Computers & Industrial Engineering 64 (2013) 972–986

Contents lists available at SciVerse ScienceDirect

Computers & Industrial Engineering

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

Modeling and Pareto optimization of multi-objective order scheduling problems in production planning ☆

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ARTICLE INFO

Article history:
Received 19 February 2012
Received in revised form 2 January 2013
Accepted 11 January 2013
Available online 30 January 2013

Keywords:
Production planning
Multi-site order scheduling
Mathematical model
Pareto optimization
NSGA-II
Simulation model

ABSTRACT

This paper addresses a multi-objective order scheduling problem in production planning under a complicated production environment with the consideration of multiple plants, multiple production departments and multiple production processes. A Pareto optimization model, combining a NSGA-II-based optimization process with an effective production process simulator, is developed to handle this problem. In the NSGA-II-based optimization process, a novel chromosome representation and modified genetic operators are presented while a heuristic pruning and final selection decision-making process is developed to select the final order scheduling solution from a set of Pareto optimal solutions. The production process simulator is developed to simulate the production process in the complicated production environment. Experiments based on industrial data are conducted to validate the proposed optimization model. Results show that the proposed model can effectively solve the order scheduling problem by generating Pareto optimal solutions which are superior to industrial solutions.

1. Introduction

In manufacturing companies, production planning is at the top level of production management and is crucial to successful production management because its performance greatly affects the performance of production control and supply chain management. This paper investigates a decision-making problem in the production planning stage, a multi-objective multi-site order scheduling problem in a medium-term planning horizon, by developing an effective methodology for the problem.

1.1. Multi-site order scheduling in production planning

Consider the real-world production environment of the manufacturing company with multiple plants (sites), multiple production departments and multiple production processes. The manufacturing company receives a large number of production orders from different customers, which need to be assigned to the company's self-owned or collaborative plants for production. The production of a product (or a production order) involves multiple production processes, including ordinary processes and special processes. Each plant can produce all ordinary processes. However, not every plant can produce special processes because some plants do not have the production department required for the corresponding special processes. As a variety of production orders need to be assigned to appropriate plants for production, it is probable that different production processes of an order need to be assigned to different plants. The manufacturer must determine how to assign each production process of this order to an appropriate plant (site) and determine the beginning time of each process in a planning horizon of several months, which is called the multi-site order scheduling (MSOS) problem. This problem is faced by a large number of manufacturing companies from labor-intensive industries such as the apparel industry. The investigation on this problem is very important because its performance greatly affects the performance of downstream production control and the entire supply chain.

The MSOS problem is a complicated combinatorial optimization problem with a huge solution space. Take a simple order scheduling problem considering 10 production orders and 3 factories as an example. There are 3^{10} candidate solutions for this problem even if each order has only one production process. The real-world problems have a much greater solution space because they need to handle the production of a large number of production orders (often more than 100) with multiple production processes in a longer time period and determine the values of a large number of variables. There does not exist an effective methodology for this problem nowadays. The order scheduling process in today's labor-intensive manufacturing mainly rests on the experience and subjective assessment of the production planner.

☆ This manuscript was processed by Area Editor Subhash C. Sarin.
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http://dx.doi.org/10.1016/j.cie.2013.01.006

1.2. Research issues in production planning decision-making

Production planning decision-making involves a wide variety of research issues, including master production schedule (Sahin, Robinson, & Gao, 2008; Venkataraman & Nathan, 1994), material requirements planning (Dolgui & Prodhon, 2007; Le, Gunn, & Nahavandi, 2004), manufacturing resource planning (MRP II) (Sawyer, 1990; Wazed, Ahmed, & Nukman, 2010), enterprise resource planning (Ehie & Madsen, 2005; Parush, Hod, & Shtub, 2007), and aggregate planning (Jamalnia & Soukhakian, 2009; Lee, Steinberg, & Khumawala, 1983). A great number of papers have been published in this area and some researchers provided comprehensive review papers (Dolgui & Prodhon, 2007; Mula, Peidro, Diaz-Madronero, & Vicens, 2010; Wang, Keshavarzmanesh, Feng, & Buchal, 2009; Wazed et al., 2010).

Some researchers investigated the decision-making problems in production planning from other perspectives. Li, Man, Tang, Kwong, and Ip (2000) addressed the production planning and scheduling problems in a multi-product and multi-process production environment with the lot-size consideration. Jozefwska and Zimniak (2008) presented a decision support system for short-term production planning and scheduling in production plants characterized by a single-operation manufacturing process. Some researchers investigated the multi-site production planning problem (Guinet, 2001; Leung, Tsang, Ng, & Wu, 2007; Timpe & Kallrath, 2000), which consider each site as an independent and parallel production unit and usually belong to aggregate planning problems. However, few studies have focused on release and scheduling of production orders (or processes) among different sites in production planning stage so far.

Ashby and Uzsoy (1995) presented a set of heuristic rules to integrate order release, group scheduling and order sequencing in a single-stage production system. Axsater (2005) addressed the order release problem in a multi-stage assembly system, which focused on determining the starting time of different production operations but did not consider where the process was produced. Chen and Pundoor (2006) addressed order allocation and scheduling at the supply chain level, which focused on assigning orders to different production plants and exploring a schedule for processing the assigned orders in each plant. However, their study has not considered the effects of different production departments and their production capacities on scheduling performance. Each production department indicates a type of shop floor. The order release and scheduling problem in the production planning stage, considering multiple plants and multiple production departments and multiple production processes, has not been investigated.

This paper will investigate the MSOS problem with the consideration of multiple production plants and multiple types of production processes. Due to the complexity of the investigated problem, the values of objective functions of each candidate order scheduling solutions cannot be obtained directly by mathematical formulas, which can only be derived by simulating the production of all production processes in appropriate plants. Unfortunately, no simulation model is available so far.

In this paper, the mathematical model of the investigated MSOS problem in the production planning stage will be established firstly. Based on the mathematical model, an effective optimization model is developed to solve the MSOS problem. In the optimization model, a simulation model, called the production process simulator, is proposed to simulate the production of different production orders in multiple plants.

1.3. Multi-objective optimization techniques in production decision-making

In real-world production decision-making, it is usual that multiple production objectives need to be considered and achieved simultaneously. Some researchers use the weighted sum method to turn the multi-objective problems to single-objective ones (Guo, Wong, Leung, Fan, & Chan, 2008a; Ishibuchi & Murata, 1998). However, it is difficult for some problems to determine the weights of different objectives. It is also impossible to have a single solution which can simultaneously optimize all objectives when multiple objectives are conflicting. To handle this problem, some researchers used the concept of Pareto optimality to provide more feasible solutions (Pareto optimal solutions) to the production decision-maker (Chitra, Rajaram, & Venkatesh, 2011; Ishibashi, Aguirre, Tanaka, & Sugimura, 2000; Jozefwska & Zimniak, 2008; Liu, Yan, & Yu, 2009; Zhang & Gen, 2010).

The GA is the most commonly used meta-heuristic technique for multi-objective optimization problems (Chang & Chen, 2009; Deb, Pratap, Agarwal, & Meyarivan, 2002; Guo, Wong, Leung, & Fan, 2009; Guo et al., 2008a, Guo, Wong, Leung, Fan, & Chan, 2008b; Jones, Mirrazavi, & Tamiz, 2002; Zhang & Gen, 2010). Some researchers focused on developing multi-objective GAs to seek Pareto optimal solutions (Deb et al., 2002; Ishibashi et al., 2000). A significant paper for multi-objective GA was published by Deb et al. (2002), in which a fast elitist non-dominated sorting GA (NSGA-II) was proposed. Since then, the NSGA-II has attracted more and more attention, and was used and modified for various optimization problems. However, the NSGA-II has not been reported to handle the combinatorial optimization problems in production planning. The existing NSGA-II cannot be directly used to handle the MSOS problem because different chromosome representations and genetic operators are required for different optimization problems.

An effective Pareto optimization model, which combines a NSGA-II-based optimization process and a production process simulator, is developed to provide Pareto optimal solutions for the investigated MSOS problem. To construct the NSGA-II-based optimization process, the chromosome representation and genetic operators are modified to handle the MSOS problem.

The rest of this paper is organized as follows. Section 2 presents the mathematical model of the investigated MSOS problem. In Section 3, a Pareto optimization model is developed to solve the problem. In Section 4, experimental results to validate the performance of the proposed model are presented. Finally, this paper is summarized and future research direction is suggested in Section 5.

2. Mathematical model of the order scheduling problem in production planning

This section presents the mathematical model of the MSOS problem in the production planning stage.

2.1. Nomenclature

The notations used in developing the mathematical model of the MSOS problem investigated are classified into 3 categories, including production order-related, production process-related and production department-related notations, which are listed out below.

Production order-related notations	
G_h	hth production order group
O_i	ith production order ($1 \leqslant i \leqslant m$)
$\boldsymbol{m}$	the number of production orders (parameter)
D_i	due date of order O_i (parameter)
$\boldsymbol{F_i}$	finishing time of order O_i, the time when order O_i is delivered to central warehouse (intermediate variable)
TD_i	tardiness (tardy days) of order O_i (intermediate variable)
TPT_i	throughput time of order O_i (intermediate variable)

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