Computers & Industrial Engineering 72 (2014) 58–71

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

An optimization approach for the lot sizing and scheduling problem in the brewery industry

Tamara A. Baldo [a], Maristela O. Santos [a], Bernardo Almada-Lobo [b], Reinaldo Morabito [c,*]

[a] Universidade de São Paulo, Instituto de Ciências Matemáticas e de Computação, Av. Trabalhador São-carlense, 400, 13560-970 São Carlos, SP, Brazil
[b] INESC-TEC, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias s/n, Porto 4200-465, Portugal
[c] Universidade Federal de São Carlos, Departamento de Engenharia de Produção, Via Washington Luiz, km. 235, 13565-905 São Carlos, SP, Brazil

ARTICLE INFO

Article history:
Received 20 June 2013
Received in revised form 3 February 2014
Accepted 24 February 2014
Available online 4 March 2014

Keywords:
Mixed integer programming
Brewery industry
MIP based heuristic
Production planning and scheduling

ABSTRACT

This study considers a production lot sizing and scheduling problem in the brewery industry. The underlying manufacturing process can be basically divided into two main production stages: preparing the liquids including fermentation and maturation inside the fermentation tanks; and bottling the liquids on the filling lines, making products of different liquids and sizes. This problem differs from other problems in beverage industries due to the relatively long lead times required for the fermentation and maturation processes and because the "ready" liquid can remain in the tanks for some time before being bottled. The main planning challenge is to synchronize the two stages (considering the possibility of a "ready" liquid staying in the tank until bottling), as the production bottlenecks may alternate between these stages during the planning horizon. This study presents a novel mixed integer programming model that represents the problem appropriately and integrates both stages. In order to solve real-world problem instances, MIP-based heuristics are developed, which explore the model structure. The results show that the model is able to comprise the problem requirements and the heuristics produce relatively good-quality solutions.

1. Introduction

Recently the Kirin Institute of Food and Lifestyle (Kirin, 2012) published a survey on the global beer production per country. The production went up 3.7% from 2010 to 2011, marking its 27th consecutive year of growth. China has been the largest beer-producing country in the world for the tenth year in a row, while United States is the second-largest producer. China produced 10.7% more beer in 2011 than in 2010. Brazil achieved a 3.4% growth in 2011, after reporting a 18.2% annual increase in the previous year, and now it is the third largest beer producing country (overtaking Russia in 2010). It has had the highest percentual growth in the past 11 years. This increase has made industries seek for more efficient and effective production planning and control methods.

The production lot sizing and scheduling in a brewery needs to consider various pieces of information in the planning time horizon simultaneously, such as several machines with different capacities and specificities, multiple items to be produced with different demands, more than one production stage involving sequence-dependent setup times and costs, multitanks for preparation and fermentation of different liquids, production synchronization of the stages, storing "ready" liquid waiting for the bottling, among others. Even with all the data variables, it is still hard to devise good production plans. In practice, many companies determine the production planning manually, which can take hours until a satisfactory plan is achieved. Moreover, during the planning horizon, it is often necessary to reschedule the production due to the occurrence of unforeseen events and changes of information, for example, extra client requests, machine shutdowns and unexpected shortages of raw material.

Lot sizing problems can be difficult to solve in practice, depending on the features of the problem. In general, they are NP-hard problems (Bitran & Yanasse, 1982; Meyr, 2002). Models and algorithms for the single-level lot sizing problem with incapacitated and capacitated constraints are discussed by Karimi, Fatemi Ghomi, and Wilson (2003) and Jans and Degraeve (2007). When there is fragmentation of production by stages, a final item has precedent items that should be programmed for production and/or procurement. The different stages have to be coordinated, which introduces an additional dimension of complexity to the lot sizing, referred to as a multi-stage problem (Billington, McClain, & Thomas, 1986). For example, in brewery industries, bottling at a

* Corresponding author. Tel.: +55 1633519516; fax: +55 16 33518240.
E-mail address: morabito@ufscar.br (R. Morabito).

http://dx.doi.org/10.1016/j.cie.2014.02.008
0360-8352/

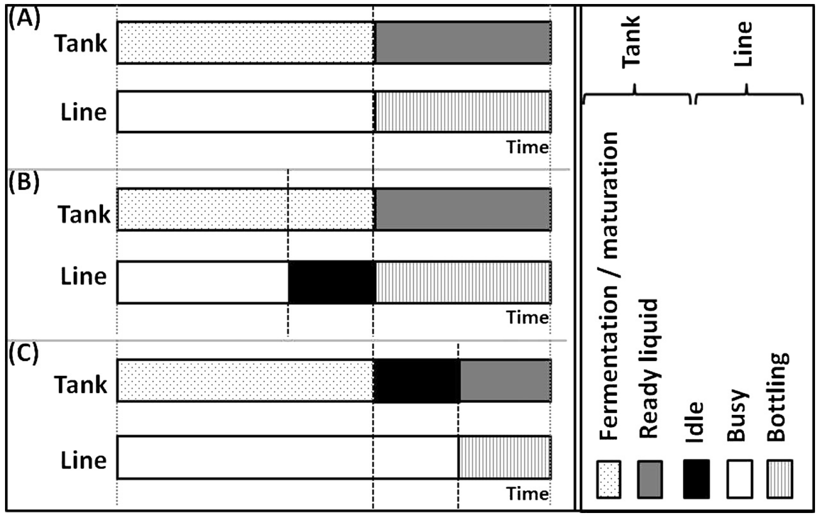

Fig. 1. Synchronization between tanks and filling lines with the possibility to stock "ready" liquid in the tank.

filling line can only start after the liquid gets ready in a tank. Fig. 1 illustrates three feasible situations regarding the interdependencies between tanks and lines. In each case, the production of the tanks (above) and the filling lines (below) are depicted as Gantt charts. In Fig. 1A, an ideal scenario is illustrated where the liquid gets ready after the fermentation/maturation process in the tank at the same instant as the bottling starts on the line. In situation Fig. 1B, the line waits for the fermentation/maturation of the liquid in the tank. Finally, in Fig. 1C the "ready" liquid in the tank waits until the line becomes available for bottling.

Lot sizing problems can consider the sequence-dependent production, i.e., sequence-dependent setup times and costs between the production of different items (Araujo & Clark, 2013; Clark & Clark, 2000; Fleischmann, 1994; Haase & Kimms, 2000; Meyr, 2000; Meyr & Mann, 2013; Shim, Kim, Doh, & Lee, 2011). The underlying lot sizing and scheduling problem can be found in different industrial settings, for example in packaging (Marinelli, Nenni, & Sforza, 2007), foundries (Araujo, Arenales, & Clark, 2007; Santos-Meza, dos Santos, & Arenales, 2002), textile (Silva & Magalhaes, 2006), in the production of glass containers (Almada-Lobo, Oliveira, & Carravilla, 2008), electro fused grains (Luche, Morabito, & Pureza, 2009), animal nutrition (Clark, Morabito, & Toso, 2010; Toso, Morabito, & Clark, 2009), soft drinks (Ferreira, Clark, Almada-Lobo, & Morabito, 2012; Ferreira, Morabito, & Rangel, 2009; Toledo, da Silva Arantes, França, & Morabito, 2012; Toledo, França, Morabito, & Kimms, 2009) and pulp and paper (Santos & Almada-Lobo, 2012). Reviews on lot sizing and scheduling with sequence independent/dependent setups can be found in, e.g., Drexl and Kimms (1997) and Jans and Degraeve (2007). The hardness of solving these problems is linked to the features to be met and the model sizes, thus most of the literature focuses on heuristics and metaheuristics methods to solve the integrated lot sizing and scheduling problem.

A few mixed integer production planning models of beverages have been proposed, for instance Toledo et al. (2009, 2012) and Ferreira et al. (2009, 2012), for the soft drink industry. Similarly to soft-drinks, beer production can also be considered as a two stage production process: preparation and bottling (or kegging) of the liquids. However, there are some differences between these problems, mainly regarding the first stage. Generally, the preparation times of the liquids in soft drinks and other beverage industries only take a few minutes and, in some cases, a few hours. On the other hand, in brewing, fermentation and maturation times last several days (from 3 up to 41 days, depending on the type of beer), which affect the beer production plans in an important way. Another difference is that in brewing, after the fermentation and maturation processes, the "ready" liquid can be stored in the preparation tanks for several days while waiting for being bottled in the filling lines, differently to the soft-drink production processes. Few attempts regarding beer production planning are presented in the literature and some issues remain to be addressed, such as effective optimization approaches dealing with the integrated lot sizing and scheduling in breweries to support operational decisions in the short term, which is the objective of this study. In Guimarães, Klabjan, and Almada-Lobo (2012), the authors consider the assignment and sizing of production lots in a multi-plant environment (each plant has a set of filling lines that bottle and pack beverages – beer and soft drinks), including the transfers of the final products between plants. It relates to the tactical level of the beer industry production planning and, therefore, it does not consider the necessary level of detail to perform a short-term plan (issues such as the fermentation and maturation tanks are disregarded there) as in the present study.

As mentioned before, the aim of this study is to address a production lot sizing and scheduling problem appearing at a standard brewery industry and to present optimization approaches based on mixed integer programming (MIP) formulation of the problem and MIP-based heuristics to deal with it, namely the relax-and-fix and fix-and-optimize (Pochet & Wolsey, 2006). A novel MIP model is presented to integrate the two main production stages, preparing the liquids including fermentation and maturation inside the fermentation tanks and bottling the liquids on the filling lines, making products of different liquids and sizes. Moreover, the planning horizon is discretized into periods (days). In addition, each period of the first part of the horizon is subdivided into a number of slots of variable widths, allowing for the scheduling and sequences of production lots. The second part (end) of the planning horizon is focused on lot sizing decision, disregarding few scheduling details. This two-dimensional time matrix allows for different granularities along the planning horizon, more accurate scheduling decisions are considered in the first part, contrarily to the rough lot sizing decisions in the second. This model can be used on a rolling-horizon approach.

To the best of our knowledge, this is the first work to address the brewery production planning problem in this line of research. The MIP model solution provides feasible production plans to the lot sizing and scheduling problem. However, for large problem instances as the ones found in practice, the model becomes difficult to solve, motivating the development of MIP-based heuristics. MIP-heuristics consider several novel partition schemes, which are