Int. J. Production Economics 129 (2011) 43–50

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Outsourcing and production scheduling for a two-stage flow shop

Xiangtong Qi *

Department of Industrial Engineering and Logistics Management, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 5 May 2008
Accepted 2 August 2010
Available online 19 August 2010

Keywords:
Production scheduling
Outsourcing
Flow shop

ABSTRACT

In this paper we study the production scheduling problem for a two-stage flow shop in which there are options of outsourcing some operations to subcontractors. The basic objective is to look for a production schedule that can optimally utilize the resources of both the in-house production and outsourcing so that the makespan is minimized. The logistics issue between the subcontractor and the in-house shop further complicates the problem. We present models for different situations of outsourcing. For each model, we develop optimization algorithms and conduct computational experiments to study the managerial insights for the models and the algorithms.

1. Introduction

1.1. Motivation

With the economy globalization and the development of information technology, outsourcing is playing a more and more important role in manufacturing industries. Outsourcing can help a manufacturer in different ways. By fully outsourcing some non-critical operations to subcontractors, a company can focus more on its core business. This has become a popular business practice for many high-tech manufacturers. Outsourcing may also be taken for the purpose of tax benefit. For example, to avoid the restriction of the import quota imposed on the textiles made in China, companies in Hong Kong can use suppliers in nearby cities in China to do a portion of the work as preprocessing, then transport the unfinished products to Hong Kong where they would undergo additional processing to become Hong Kong-made products. In other situations, outsourcing can be used as a secondary supplying source in addition to the in-house production. In such a way, a manufacturer can effectively handle demand fluctuations without the need of maintaining a high production or inventory capacity.

While a manufacturer can benefit from outsourcing, the potential maximum benefit cannot be achieved unless there is an efficient and effective production plan and schedule that can cope with the complexity of outsourcing. The problem is challenging in that we have to take care of the scheduling for both the in-house production and the subcontractor's production, as well as their coordination.

The purpose of this paper is to study the production scheduling problems in a two-stage flow shop with the options of outsourcing. In the base line of the problem, the in-house production is the sole supplying source. There are a set of jobs to be processed, and each job has to go through two sequential operations by two different machines. The problem is to determine a sequence for processing the jobs on the two machines so that the makespan, i.e., the completion time of the last job on the stage-two machine, is minimized. This is one of the classic scheduling problems, and can be solved by the well-known Johnson's rule.

The problems to be studied in this paper are about the mixture of the in-house production and outsourcing in a two-stage flow shop where a job or a specific operation of a job can be processed by either the in-house production or outsourcing. With the resources provided by the subcontractors, it is possible that the manufacturer can reduce the makespan, and thus improve the productivity and service level. In such a new situation, besides the sequencing decisions in conventional scheduling problems, we face another new dimension of decisions for job allocation, i.e., to determine where a job is to be processed.

In general, outsourcing opportunities may exist in different forms. Some subcontractors may be able to provide services for the operations in both stages; some subcontractors may be dedicated to the operation in one stage only. The manufacturer may fully outsource all jobs to a subcontractor for one operation, or partially outsource a subset of the jobs. There are various variants of the problems to be studied.

In the rest of this paper, we will discuss the new concerns caused by outsourcing, followed by a brief literature review. After introducing the general models and assumptions, we will study three specific models. In order to maintain the relative independence for each individual model, we will use one independent section to cover the formulation, algorithm design, and computational results for each model.

* Fax: +852 23580062.
E-mail address: ieemqi@ust.hk

0925-5273/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2010.08.011

1.2. New concerns in outsourcing

In view of production scheduling models, a subcontractor provides additional machines that are parallel to the in-house machines. Thus it may be assumed that such problems can be simply modeled as the so-called hybrid flow shop problems where each stage has multiple parallel machines. However, the practice of outsourcing makes the problems more complicated than the hybrid flow shops studied in the literature. We have the following new features to be incorporated in modeling outsourcing.

The first issue is the transportation between the subcontractor and the manufacturer. In many cases, the subcontractor is in a different location from the manufacturer. Thus the transportation delay has to be considered together with the production schedule for the jobs being outsourced. Sometimes the transportation cost also needs to be considered, which leads to the batching-based transportation mode for the aim of transportation cost reduction.

The second issue is the explicit consideration of the production cost. In conventional scheduling problems, the objective function is usually about job completion times. This is reasonable because the production cost for processing all jobs can be assumed to be a constant independent of the production schedule. When a subcontractor is involved, however, the subcontractor may charge a cost different from the in-house production cost. Therefore we have to consider the possible production cost difference caused by outsourcing. In this paper, we assume that the subcontractor charges the manufacturer based on the total processing time for all outsourced jobs at a fixed charging rate which may be either higher or lower than the marginal in-house production cost.

The outsourcing cost difference makes the problem being a bicriteria optimization problem for minimizing both the makespan and the production costs. In our analysis, we will mainly focus on the makespan as a single criterion, and then discuss how the results can be extended to handle the production cost difference caused by outsourcing.

1.3. Literature review

The study of outsourcing under machine scheduling models just starts recently, and most such work focuses on the single-stage problems. Chen and Li (2008), and Lee and Sung (2008a,b) have studied the scheduling problem with outsourcing options under the assumption that the subcontractor has virtually unlimited capacity. Therefore they do not need to schedule the outsourced jobs. Cai et al. (2005) consider a scheduling problem involving third-party machines where all jobs are outsourced and have to be transported back from the third-party machines after completion. Qi (2008) addresses the coordination of production scheduling, outsourcing and transportation issues. Aydinliyim and Vairaktarakis (2010), and Vairaktarakis (2006a,b) have used game-theoretic models to analyze different cases of multiple manufacturers sharing a single subcontractor with the emphasis on understanding the issues of competition and cooperation.

Different from the above single-stage models, in this paper we study a two-stage flow shop model in which outsourcing may be taken at either stage with different shop configurations.

Research on scheduling with outsourcing options in a complex shop environment is very limited. Lee et al. (2002) discuss a scheduling model in a supply chain with outsourcing options, and develop a genetic algorithm to solve the problem. Chung et al. (2005) study a job shop scheduling model where an operation of a job can be done either on an in-house machine or on an outsourcing machine with an extra cost. Both papers study shop configurations different from the models in our paper. Qi (2009) considers a two-stage flow shop with an option of outsourcing for stage one. In this paper, we extend the work to include other forms of outsourcing.

Beyond the scheduling area, some inventory management models have been developed to study the coordination of in-house production and outsourcing where outsourcing is used as a secondary supplying source. For example, see Atamturk and Hochbaum (2001), Bradley (2004), Van Mieghem (1999), and Yang et al. (2005). In these models, products are assumed to be identical, customers are assumed to be equally important, and all demands are aggregated. The major difference of a production scheduling model to an inventory model is that in a scheduling model customers are differentiated, for example, each with a unique technical specification. In scheduling model, one operation of a job for one customer is either processed by the in-house production or outsourced. Splitting the operation of a job is not allowed. Studying the scheduling models for outsourcing is important for the implementation in practice.

Integrating the production scheduling and transportation for multiple parties, our work belongs to the recent research on supply chain scheduling and logistics scheduling (e.g., Kreipl and Pinedo, 2004). Such work include the research on machine scheduling followed by job delivery to customers, for example, Chang and Lee (2004), Chen and Vairaktarakis (2005), Hall and Potts (2005), Lee and Chen (2001), Li et al. (2005), Wang and Lee (2005), and Wang and Cheng (2009); it also include the production scheduling coordination for multiple parties, for example, Agnetis et al. (2006), Chen and Pundoor (2006), Cheng and Kovalyov (2001), Dawande et al. (2006), Hall and Potts (2003), Lee et al. (2006), Li and Xiao (2004), and Qi (2005, 2006).

There have been various models for considering transportation issues in a flow shop; see Brucker et al. (2004) for a recent review. However, situations raised by outsourcing as modeled in this paper have not been well studied in the literature.

As we have discussed, our model is similar to the so-called hybrid flow shop scheduling (e.g., Lee and Vairaktarakis, 1994) in which there are multiple parallel machines in each stage of a flow shop. While there exists extensive research on hybrid flow shop scheduling, e.g., some of the most recent papers by Kyparisis and Koulamas (2006), Oguz and Ercan (2005), and Tang et al. (2006), failing to consider the transportation issues makes the hybrid flow shop inappropriate to model the practice of outsourcing.

2. Basic models and assumptions

Suppose that a manufacturer has n jobs that need to be processed by a two-stage flow shop. For each job j, its stage-one processing time is p_j, and stage-two processing time is q_j, all being non-negative integers. For notational convenience, let $P_{jk}=\sum_{l=j}^{k} p_l$, $Q_{jk}=\sum_{l=j}^{k} q_l$, $P=P_{1n}$, and $Q=Q_{1n}$. In the basic configuration of the flow shop, the manufacturer has one machine at each stage. We have the standard assumptions for flow shop models: at any time, one job can only be processed by one machine, and one machine can only process one job. All jobs are available at time zero, and job preemption is not allowed.

When a schedule is given, each job j has a completion time at stage one, denoted by $C_{j\,1}$, and a completion time at stage two, denoted by $C_{j\,2}$. Define the makespan as the maximum stage-two completion time for all jobs, $C_{\max}=\max_{1\le j\le n}\{C_{j2}\}$. When the objective is to minimize the makespan $C_{\max}$, the problem is conventionally denoted by $F2||C_{\max}$, and can be solved by the Johnson's rule.

The Johnson's rule: let jobs with $p_j \le q_j$ be in group 1, and jobs with $p_j > q_j$ be in group 2. Schedule jobs in group 1 first according