A Study of Different Subsequence Elimination Strategies for the Soft Drink Production Planning

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ABSTRACT
The production of soft drinks involves two main stages: syrup preparation and bottling. To obtain the lots sequence in the bottling stage, three approaches are studied. They are based on the sub-tour elimination constraints used in mathematical models for the Asymmetric Traveling Salesman Problem. Two of the mathematical models are from the literature and use classical constraints. The third model includes multi-commodity flow constraints to eliminate disconnected subsequences. The computational behavior of the three models is studied using instances generated with data from the literature. The numerical results show that there are considerable differences among the three models and indicates that the multi-commodity formulation provides good results but it requires far more computational effort when the instances are solved by a commercial software.

Keywords: Production planning, integrated lot sizing and scheduling models, asymmetric travelling salesman problem, multi-commodity flow.

1. Introduction

Supply chains management has received a lot of attention by practitioners as well as by the research community. The speedup of the computational technology has allowed the incorporation of several aspects of a supply chain into a single model. Chiu et al. [1] studies Economic Production Quantity problem considering multiple or periodic deliveries of finished items. Vanzela et al. [2] address the integration of the lot sizing and the cutting stock problem in the context of furniture production. Another recent trend has been on mathematical models that capture the relationship between the lot sizing and scheduling problems [3]. The so named lot-scheduling models have been proposed for several industrial contexts. For example, the glass container industry [4] and the animal feed supplements industry [5]. It is also considered in the design of virtual cellular manufacturing systems (e.g. [6]).

Two main approaches have been used to model the scheduling decisions. The first one is a small bucket approach in which each period of the planning horizon is divided into sub-periods. For each sub-period only one item can be produced. This approach is based on the GLSP model [7]. The second approach is a big bucket one that allows the production of several items in a given period. Sub-tour Elimination Constraints (SEC) from the Asymmetric Travelling Salesman Problem (ATSP) are added to the lot sizing formulation to obtain the production sequence.

The small and big bucket approaches have been used to model the lot-scheduling problem in the context the soft drink production ([8], [9], [10], [11]). The objective of this work is present a multi-commodity formulation to model the scheduling decisions considering a big bucket strategy. The computational behavior of the proposed model using data from the literature is compared with two other big bucket models presented in the literature, one that uses the SEC proposed by Miller, Tucker and ZEMLIN [10] denominated here by MTZ, and another that uses the SEC proposed by Dantzig, Fulkerson and Johnson [11] denominated here by DFJ.

The paper is organized as follows. In Section 2 the soft drink process and a mathematical model according to literature review are presented. In Section 3 the alternative formulation to model the sequences of lots and an adapted strategy from the literature are presented. Section 4 describes the computational studies and in Section 5 the final remarks are discussed.

2. Brief description of previous work for planning the soft drink production process

The production process of soft drinks in different sizes and flavors is carried out in two stages: liquid flavor preparation (Stage I) and bottling (Stage II). The model considers that there are J soft drinks (items) to be produced from L liquid flavors (syrup) on one production line (machine). To model the decisions associated with Stage I, it is supposed that there are several tanks to store the syrup and that it is ready when needed. Therefore, it is not necessary to consider the scheduling of syrups in the tanks, nor the changeover times since it is possible to prepare a new lot of syrup in a given tank, while the machine is bottling the syrup from another tank. However, the syrup lot size needs to satisfy upper and lower bound constraints in order to not overload the tank and to guarantee syrup homogeneity. In Stage II, the machine is initially adjusted to produce a given item. To produce another one, it is necessary to stop the machine and make all the necessary adjustments (another bottle size and/or syrup flavor). Therefore, in this stage, changeover times from one product to another may affect the machine capacity and thus have to be taken into account. In Section 2.1, we review the single stage, single machine model proposed in [10] to define the lot size and lot schedule taking into account the demand for items and the capacity of the machine and syrup tanks, minimizing the overall production costs. It assumes that there is an unlimited quantity of other supplies (e.g. bottles, labels, water).

2.1 The lot-scheduling model from literature

In the model proposed in [10] the decisions associated with lot sizing are based on the Capacitated Lot Sizing Problem (CLSP) (e.g. [12]). The scheduling decisions use the ATSP approach with the MTZ [13] constraints to eliminate subsequences.

To present the model, let the following parameters define the problem size:

J number of soft drinks (items).

L number of syrup flavors.

T number of periods in the planning horizon;

and the following index:

i, j, k $\in \{1, ..., J\}$; l $\in \{1, ..., L\}$; t $\in \{1, ..., T\}$.

Also consider that the following data are known, superscript I relates to stage I (syrup preparation) and superscript II relates to stage II (bottling).

Data:

a_j^{II} production time for one unit of the item j.

b_{ij}^{II} changeover time from item i to j.

d_{jt} demand for item j in period t.

g_j backorder cost for one unit of the item j.

h_j inventory cost for one unit of the item j.

I_{j0}^{+} initial inventory for item j.

I_{j0}^{-} initial backorder for item j.

K_j^{II} total time capacity of the machine in t.

s_{ij}^{II} changeover cost from item i to j.

S_t maximum number of tank setups in t.

K^{I} total capacity of the tank.

q_l minimum quantity of l necessary.