Computers & Operations Research 48 (2014) 40–52

Contents lists available at ScienceDirect

Computers & Operations Research

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

A genetic algorithm/mathematical programming approach to solve a two-level soft drink production problem

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ARTICLE INFO

Available online 12 March 2014

Keywords:
Genetic algorithms
Mathematical programming
Mathheuristics
Soft drink industry
Production planning
Lot sizing and scheduling

ABSTRACT

This study applies a genetic algorithm embedded with mathematical programming techniques to solve a synchronized and integrated two-level lot sizing and scheduling problem motivated by a real-world problem that arises in soft drink production. The problem considers a production process compounded by raw material preparation/storage and soft drink bottling. The lot sizing and scheduling decisions should be made simultaneously for raw material preparation/storage in tanks and soft drink bottling in several production lines minimizing inventory, shortage and setup costs. The literature provides mixed-integer programming models for this problem, as well as solution methods based on evolutionary algorithms and relax-and-fix approaches. The method applied by this paper uses a new approach which combines a genetic algorithm (GA) with mathematical programming techniques. The GA deals with sequencing decisions for production lots, so that an exact method can solve a simplified linear programming model, responsible for lot sizing decisions. The computational results show that this evolutionary/mathematical programming approach outperforms the literature methods in terms of production costs and run times when applied to a set of real-world problem instances provided by a soft drink company.

1. Introduction

This paper applies a combined genetic algorithm/mathematical programming approach to deal with a two-level production planning and scheduling problem, in which interdependence and synchronization issues should be considered. As pointed out in [1,2], this problem can be found in some industrial settings, mainly soft drink companies, where the production process involves two interdependent production levels or stages, with decisions concerning raw material preparation/storage and soft drink bottling. In the first level, tanks prepare and store soft drink flavors, which are then spread to bottling lines at the second level. This soft drink production problem also requires synchronization issues, which have to be considered when making lot sizing and scheduling decisions in these two production levels. This paper proposes a new hybrid metaheuristic approach combined with an exact approach in order to solve this problem.

The main challenge is how to simultaneously determine the lot sizing and scheduling of raw materials in tanks and of soft drinks in bottling lines, with sequence-dependent setup costs and times (i.e., they depend on the items previously stored and bottled) and production capacity constraints at each level, so that the total production costs are minimized. First-level decisions about which, how much and when the raw materials should be prepared and stored in the tanks have to be made. Similarly, second-level decisions about which, how much and when the soft drink flavors should be bottled in the filling lines (and in the bottle types) have to be made. A problem solution (i.e., a valid minimum cost production plan) should couple the lot sizing and scheduling decisions taken for these two production levels.

The paper is organized as follows. A literature review focusing on related works is reported in Section 2. Then the soft drink integrated lot sizing and scheduling problem is detailed in Section 3, where a mathematical programming formulation presented in [2] is briefly reviewed. Section 4 describes the genetic algorithm/mathematical programming proposed in this study, and its computational

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http://dx.doi.org/10.1016/j.cor.2014.02.012
0305-0548/

performance is evaluated in Section 5. The conclusions about this study and perspectives for future research are discussed in Section 6.

2. Literature review

In this section we briefly review the literature related to this study. A comprehensive literature review about general lot sizing and scheduling problems is found in [3], in which several mathematical models and solution approaches are described. A survey particularly concerned with capacitated lot sizing problems containing interesting discussions regarding the problem formulations and their complexity issues is reported in [4]. It mainly reviews models and algorithms for the single level lot sizing problems, as well as related studies proposing exact and heuristic methods to solve these problems. Methods, formulations and real-world cases, as well as related complexity issues, are also reviewed and discussed in [5] for capacitated and uncapacitated single item lot sizing problems.

An overview on metaheuristics applied to solve lot sizing problems is presented in [6]. Hybrid approaches are evaluated and different solution representation, evaluation functions, neighborhoods and operators are discussed. A survey on modeling for industrial extensions of the single-level dynamic lot sizing problems is presented in [7]. Operational aspects like setups, production processes, inventories, demands and time horizons are taken into account in this modeling review. Models and algorithms for the dynamic demand and coordinate lot-sizing problems are also reviewed in [8]. This class of problems includes issues such as single and multiple items, coordinated and uncoordinated setup structures, uncapacitated and capacitated problems, among others.

In particular, different studies concerning lot sizing decisions involving sequence-dependent setup costs and times are reported in the literature. The discrete lot sizing and scheduling problem and the same problem with sequence dependent setup costs were studied in [9,10]. The time horizon in this problem is subdivided into micro-periods having identical capacities and only one product is assigned to each micro-period. A problem formulation is also proposed in [11] for the capacitated lot sizing problem with sequence dependent setup costs. The time horizon is subdivided into macro-periods with the same length and the product demands should be met at the end of the macro-periods. The model proposed in [11] differs from the one in [9] as it allows for continuous lot-sizes and preserves the setup states over idle time. A backward heuristic is proposed to solve artificial instances and instances taken from the literature.

A hybrid method is proposed in [12] for the general lot sizing and scheduling problem with sequence dependent setup costs. A mathematical model with the time horizon divided into several micro-periods is presented, but each micro-period length is defined as the time spent on producing the product assigned to it. This hybrid method combines a threshold accepting heuristic with a greedy method. A lot sizing and scheduling problem with setup costs and times is formulated as a general lot sizing and scheduling problem in [13].

There are several studies presenting mathematical formulations and applying solution methods for different industrial problems. For instance, in [14] is presented a model extension for the single-machine capacitated lot sizing problem to describe a real world problem found in the glass container industry. The problem is solved using a variable neighborhood search (VNS) metaheuristic, where the sequencing of the neighborhoods is generated based on a distance function. A capacitated lot-sizing problem with multiple items and unrelated parallel machines using a Lagrangian-based heuristic is solved in [15]. In [16] a mixed integer programming (MIP) model for a lot sizing and scheduling problem found in foundry industries is presented. This multi-item, single machine problem with sequence-dependent setup costs and times is solved by a relax-and-fix method with three types of local search-based heuristics: a descendent heuristic, a diminishing neighborhood and simulated annealing. Computational results indicate that the solutions obtained by relax-and-fix are better than those obtained by the CPLEX solver within the time limit in medium-to-large sized instances. Rolling-horizon and relax-and-fix heuristics to solve the identical parallel machine lot sizing and scheduling problem with sequence dependent setup costs is proposed in [17]. The relax-and-fix heuristic outperformed the rolling-horizon heuristic returning results closer to the instance lower bounds.

In [18] a model based on the model introduced in [19] for the lot sizing and scheduling problem with sequence-dependent setup times is described. The production of a product in a given time period is indicated by binary variables and a heuristic defines the model parameters. In [20] is proposed a mathematical model to integrate lot sizing and scheduling decisions for a capacitated problem with sequence dependent setups. MIP models for lot sizing and scheduling problems found in electrofused grain and animal nutrition industries are studied in [21,22], respectively. In [23] a lot sizing and scheduling problem in a manufacturing plant producing animal feed compounds is studied. Model formulations and relax-and-fix heuristics are proposed. In [24] is introduced a new formulation for the capacitated lot sizing and scheduling problem with a sequence dependent setup and setup carryovers between adjacent periods. The authors propose a method that dynamically disconnects sub-tours when dealing with large problems.

A MIP for a soft-drink production problem similar to the one studied in this paper is presented in [25], referred by the authors as the synchronized and integrated lot sizing and scheduling problem (SITLSP). Sets of problem instances are generated from data provided by a soft drink company, which are solved by the CPLEX solver. The CPLEX was able to return solutions only for instances of small-to-moderate size. Better results solving the same instances are reported in [1] using a multi-population genetic algorithm (GA) with populations hierarchically structured.

As discussed in next sections, the problem of the present study is based on a simplified formulation proposed for the SITLSP in [2], called P2SMM (two-stage multi-machine lot-scheduling). The simplification assumes that each bottling line has a dedicated tank and each tank can be filled with all liquid flavors needed by this line. In that study, relax-and-fix heuristics are applied to solve real-world instances. A relaxation approach named RA is also proposed which outperformed the empirical method used by the company.

The solution approach of the present paper applies a GA embedded with mathematical programming techniques where the GA level defines production sequences, while a linear programming model related to the P2SMM is solved next for lot sizing decisions. The idea of applying a metaheuristic to generate setup sequences and solve the remaining mathematical programming model has also been successfully explored before, as in, e.g., [13,26]. However, the approach presented in this paper, associating a GA and mathematical programming, is not usually applied to real-world manufacturing problems.

The P2SMM is characterized as a capacitated lot sizing and scheduling problem with multi-item (several products and raw materials) and sequence-dependent setup times. The capacitated lot sizing problem (CLSP), a much simpler form of the aforementioned problem, is proven to be an NP-hard optimization problem [27]. The multi-item CLSP is strongly NP-hard. In [28,29] it is shown that even finding feasible solutions for the CLSP with setup times is an NP-hard problem.

Recently, four corresponding single-stage formulations for the P2SMM are presented in [30], two of them are based on the general lot sizing and scheduling problem (GLSP) and the other two are