European Journal of Operational Research 234 (2014) 266–277

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Innovative Applications of O.R.

HOPS – Hamming-Oriented Partition Search for production planning in the spinning industry

Victor C.B. Camargo [a,b,*], Franklina M.B. Toledo [b], Bernardo Almada-Lobo [a]

[a] INESC TEC, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias s/n, Porto 4200-465, Portugal
[b] Instituto de Ciências Matemáticas e de Computação, Universidade de São Paulo, Caixa Postal 668, São Carlos SP 13560-970, Brazil

ARTICLE INFO

Article history:
Received 18 June 2012
Accepted 6 October 2013
Available online 22 October 2013

Keywords:
Matheuristic
Lot-sizing and scheduling problems
Textile industry
Mixed integer programming

ABSTRACT

In this paper, we investigate a two-stage lot-sizing and scheduling problem in a spinning industry. A new hybrid method called HOPS (Hamming-Oriented Partition Search), which is a branch-and-bound based procedure that incorporates a fix-and-optimize improvement method is proposed to solve the problem. An innovative partition choice for the fix-and-optimize is developed. The computational tests with generated instances based on real data show that HOPS is a good alternative for solving mixed integer problems with recognized partitions such as the lot-sizing and scheduling problem.

1. Introduction

The textile industry is very important for the Brazilian economy as it generates employment and increases regional development. According to the annual report of the textile sector (ABIT, 2011), Brazil plays a major role in the textile and apparel international market, as it generated a revenue of US$ 41.8 billion in 2010. There are currently 1.6 million employees in textile industries in Brazil and spinning factories employ approximately 80,000 workers.

The production system of the spinning industry is characterized by a multi-stage process, with single or parallel machines on each stage. In general, these machines have dissimilar production characteristics, such as processing speeds and changeover times. The setups depend on the sequence of products manufactured by the machines. The main products are made of natural or synthetic fibers, but the most commonly used raw material is cotton. Production orders or lots must be achieved in order to satisfy customer demand in the most cost-effective manner. Therefore, the spinning industry requires simultaneous size and sequence production lots. The integration of scheduling and lot-sizing problems helps to define better production plans than those generated from the solution of these problems in a hierarchical way. The integrated lot-sizing and scheduling problem is considered the major issue in operational production planning (Drexl & Kimms, 1997) and is also present in other industrial processes, such as foundry (Araujo, Arenales, & Clark, 2007), glass containers (Almada-Lobo, Oliveira, & Carravilla, 2008), soft drinks (Ferreira, Morabito, & Rangel, 2009) and beverages (Guimarães, Klabjan, & Almada-Lobo, 2012).

The research reported in the literature on production planning in the textile industry is rather scarce. Silva and Magalhaes (2006) focus on the lot-sizing and scheduling problem of an acrylic fiber industry. The fiber manufacturing process appears upstream the spinning in the textile supply chain. Nevertheless, three studies address the production planning problem downstream the spinning. Serafini and Speranza (1992) focus on the weaving process, Karacapilidis and Pappis (1996) tackle the integrated process of the warp making, starching and weaving machines and Pimentel, Alvelos, Duarte, and de Carvalho (2011) address the knitting process. To the best of our knowledge, few studies have focused on the production planning in the spinning process. In addition to that, a weak point regarding the efficiency of this industry is the difficulty to quickly devise good production plans. By overcoming this weakness, companies' competitiveness may be increased.

Solution methods for this type of problem rely on MIP solvers or (meta) heuristics. Usually, MIP solvers are exact methods that aim to provably find optimal solutions. In some cases, the running time may be prohibitive. On the other hand, (meta) heuristics provide better feasible solutions faster, although the optimality proof is (often) not guaranteed. Recent research focused on problem-oriented methods (James & Almada-Lobo, 2011), such as relax-and-fix (Beraldi, Ghiani, Grieco, & Guerriero, 2008) and fix-and-optimize (Sahling, Buschkhl, Tempelmeier, & Helber, 2009) heuristics. Variables belonging to a problem partition are fixed to a certain value to create a reduced problem of an easier solution. These problem-oriented methods carry problem aspects into the solution procedure, as the variable partition is inherent to the problem.

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* Corresponding author at: Instituto de Ciências Matemáticas e de Computação, Universidade de São Paulo, Caixa Postal 668, São Carlos SP 13560-970, Brazil. Tel.: +55 1633739648.

0377-2217/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2013.10.017

State-of-the-art MIP solvers incorporate heuristics in the exact methods (e.g. relaxation induced neighborhood search (Danna, Rothberg, & Pape, 2005), Local Branching (Fischetti & Lodi, 2003) and some variants) to quickly find better solutions. These hybrid methods follow the variable fixing ideas. Each branch-and-bound node provides information for the decision variables and a reduced problem is created by fixing some variables based on this information. In case the reduced problem returns a solution, it is also a solution to the original problem and this new solution can be injected into the branch-and-bound tree as a new upper bound. These improvement strategies can accelerate the optimality proof. The cross fertilization between exact and (meta) heuristic methods is called matheuristics (Maniezzo, Stützle, & Voß, 2010).

In this paper, we propose a mathematical model that integrates the lot-sizing and scheduling decisions of a spinning industry taking into account the synchronization between the first and second stages. The model is based on the multi-stage general lot-sizing and scheduling problem. Equally important, the exact approach called HOPS (Hamming-Oriented Partition Search) is proposed as a new method based on mathematical programming to solve this problem. It involves the problem solution with the branch-and-bound method combined with a problem-oriented procedure that injects new and better upper bounds into the original problem. The Hamming distance (Hamming, 1950) between the solutions found when exploring the branch-and-bound tree is used to define the problem partitions of stabilized values. The stabilized partitions are fixed to create the reduced problems and their solutions can be injected into the branch-and-bound tree of the original problem. Initially, HOPS is tested on a well-known lot-sizing problem and its performance is compared against that of a recent tailored heuristic reported in the literature. For the spinning problem, an instance generator is designed to conduct computational experiments in an extensive dataset. The HOPS validation in the production planning in the spinning industry is also supported by real-world data based on instance settings.

The paper is organized as follows: Section 2 describes the production problem of the spinning industry, which is then formulated by adapting a known mathematical model; Section 3 gives an overview of the fixing variable matheuristics; Section 4 introduces the HOPS algorithm; Section 5 sets benchmarks for the results of HOPS compared to those obtained by other state-of-the-art approaches based on mathematical program available in commercial software. Section 6 addresses some concluding remarks.

2. The production system

The manufacturing system in a spinning industry can be defined as a procedure in which fibers are processed and then used to make different types of yarns. This procedure is described in the sequence of processes represented in Fig. 1. In the beginning, lints from various bales are mixed and blended in order to achieve a uniform blend of fiber properties. The fiber blend is blown by air from a feeder through ducts to intermediate machines for cleaning and carding and these machines separate and align the fibers into a thin web. The fiber web is then pulled through a conical device, providing the sliver that is pulled again and then twisted to make the sliver tighter and thinner until it complies with yarn specifications. After spinning, the yarns are tightly wound around bobbins or tubes. The yarn packages are then ready for distribution.

The spinning process is categorized according to the types of spinning, such as open-end, ring, air jet and Vortex spinning. In the open-end spinning, the yarn is directly produced from the sliver, eliminating the additional pulling process presented in the ring spinning. The air jet and Vortex spinning systems have also eliminated the need for the additional pulling process.

This study deals with open-end spinning and all its intermediate processes can work in a synchronized mode with the opening and mixing processes. The capacities of the first processes are sufficient to maintain the spinning process working. Therefore, the last process – spinning – is considered the production bottleneck.

In order to detail the production features, consider N yarns to be scheduled on M parallel machines over a finite planning horizon with a given length T. The demand for yarns is known prior to each period of the planning horizon that should be met in case capacity is sufficient. Although the production line operates 24 h on a 7-day week basis, there may occur delays when the demand for yarns is high, thus backlogs must be represented in the model.

A yarn cannot be manufactured in a given time period unless a fiber blend that ensures its quality is also processed in this period. Therefore, the planning of the first-stage product is also required. A fiber blend is often used in several yarns, but a yarn is only made using a fiber blend that respects its quality limits. As only one fiber blend can be processed in this type of production line, all the machines must produce yarns that require the same quality of fibers at each point in time. The production dependency between the two stages is represented in Fig. 2.

The machines may differ in the processing rates of the same yarn, thus the fiber blend can be consumed at different speeds. A setup changeover from one yarn to another consumes capacity time, which is dependent on the sequence in which the yarns are processed. The setup can be carried from one period to the next. The setup changeover for the fiber blend can be considered null as another fiber blend is immediately available for a later use in the production. This fact reinforces the statement that the fiber blend sub-process is not the production bottleneck.

The production plan must determine the size and sequence of the lots on all machines with minimal backlog, inventory and changeover costs. An example of a production plan for the spinning case is illustrated in Fig. 3. Five yarns of two different fiber qualities are scheduled on three parallel machines over three planning periods. The dark gray rectangles represent the time wasted on setting up the machine for the yarn production. The first two blends are dedicated to the same product family, that is, the set of yarns that requires the same fiber blend quality. The third blend is dedicated to a different product family.

2.1. Mathematical model

This section describes an MIP formulation adapted from the Multi-Stage General Lot-sizing and Scheduling Problem (MSGLSP) – introduced in Camargo, Toledo, and Almada-Lobo (2012) – for the problem addressed. Backlogging must be taken into account as it is a common feature in the spinning industry. The MSGLSP divides the planning horizon into T periods. Each period is sub-divided into a number of micro-periods in which only one yarn can be produced as a small-bucket model (Meyr, 2002). Therefore, the sequence of production is obtained in a rather straightforward manner allowing for the incorporation of sequence-dependent setups. The fundamental assumption is that a user-defined parameter restricts the number of micro-periods per period and, consequently, the upper bound on the number of setups. However, the micro-periods have no predefined length. A micro-period is confined to be within a single period and its length cannot exceed the length of its period. Without loss of generality, we have assumed the length of each period to be equal to one. This assumption ensures some parameters to be standardized accordingly. The model makes use of the same micro-period length