BACKWARD SIMULATION IN FOOD INDUSTRY FOR FACILITY PLANNING AND DAILY SCHEDULING

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ABSTRACT

In the light of high capital expenditure for manufacturing facilites in food and process industry, an increasing number of variants and frequentliy changing sales developments, simulation models are becoming more and more important for the support of capacity and production planning.

In the following, the use of a simulation toolset for the support of tactical capacity planning and operative production planning is presented. It was implemented in cooperation with a global player of food industry.

The challenge of the project was the implementation of a backward simulation. Instead of filling food from a tank into cups, the computer simulates the process inversely. The advantage of the chosen procedure is that the provision of all components of a dessert or yogurt product at the time of filling as well as an efficient utilization of resources is ensured.

Figure 1: Picture of a production line

INTRODUCTION

New products and an increasing number of variants define the requirements to production planning in food industry. In the milk processing industry, production planning and production control are particularily complex as the sequence in which aggregates are provided with different products is highly influential on cleaning effort and therefore on the productivity of the facility. Due to storage life restrictions, pre-defined periods of time for aggregate occupancies have to be respected in the production process. In addition, the products are produced at the latest moment possible in order to meet the retailers' and consumers' demands for fresh products.

Statements whether the facilities can produce the forecast order size on schedule or capacity adaptations are necessary were difficult to make up to now. For production planning, there were no software tools at the orderer's disposal which made it possible to calculate aggregate occupancies on the basis of weekly bottling plans (figure 1) [1, 2].

THE SIMULATION PROJECT

Our customer decided to approach the problem by representing the existing dessert and yogurt production in a simulation model. Thus, the task was to conceive and develop a flexible simulation model and to train the employees of the company in handling the simulation tool.

The existing facility and its aggregates, facility topology and product-specific facility occupancies was represented in the simulation model. Aggregate- and product-specific cleaning restrictions were included in the model. The aggregates are at the simulation model's command in the form of a library. The advantage of doing so is the possibility to transfer this library into other simulation models. Thereby, development time for new facility topologies of comparable facilites can be significantly reduced.

The simulation model is parametrized by an Access data base. Specific know-how about the simulation software therefore is not necessary for the application as it is controlled via the data base. The master data of the aggregates, products, restrictions and facility topology are stored there and can be modified by the user. In addition, even the strategies for facility occupancy can be influenced by the user via

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the data base. The existing control logic, which guarantees an optimum load of the filling lines and a resource-saving aggregate occupancy, are accounted for in the simulation model.

THE YOGURT AND DESSERT PRODUCTION

The production of fresh milk products is a multi-level process. In the following, this process is presented very roughly only, as the process wanted to be kept secret by our partner.

1. Preparation of mixing = Pumping milk, sugar, vanilla powder from storage containers via pipelines into mixing tanks.

2. Mixing = The ingredients are mixed during a certain period of time.

3. Storing in tanks = The mixed matter is stored until a production line is prepared.

4. Production = The dessert (cream) matter is heated via pipelines and afterwards chilled again.

5. Incubating = The heated yogurt matter is filled into tanks. Subsequently, a bacteria culture is added and the matter has to maturate for about 12-36 hours.

6. Chilling = The yogurt matter is chilled at a cooler to slow down bacteria activity.

7. Storing = The finished dessert matter is stored until the filling facility is prepared.

8. Filling = The dessert matter is frothed up with whiskers and then filled into cups.

As it becomes clear, it is a long way from milk to yogurt and dessert. Several aggregates, each with specific properties as throughput, capacity, cleaning time etc., are necessary to run this process.

– Tanks: Filling tanks, incubation tanks, mixing tanks with their properties as mass flows, volume, cleaning restrictions.

– Filling lines with the properties throughput in cups/h, cleaning restrictions, changeover.

– Production lines with their properties throughput in liters/h, sterilization processes, line occupancy.

– The yogurt and dessert matter which is continuously transforming during the process from raw milk to the cup.

Dessert and yogurt products mostly consist of 2-3 components (semi-finished products), which – in different flavours – are filled into cups of different dimensions. Thus, two semi-finished products, e.g. yogurt and strawberry, have to be filled synchronously. Though, the production start of the semi-finished products thereby is totally different.

The challenges in daily planning are the following:

– The lines should never stand still as they are determinative for the throughput.

– Cleaning is to avoid as this is waste of material and expenditure.

– The number of tank occupancies should be as small as possible in order to economize cleaning effort.

– Simultaneous filling and draining of tanks cuts down throughput time.

– Combining filling orders of the same flavor which are filled into different coutry-specific packings in the last production step.

CONTINUOUS PROCESSES IN THE DISCRETE SIMULATOR

In discrete simulation, only defined points of time on a fictive time bar are taken into account. Discrete here means isolated resp. disjoined. When a mobile object enters a resource, the simulator puts a mark shifted of the processing time. The administrator of the incident, who controls all chronological simulation activities, subsequently jumps directly to the next discrete point on the time bar and executes the given orders.

The production considered here is a batch-oriented production. But many decisions go on at discrete points of time so that modelling takes place both batch- and incident-oriented.

Incident-oriented: In the receptacles, the semi-finished and finished products are represented as single objects (object with one volume resp. one mass). Advantage: easy batch management in the simulator. Realization of a decentral control.

Continuous: In the continuous processes (e.g. production line), there is a flow-oriented representation, i.e. no disintegration of batches into a multitude of objects, but an exact, mathematically correct representation. Advantage: higher simulation speed.

As control and scheduling logic made up for the main complexity in the project, a discrete simulator was used in the presented project and the continuous processes were emulated.

SCHEDULING LOGIC

In this paragraph, it is shown why a pure forward simulation is not target-oriented. The backward simulation-based approach was realized [3, 4, 5].

Forward simulation-based approach

By forward simulation, we understand the simulation of production orders in the direction of the material flow. Starting from the start date, the production orders are dispatched to production until they leave production after the processing.

For a better illustration, a production and assemply process is represented in figure 2. A module consists of three components. Each sphere symbolizes a process step. When the three components are completed, assemply can begin.

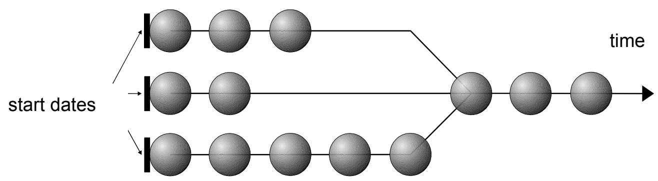

Figure 2: Forward simulation

A weak point of pure forward simulation is that only in a special case all components are completed at the same time. In figure 2 unwanted waiting time arises for the components in the two upper rows.

In order to minimize throughput time, the start dates of the components can be varied. When the processing procedures interact, it is not sufficient to only begin the start times delayed by the waiting times. Such an interaction exists when the processing procedures of different components are executed on the same resources.

A backward simulation is recommended in order to minimize unwanted waiting time.

Backward simulation-based approach

The backward simulation corresponds to the inversion of forward simulation. The clocks quasi run backwards. The finished products are “decomposed” into their components in the course of time. In figure 3, the “decomposition” of a finished product into its components is depicted. As start date of simulation, the delivery date is is chosen.

- For each work step we get the latest start and finish date. Thus, short throughput times can be obtained. When a work step starts later than the corresponding basic date, this unavoidably leads to scheduling delay.
- The completion date of the last work step can be used as start date for forward simulation.

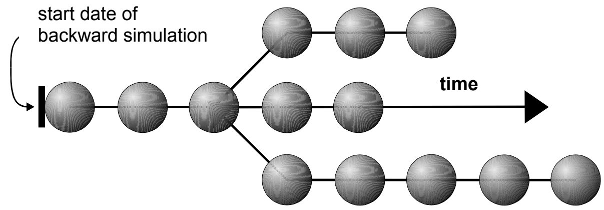

Figure 3: Backward simulation

In some cases, the backward simulation is insufficient for complete scheduling of dessert production as not all processes can be exactly inverted. For instance, many restrictions can only be formulated forwardly. Furthermore, in a pure backward simulation no statements about receptacle occupancies etc. can be made. Thus, subsequent to the backward simulation, a forward simulation is executed.

Forward simulation (subsequent to backward simulation)

The above-mentioned cognitions show that neither a pure backward simulation nor a pure forward simulation bring about satisfactory results. When executing a forward simulaiton after a backward simulation and taking over the start dates of the components, the advantages of both simulations are unified (figure 4).
By this combined backward-forward simulation, advantageous start dates of the components are obtained whereby short throughput times result. The modeling discrepancies which may occur because of backward simulation can be compensated by a forward run that can be exactly modeled.

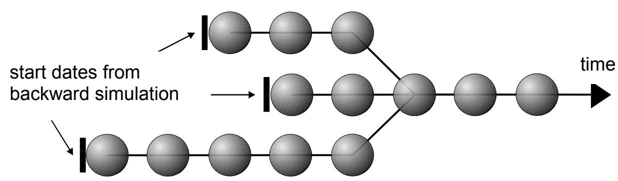

Figure 4: Backward-forward simulation

REALIZED SCHEDULING LOGIC

The starting point of utilization planning are the delivery dates of customers' orders. Hence, the desired finish dates of a filling order resulting thereof are taken as starting point for the simulation. The decisive question is at which point of time the first process step has to be started at the latest.

This task is solved by undertaking the aggregate occupancies backwards, starting from the last process step "filling" at the desired point of time. The material flow and the time recording comport inversely to reality in the simulation model. A disassembly of yogurt into its basic ingredients can be clearly imagined.

The chosen approach has the advantage that provision of all ingredients of a dessert or yogurt product at the time of filling as well as an efficient resource utilization are ensured. For instance, a classic product of our partner from food industry consists of pudding and cream. It has to be ensured that, at the time of filling, enough pudding and cream are provided in tanks.

The challenge for the developer team in the project therefore always consisted in thinking "backwards" in relation to the production run. After some doubts at the beginning it became clear that rules and restrictions of any kinds in the production run are reversible.

THE CONFIGURABLE SIMULATION TOOLSET

Higher planning security in tactical capacity planning

A requirement of our industrial partner was to make reliable statements for tactical capacity planning. The requirement was fulfilled by parametrizing all important master data in the model via the data base. The capacity of an aggregate can be varied, an aggregate blocked and a thitherto in the real facility non-existing "virtual" aggregate can be added. Cleaning restrictions can be abolished or tightened or the facility topology, i.e. the aggregate sequence, can be modified.

The user has the possibility to act out manifold scenarios in the model, e.g.:

- "Can the order load also be produced at the right time with one tank less?",
- "By how many tons can the filling quanity be augmented when investing in one additional tank?" or
- "What influence does easing of a cleaning restriction have on load and productivity?"

So as to answer these questions, the user can dispose of a detailed automatically generated evaluation of a simulation run. For a fast analysis, the user can consult load diagrams of the aggregates generated in HTML (figure 5). For a detailed evaluation, manifold key figures are calculated and the complete occupancy is shown in a Gantt diagram. In this Gantt diagram, the aggregate occupancy in the course of time is depicted graphically. The aggregate occupancy of an order can be retraced in this depiction.

The model had to be proved shortly after completion for real planning tasks. One question was "What influence do new product variants have on my facility?" resp. "Are the existing capacities sufficient for the forecast sales development?" Furthermore, the consequences of a planned capacity expansion were analyzed.

Within a short period of time, these questions could be answered comprehensibly. Capacity bottlenecks could be identified by the aid of evaluation facilities and the eventual necessary capacity adaptation could be found and proved.

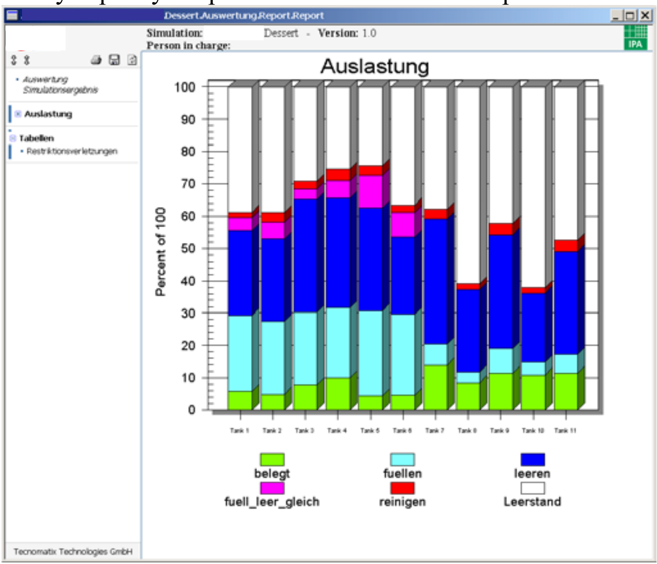

Figure 5: Evaluation of a simulation run – load

Higher quality and less effort in operative production planning

Another requirement was supporting operative production planning.

Validation of the results showed a discrepancy of the simulaiton results of less than 5% from reality. The discrepancies are related to the highly fluctuating efficiencies of some aggregates.

This lead to high acceptance of the employees in production planning. Another benefit is the short duration of a simulation run. Weekly planning on a standard computer lasts less than three minutes.

Production can be controlled by defining the latest possible start dates for production orders and detailed aggregate occupancy in the Gantt diagram (figure 6).
Furthermore, the user can check the influence on the facility occupancy by exchanging orders and thus, by trying, carry out a sequence optimization of order processing.

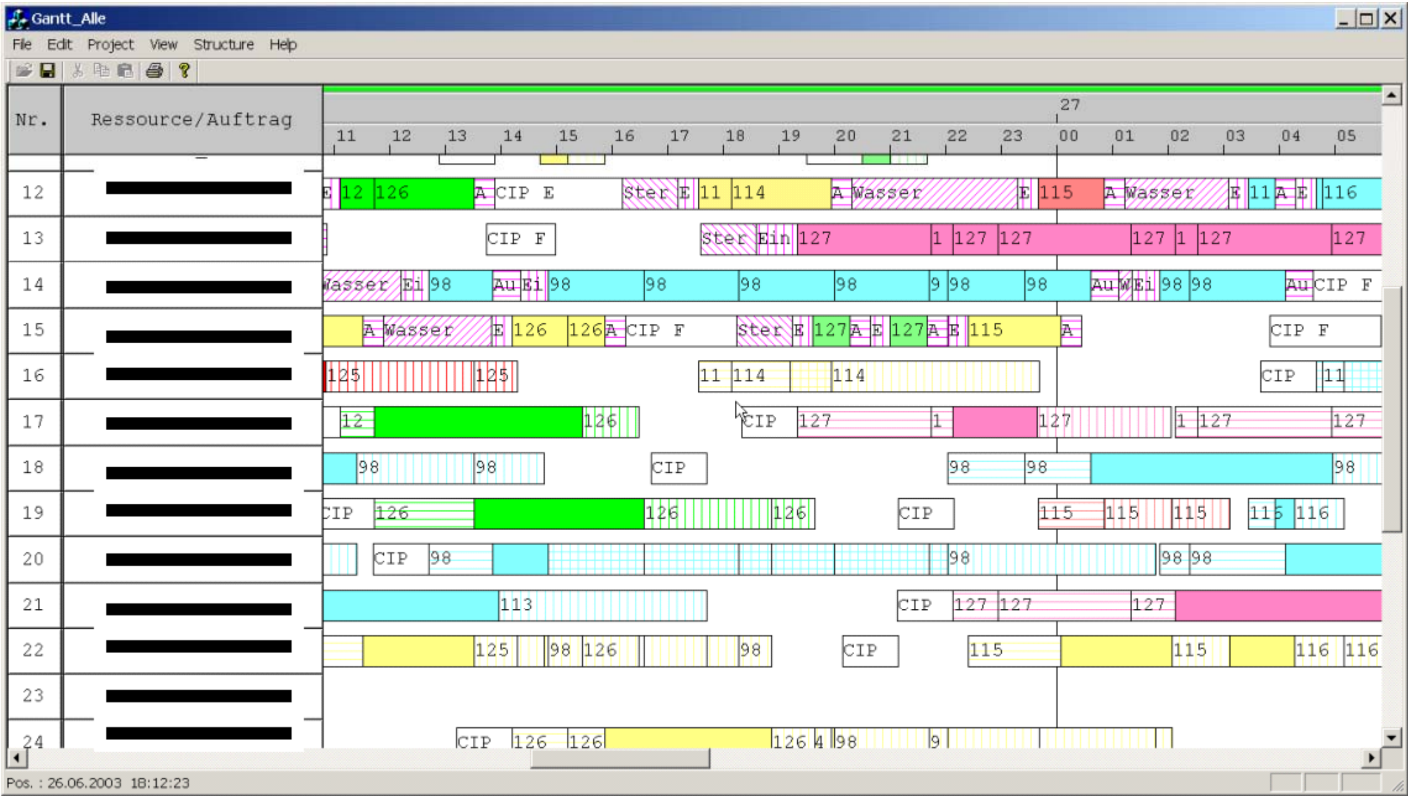

Figure 6: Evaluation of a simulation run – Gantt

BENEFIT FOR OUR CUSTOMER

A requirement of our industrial partner was to make reliable statements for tactical capacity planning. The user gets the chance to do so by configuring the production, acting out scenarios in the model and analyze them by the aid of detailed evalutations.

Capacity bottlenecks can be identified by means of evaluations and necessary capacity adaptations can be found and proved.
The simulation model has also been used for other plants since it has been completed. Its modular construction makes possible – with little effort only – to picture other plants, too.

The project shows the considerable use of simulation models in automized process industry. It is obtained by higher planning security, quality and speed. Thereby, the ability to quickly react to altered general conditions is increased.

CONCLUSION

The project shows the considerable use of simulation models in automized food industry. It is achieved by higher planning security, high quality in production planning and an increase in planning speed. The ability to quickly react to altered general conditions is increased.

Withal, development costs of a simulation model mostly only make up for a trickle of the costs caused by a misinvestment.

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