An MILP-based approach to short-term production scheduling and lot sizing with major and minor setups
A case study from the beverage industry

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1 Introduction

As a case study, the production of beverages, e.g. fruit juices and soft drinks, is considered. In this industry, there is often only one single production stage after which final products are packed and shipped to warehouses or individual customers. This type of production environment is known as “make-and-pack production”. Specifically in the production of beverages, combined bottling and packaging lines are established for each package type, e.g. plastic bottles, carton boxes, and bag-in-box containers. A line usually produces a number of product types, e.g. juices of different flavor, and packages them into individual units for use by end customers. Each product type, e.g. orange or pineapple juice, corresponds to a specific recipe which determines the ingredients and the processing conditions of the product type.

To cope with the increased product variety, manufacturers mostly pursue a production policy with short production cycles for product types and frequent changeovers between products within the same product family. Typically, production lines are set up for a specific package form requiring a major setup such that the changeover between the individual product types can be accomplished with only a minor setup operation or cleaning out the equipment and the pipelines which connect the pre-mix tanks with the filling lines.

The intention of this paper is to develop an optimization model for short-term scheduling and lot sizing in beverage production. The model formulation is based on the block planning concept proposed in [1].

2. Block planning

Scheduling problems with sequence-dependent setup costs and times have been an area of considerable scientific interest (cf. the comprehensive reviews given in [2,3]. In many industrial applications, however, setup sequences are determined by technological restrictions. For instance, in industrial make-and-pack production systems, scheduling policies can be found which rely on a given sequence of product variants within a product family. For example, setups are sequenced from products with high to low purity requirements, from the lower taste of a food product to the stronger, or from the brighter color of a product to the darker. Such policies are known in practice as “block planning”. So far, in the scientific literature the application of block planning concepts and the development of corresponding optimization models are widely neglected though block planning concepts are easy to implement and reflect managerial practice prevalent in make-and-pack production. Only a few papers presenting ap-
Applications of the block planning approach can be found, e.g. [1,4,5]. Major characteristics of the block planning concept are the following.

- Given the assignment of products to setup families, fixed setup sequences of products are defined based on human expertise and technological requirements.
- Each block corresponds to a setup family and is scheduled in a cyclical fashion, e.g. one block per week.
- The composition of the individual blocks is not necessarily the same. Binary decision variables indicate whether a product is set up or not and continuous decision variables reflect the lot size of each product in the block. Depending on the development of demand over time, the lot sizes of an individual product may vary from block to block. As a result, also the time needed to complete a block is variable.
- The start-off and completion dates of a block are not directly linked to the period boundaries. Hence, a block is allowed to start in an earlier period as soon as the predecessor block has been completed. However, the execution of a block must be finished before the end of the assigned period.
- Typically, a major setup operation is performed before starting or after completing a block (e.g. for cleaning the manufacturing equipment), while only a minor setup operation is required when changing between products within the same block (e.g. for provision of material or for adjusting the processing conditions).
- The usual objective function is to minimize total inventory holding and setup costs. Major constraints arise from the available production capacities and the satisfaction of external demand.
- Macro-periods, e.g. weeks, are used for the assignment of blocks while the assignment of external demand elements is based on micro-periods, e.g. days.
- For each product inventory balances are updated on a daily basis according to the production output from the various production lines and the given external demand.

3. Model formulation

Generally, the problem of determining production order sizes, their timing and sequencing in make-and-pack production with setup considerations is equivalent to a capacitated lot size problem. However, the related models presented in the academic literature do not sufficiently reflect the need for scheduling production orders on a continuous time scale with demand elements being assigned to distinct delivery dates. Moreover, issues like the definition of setup families with consideration of major and minor setup times and multiple non-identical production lines with dedicated product-line assignments are seldom addressed in a realistic way.

For application in make-and-pack production an MILP model based on the block planning concept is developed. It reflects major issues arising in the beverage industry, e.g. cyclical production policy, major and minor setups, clean-out of equipment at the end of the week, and daily demand assignments. The MILP model formulation uses a continuous time representation to model the production runs for all products within a setup family while a discrete time representation is used for the assignment of blocks to macro-periods and for the daily assignment of demand elements. Binary decision variables refer to the setup of blocks, production lots for packaging forms, and sub-lots for product types. Continuous variables are used to model the lot sizes and sub-lot sizes, inventory levels and the timing of the various production activities.

The objective function minimizes total production costs, clean-out costs at the end of a block, major setup costs for production lots, minor set up costs for sub-lots, and inventory holding costs. The MILP model contains a number of constraints in order to model the setup conditions, the allocation of production quantities between the production lot and the sub-lot level as well as the succession of production activities and setup operations on the bottling and packaging line. Since customer demands are assigned to daily delivery periods, a discrete heaviside function consisting of a sequence of binary decision variables is introduced in order to
trace the completion of production lots on a daily time scale. Through a switch from 0 to 1 these variables indicate that a specific production lot has been finished up to a particular day and the production output becomes available for delivery to customers or distribution centres.

4. Numerical experiments

The proposed optimization model was implemented on a standard PC using CPLEX as solver. Optimal solutions are obtained within a few seconds of CPU time for problem instances with a four-week planning horizon. Numerical results are carried out in order to compare a flexible block planning approach which allows a considerable time window for the execution of the production activities with rigid block planning which assumes narrow time limits for scheduling the individual blocks.

Data used in the numerical investigation reflect realistic industrial settings in the production of beverages. Since a short-term planning horizon of four weeks is considered, seasonal demand variations are reflected by two scenarios which assume an average workload of 75% and 90% of the available total capacity, respectively. Moreover, since demand in the fast moving consumer goods industry is driven by customer orders of various sizes, we consider the granularity of demand elements as a key factor in our numerical experiments. In order to reflect these issues, we examine three levels of demand granularity: high, medium, and low. For instance, high demand granularity implies a large number of small-sized customer orders while low demand granularity is given by a comparatively small number of large-sized orders. Numerical results clearly reveal the superiority of the flexible block planning approach.

References