Production Scheduling of Multi-Stage, Multi-product Food Process Industries

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Abstract

The production scheduling of a real-life multi-product, mixed batch and continuous food industrial facility is considered in this work. More specifically, the scheduling of canned fish production in a large-scale Spanish industry is studied in detail. The deployment of an efficient solution strategy is proposed to handle the computationally challenging scheduling problem. In particular, a Mixed-Integer Linear Programming (MILP) model is used, in parallel with a decomposition technique. The problem under consideration focuses on two important stages of the plant, the sterilization and the packaging. The proposed strategy takes into account the specific characteristics of the canned fish production facility resulting in interesting results. It should be noted that the same methodology can be used with appropriate modifications in other food process industries with similar production characteristics.

**Keywords**: production scheduling, multistage, food industry, mixed integer programming, decomposition.

* 1. Introduction

The scientific community has widely recognised the importance of applying scheduling solutions to industrial cases which so far is not adequately applied in real-life plants (Harjunkoski et al., 2014). Therefore, there is a growing interest in the theoretical implementation to industrial practice. Many challenges exist due to the complexity of such cases in terms of number of stages and their mode of operation, number of products and shared resources typically met in real-life processes. In this work the canned fish production is considered, which comprises of multiple batch and continuous production operations, thus working in a semicontinuous production mode. Numerous studies addressing batch or continuous production modes are found in literature (Mendez et al., 2006). Nevertheless, not much work has been done considering semicontinuous processes, despite being very common in food industries. Amorim et. al (2011) developed a hybrid genetic algorithm, for the lot-sizing and scheduling problem of a dairy industry considering perishability issues. Kopanos et. al (2010) studied a real-life yoghurt production process and proposed a novel mixed discrete/continuous time representation. The problem was mainly focused on the packaging stage, since it was identified as the production bottleneck. The main challenge in the efficient scheduling of food process industries is the integrated modelling of all production stages. Optimizing all processing stages increases the plant production capacity by reducing unnecessary idle times and reduces the production cost of final products.

* 1. Problem Statement

This work considers the scheduling of canned fish production in a real-life industrial facility. In particular, the production process of FRINSA, one of the largest canned fish industries in Europe is investigated using realistic process data. The plant can produce more than 400 final products and has a production capacity of 3-4 million cans per day. Several stages, mixed batch and continuous, are required for the production of each can (Fig.1). Initially, the fish stored in blocks is unfrozen and then filled in cans along with the ingredients (e.g. oil, tomatoes, etc.) required by the recipe. The next stage is the sterilization which guarantees the microbiological quality of the product. Finally, the sterilized cans are packaged (labelling, packing into cartons, boxes etc.) into the final products.

Process Description

Figure 1: Canned fish production line layout

The plant is a multiproduct multistage facility combining both batch (unfreezing, sterilizing) and continuous (sealing and filling, packaging) processes with multiple parallel units. In general, the large production demand and high production flexibility (multiple units can process every single final product) increases significantly the complexity. The sterilization and packaging stages are the most intensive processes of the plant and they constitute the main production bottlenecks. The short-term scheduling horizon of interest is 5 days, whereas the sterilizers and packaging units are available 24 hours. Sequence-dependent changeovers and inventory limitations are considered. The salient characteristics of the scheduling problem is to take into account a large number of design and operating constraints while ensuring demand satisfaction. The overall production schedule is affected by rather conflicting goals such as the optimal use of resources, the minimization of makespan and the reduction of costs and optimal energy use.

* 1. MILP-based Solution Strategy

The key decisions to be made are related to: a) the required number of product batches to be scheduled, b) the allocation of batches to units in every stage, c) the relative sequence of product batches in each stage and d) the start and completion time of product batches in each stage. The proposed MILP-based solution strategy consists of: (i) a pre-optimization step, where the batching problem is solved, (ii) the MILP model which is used to optimize the schedule based on a specific objective and (iii) an order-based decomposition technique, to split the initial problem into sets of tractable subproblems.

* + 1. Pre-optimization step

In most food industries, such as the one studied in this work, the industrial practice imposes operations of the intermediate batch processes in their maximum capacity. The maximum utilization of the batch stage, allows for high production levels and minimization of changeovers between products. Hence the batching problem can be solved a priori. Constraints (1) define the minimum number of batches, *βp,* to fully satisfy the demand based on the total demand, the capacity of sterilizers and storage limitations. Constraints (2) calculate the required time *tp,b* to process each batch in the packaging stage.

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* + 1. MILP model

The MILP model employed is based on an extension of a general precedence framework as developed in our previous work (Kopanos et. al, 2011). A brief description of the model follows due to the lack of space.

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Constraints (3) ensure that each product batch *p,b* will go through one unit *j* in every stage *s*, utilizing the binary variable *Yp,b,s,j*. The timing constraints (4) and (5) are imposed for a product batch in the same production stage. In particular, constraints (4) ensure that the completion time of a product batch in the sterilization stage *Cp,b,s* is equal to the starting time of the process *Lp,b,s* plus the required sterilization time for the specific product. Same holds for constraints (5), which express the connection between the start and finish of the packaging processes based on the required packing time for each product batch . Constraints (6) state that the packaging process of product batch starts exactly when the sterilization process is completed. A single production campaign policy is guaranteed by constraints (7). The sequencing constraints between product batches in both processing stages are portrayed in constraints (8) and (9). More specifically, constraints (8) enforce the starting time of a product batch *p’,b’* to be greater than the completion time of a product batch *p,b* processed beforehand, plus the corresponding changeover time *chp,p’,j*, when both batches are allocated to the same packing line. Similarly, constraints (9) define the sequencing of different products in the sterilization stage. Two general precedence binary variables are employed, *Xp,p’*, , while *M* is a big-M parameter. The objective function of the model is expressed by constraints (10), which is the minimization of the total production makespan, *Cmax*, hence it also considers the minimization of changeovers and unnecessary idle times.

* + 1. Decomposition Strategy

The goal of the decomposition strategy is to split the initial problem into several tractable subproblems, which can be solved by the proposed MILP model in a reasonable time. In each subproblem a predefined number of products are scheduled. Basic parameters of the decomposition algorithm are the position of the last scheduled product *z* and the number of products scheduled at each iteration step.

Fig. 2. illustrates the flowchart of the solution strategy algorithm. Initially, the batching decisions are made in the preoptimization step. Afterwards, the decomposition algorithm parameters are defined and the subproblem is solved utilizing the aforementioned MILP model. Next, the derived decisions made for the specific subproblem are fixed and the algorithm continues to the next iteration. Finally, when all products are considered, the final schedule is generated.

Solution Strategy

Figure 2: Solution strategy algorithm equivalent flowchart

* 1. Case study

An industrial case for the scheduling of 100 final products using realistic data from the FRINSA production plant is demonstrated. The preoptimization step calculates that 362 batches are required in total to satisfy the demand. Utilizing the proposed decomposition technique, 20 final products are scheduled in each iteration. The MILP model was implemented in GAMS 24.9 and solved using CPLEX 12.0. Optimality is reached for all iterations of the suggested solution strategy. Figure 3 illustrates the complete schedule generated for the sterilization units, while in figure 4 the corresponding schedule of the packaging units is depicted.

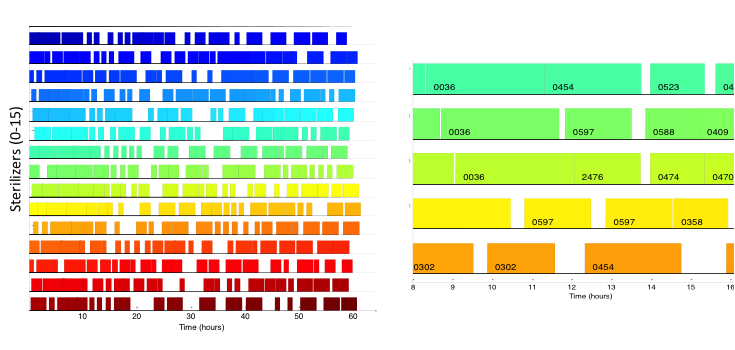


Figure 3: a) Gantt chart of the sterilization units, b) indicative schedule with product codes for the ST7-11 sterilization unit during 8hrs

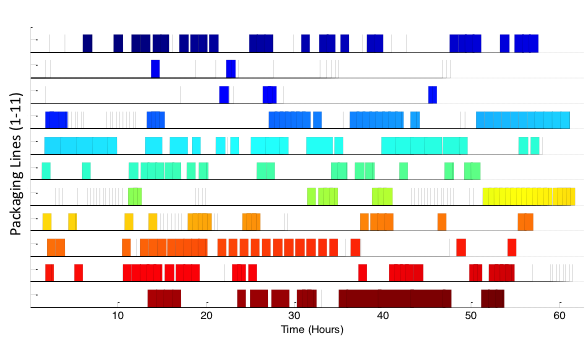


Figure 4: Gantt chart of the packaging units

It is evident from the Gantt charts (Fig. 3) that the sterilizers are more active than the packaging units. On the other hand, the utilization in the packaging stage depends on the demand profile, since each product can be processed only at specific packaging units, whereas all products can be processed in any sterilizer. Nevertheless, all packaging units are underutilized compared to the sterilizers. Hence, the sterilization stage is identified as the production’s bottleneck in line with conclusions made by the plan operators. This is also illustrated at Fig. 5, where the utilization of all units is illustrated.

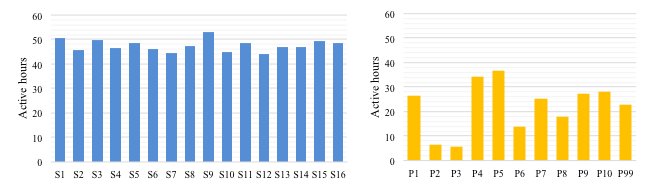


Figure 5: a) Utilization of sterilizers and b) packaging units

* 1. Conclusions

This work presents the production scheduling of a real-life industrial problem. More specifically, the sterilization and packaging stage of a canned fish production facility have been scheduled using recent advancements on mathematical programming-based scheduling. The aforementioned plant structure (a batch process followed by a packing stage) is typically met in many industries such as food and consumer packaged goods, hence, the applicability of the presented solution strategy can be implemented in other industrial problems. It was demonstrated, that the proposed MILP-based solution strategy can successfully solve a scheduling problem with significant degree of complexity in terms of number of products, shared resources, stages and multiple operational and quality constraints. The results illustrate that the sterilization stage is the main production bottleneck, an important conclusion for further investigation. As future steps, the integration of all production stages of the plant will be considered. Moreover, cost related objectives and the introduction of uncertainty in product orders will be considered in a rolling horizon scheduling framework.

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