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IMPLEMENTATION OF A SIMULATION MODEL FOR THE SCHEDULING OF A MULTI-PRODUCT DAIRY PLANT

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ABSTRACT

Dynamic scheduling of multi-product plants is one of the most difficult groups of problems of high economic importance. The well developed, conventional solutions use various methods of mathematical programming (e.g. MILP), formulated as the optimization of a simplified model. However, the specific technological details and the possible multiple use of the model require also detailed dynamic model based sub-optimal methods. Considering the inherent coupling between structural and functional characteristics of dynamic scheduling, Direct Computer Mapping (DCM) based Programmable Structures of Research Group on Process Network Engineering are experimentally applied for the generation of the dairy plant model. The generation starts from the process network representation of the flow-sheet and from one state and one transition meta-prototype. The flow-sheet comprises storages of raw materials, intermediate materials and end-products, as well as the recipes, the in parallel working multi-functional process units with the numerous time-driven and event-driven constraints. Model generation is followed by the programming of the actual prototypes and parameterization of the model. In the present work the generated process model and the simulation tests will be discussed, focusing on the combined use of the transitions for the description of the material balance, as well as for the interpretation of the time- and event-driven rules, determining the sequence of operations.
Keywords: production scheduling, dairy plant, multiproduct batch plant, dynamic simulation, process modelling, Direct Computer Mapping, Programmable Structures

INTRODUCTION

In the dynamically changing economic environment the food industry has to react and be flexible in more time horizons, which requires flexiblity not even in the field of production, but in the planning and scheduling methods as well. Science acknowledged this need and the difficulties to find the best solutions quite early (*Puigjaner*, 1999). To achieve success, in this field we need a strategy which ensures at the same time the competitiveness and the high economic results, even in variable profile, technology and management resources. The production scheduling and planning allow us to use the resources in a structured form. Consequently, the management of stock, resource and capacity will be improved.

The research in production management defines MTO (make-to-order) and MTS (make-to-stock) production systems (*Soman et al.*, 2004). MTO approaches to solve the scheduling task from the orders of customer specific products. The main

Key Performance Indicator (KPI) is the short reaction time. MTS is characterised by low range of products and low cost of production. In this case the main question is the forecast of the demand. KPIs are stock planning, batch sizes and the forecast.

Dairy industry, as several other ones, is a hybrid variation of these two clear systems. Overall, orders arrive maximum 24 hours before the required tranportation date, but only 8 hours earlier on average. Depending on the production technology of different product ranges (milk, cheese etc.), the method of the planning system changes.

Kopanos, Puigjaner and Georgiadis (2010) developed a discrete-continuous MILP model for the simultaneous production scheduling and batch sizing in a yogurt plant, assuming stable resources. The model focuses more on the packaging process, but takes time and capacity constrains into consideration, too. The whole set of rules work with time of conversions, with downtimes of different reasons, and with hygienic rules. The developed resource constrained MILP model decides about tanks and machines utilised, considering the available connections to the filling and packing lines. It finds the best time to clean the tanks and the filling lines given health and nutrition labeling requirements, and cleaning equipment availability. It synchronises the material consumption with white mass availability and freshness. It respects the batching policies for compliance with traceability regulations. It determines an optimal schedule for labour resources. It maintains a steady supply of finished goods within a minimum and maximum inventory level. It supports optimal production rescheduling under unexpected events, such as modifications in product orders.

The shortcoming of the model is that it concentrates only on a part of the flows. The solution is implemented in an off-the-shelf softwares, CPLEX 11 + GAMS 22.8 interface program. The solution reduces the complexity with complementary formulation (e.g. group of flows). The single objective function is the economic optimum. The authors conclude that „the proper treatment of uncertainty in food industries is of great importance since unpredicted events take place very frequently."

Considering the actuality of the scheduling problem, the present work focuses on the first steps of the development of a Direct Computer Mapping based scheduling application for the yogurt line of Fino-Food.

METHODS AND APPLIED DATA

Applied modelling and simulation methodology

The basic idea of Direct Computer Mapping (DCM) (*Csukás*, 1998; *Csukás et al*, 2011) is that we map the building elements and the structure of process models onto the elements and connections of a computable program code directly, without their representation in any single, specific mathematical apparatus. On the contrary, the individual brief programs can be executed by a cyclically repeated algorithm, similar to an operational system.

The recently used method automatically generates programmable structures for the simulation models from a network structure and from the meta-prototypes of the state and transition elements (e.g. *Varga et al*, 2016; *Varga et al*, 2017). In the graphical (GraphML) model the locally programmable prototypes may be edited from the prototypes. The initialised and parameterised structural model is prepared for the common consideration of „model specific conservation law based" additive measures and of the "over-writable" signals. The general interpreter first generates the case-specific declarative model database, next executes the dynamic simulation. In the applied transition oriented model representation, all of the causally coordinated consequences of the functionalities may be processed together. This feature supports the robust execution of the multiscale models by a general purpose core program. It makes also possible the unified, common generation and execution of the balance-based and the rule-based sub-models.

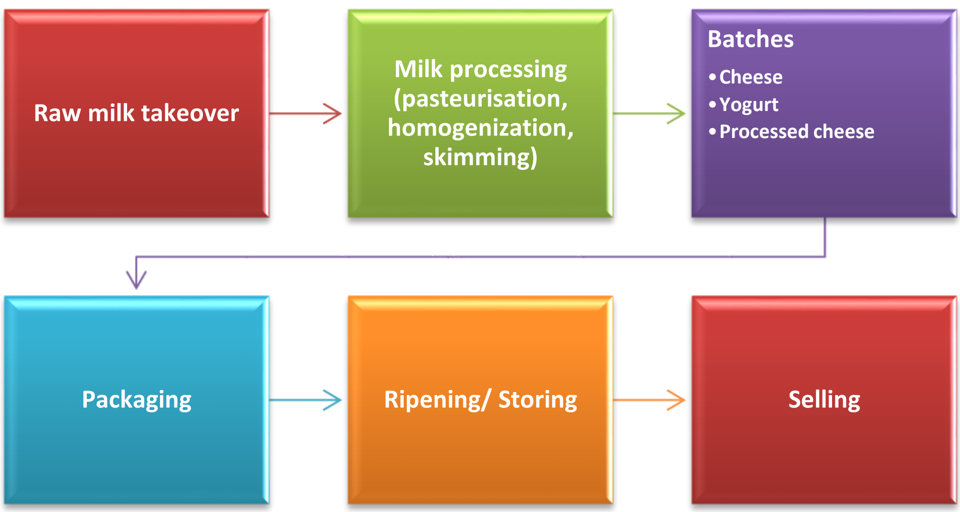
Recently the methodology has been experimentally implemented for simulation based problem solving of various agri-food systems (*Varga et al*, 2015; *Varga and Csukás*, 2015).

Modelled dairy plant and implemented data

FINO-FOOD is a Kaposvár based dairy, owned and managed by a Hungarian family in 100%. Their product range includes liquid milk, sour cream, kefir, yogurt, cheese and processed cheese. Fino-Food works with 350 partners from Hungary, Croatia and Italy. Steps of the raw milk processing system is seen on *Figure 1*.

Figure 1

Process flow of raw milk at FINO-FOOD

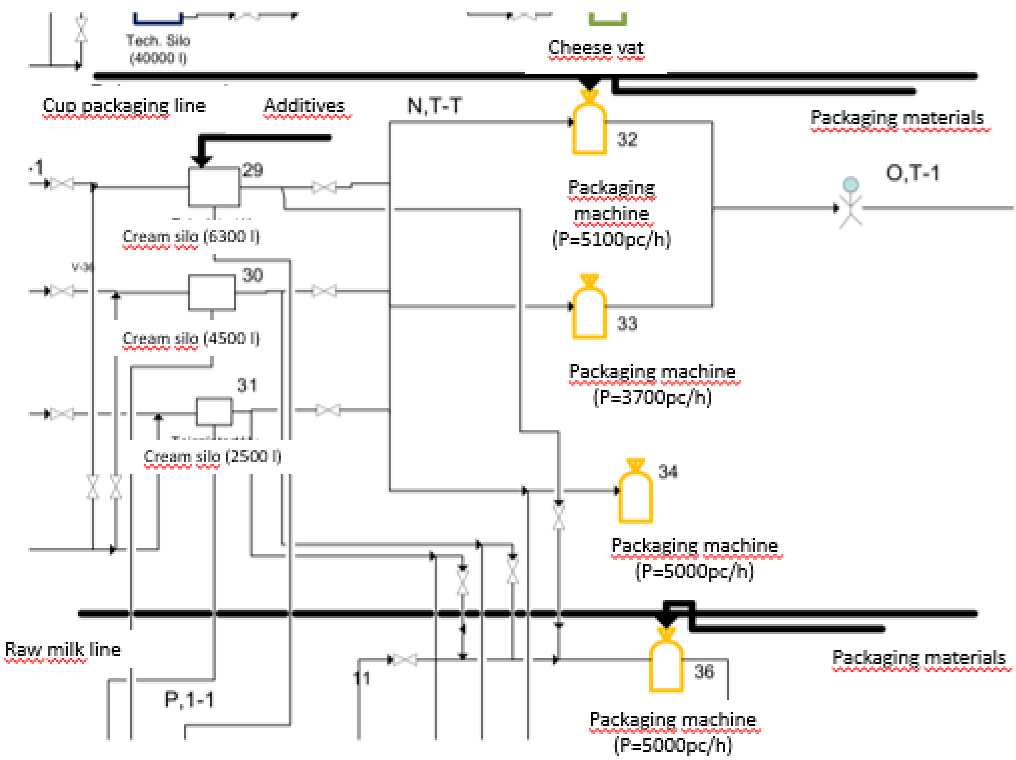


The dairy is currently operating with a three level planning system, monthly, weekly, daily or even shiftly. The targets and the constraints are different on each level. In case of monthly planning, the main target is to equilibrate the raw material balance, which is perhaps the most important factor from the financial performance point of view. The Push feature in the monthly case is the yearly based contracts for raw

milk, which means milk is coming, regardless to customers' order. From Pull side there are only empirical estimations for the expected sales. The weekly scheduling is to achive 100% serving rate. The Pull features are still only the sales from last week, without exact orders. Raw milk causes a Push feature, because the milk has to be processed in less than 48 hours. The weekly schedule is daily or even shiftly reorganised, as the orders arrive during the production day. The aim is the 100% serving rate, taking also into consideration the minimum number of conversions.
Currently, Excel worksheets help the above mentioned process. Data recording is manual from past production, from previous week and from earlier experiences. Assessment of capacity and technological barriers are individual, depending on the planners' heuristics. Because of this kind of process, it faces the problem of inefficient information flow, break-off during the shifts, and lack of resources daily, which results in uncertainty and moreover demotivated workers. As a first trial for the application a non-conventional modelling method for the scheduling of dairy processes, in the present work we focused on the yogurt production line (highlighted with red in *Figure 2.*).

Figure 2

Modelled part (inside the red contour) of dairy production by FINO-FOOD



RESULTS AND DISCUSSION

The GraphML model of the programmable structure, representing the modelled part of the dairy plant is shown in *Figure 3*.

Model building starts with the development of the model structure. In this case, the process was supported by the automatic generation of the structure from a simplified description of the underlying states and transitions. This automatic generation makes possible to develop large structures in line with DCM method. It is to be noted that in case of DCM model the structure generation covers also the automatic creation of the slots for the states and transitions, as well as the connections between them. Slots are responsible for the storage of all inputs, parameters, conditions and constraints that are used for the calculation in every time step during the forward or backward simulation.

For the investigated part of the dairy plant the state and transition elements were the followings.

Bases (state)
Base elements mean the base material of final consumer product. These elements contain the semi-products coming from the first technological process, (pasteurizing, skimming, fat setting).

Cultures (state)
These elements handle the stock of actual cultures for the various cultured products.

Culture tanks (state)
Before packaging, the bases and the culture are mixed together and matured in the so-called culture tanks. Scculttank1_4 and Sculttank5_7 are the state elements containing the constrains of each tank, like capacity, cleaning time and the cleaning frequency. These parameters are responsible for the handling of various rules.

Processes of culture tanks (transition)
Each culture tank has its transition element as well. Since culturing is a technological process, in a transition kind element we parameterise the recipe of each products. The description contains the minimum and maxium of operation time spent in the tank by each SKU, as well as the recipe for the components, wich are mixed in the tank.

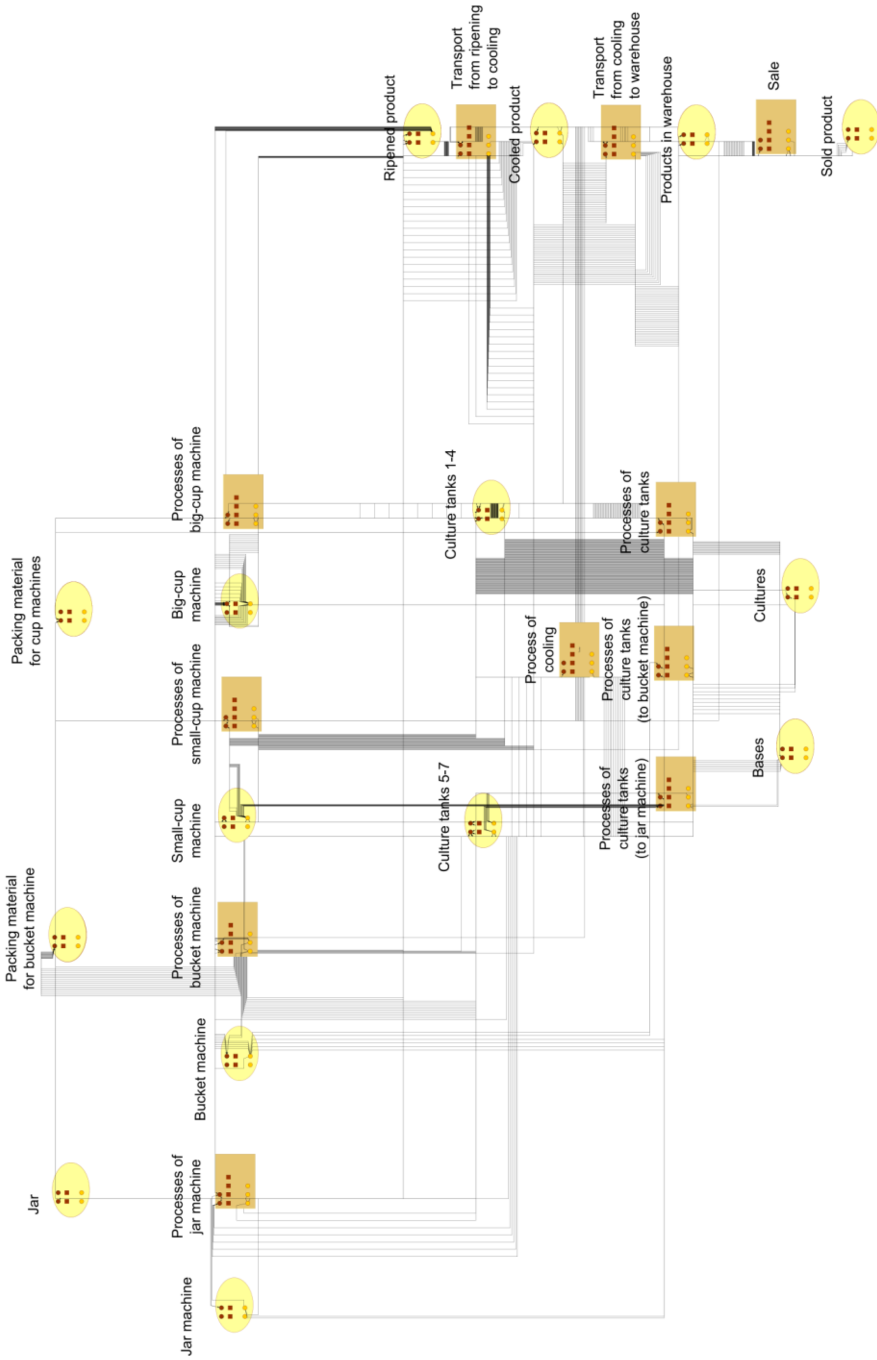
Processes of cooling (transition)
After culturing time the yogurt kind products have to be cooled and transferred to another tank. All the cooling possibilities have one element, depending on from which to which tank the process goes.

Packaging materials (state)
All other material used to the productions, like cup, layer, jar, bucket, etc.

Package machines (state)
Each packaging machine has its state and transition element. The state element contains the capacity and cleaning frequency information of the machine.

Figure 3

The programmable structure of the modelled part of the dairy plant



Processes of package machines (transition)
The transition element of machines makes us possible to put the packaging material and the cultured semi products together and to get the final SKU (stock keepin unit). They contain the recipe of materials needed to one single SKU, as well as the control cycle of the machine.

Ripened product (state)
As an important technological step the model handles the ripening of fermented SKUs, like yogurt, sour cream. After packaging, the product goes to the ripening room and we identify it as a semi-product, so called riped product. Ripening time is a part of the recipe.

Transport elements from ripening to cooling, from cooling to warehouse (transitions)
These kinds of transition elements are responsible for the transport of various stocks between the processing or storing units.

Cooled products (state)
It is the storage for the final cooling of the products with a prescribed time.

Products in warehouse (state)
It is the final storage before the sale.

Sale (transition)
Determines the scheduled sales.

Product (state)
Registers the sold products

Figures 4, 5 and 6 show some illustrative results for the forward and backward simulation of the weekly production of cultured semi product sp_10208, as well as p_10208 products of one packaging machine. Accordingly, the abscissa shows temporal data about the forward simulation from 0 to 168 hours, as well as from 168 to 0, backwards.

Figure 4

Cumulated use of culture and base for semi-product 10208

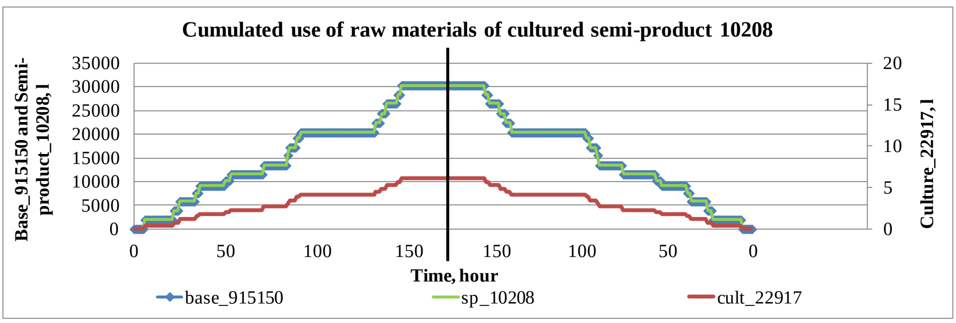


Figure 5

Cumulated use of packaging materials for product 10208

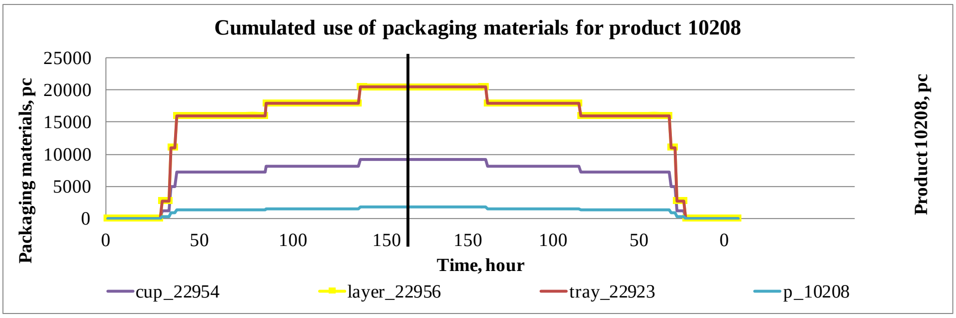
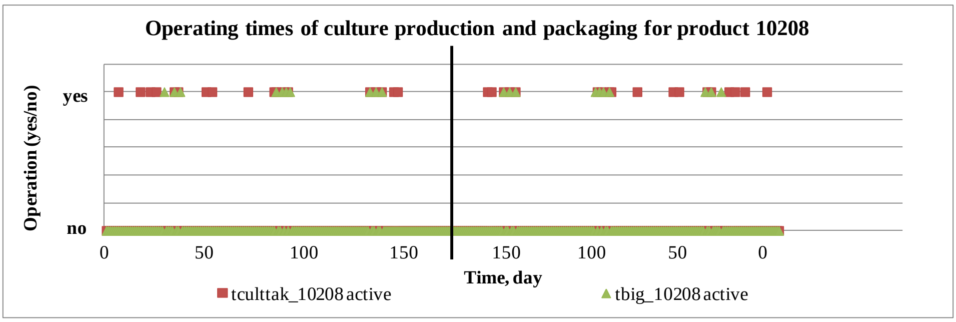


Figure 6

Operating times of culture tank and big-cup machine, producing 10208



CONCLUSIONS

The process system of a multi-product batch dairy plant was implemented in a programmable structure, in sense of Direct Computer Mapping. The automatic generation of the process network from the textual description of the underlying simple network and from the state and transition meta-prototypes was successful. It was followed by the stepwise development of actual local program prototypes of the state and transition elements. Recently the model has been tested for the forward and backward dynamic simulation of the dynamic model.

It has a significant importance in the solution of scheduling problems, because in this case we can start from the actual demands and can simulate backwards in time to determine the amount of necessary raw materials, packaging materials and operation times, with the knowledge of the underlying multiple constraints. The solution for the causally right backward simulation has been proved in the present work. The ongoing work will be continued by the development of backward simulation based dynamic scheduling.

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