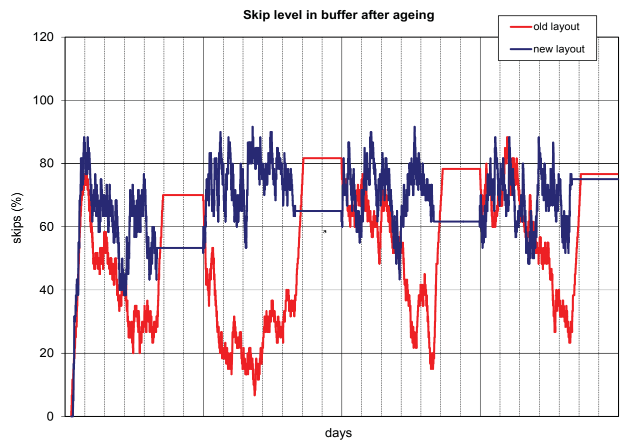

Figure 10. Simulation results: buffer levels after ageing

Conclusions

The dynamic simulation of the material flow in manufacturing systems allows efficiency analysis in complex logistical networks, more extensive than static calculations usually do by considering average values. Especially hidden bottlenecks can be identified by the instant analysis of material flow problems. A universal simulation model, mapping the entire material flow of an interrelated production system, which of the logistical equipment can be detailed in relevant plant areas, is very flexible in terms of comparison of several potential solutions. Hence, this procedure enables a comprehensive outcome regarding performance vs. investment for modernization and improvement measures as well as for the technology development.

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