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An approximation scheme for two-machine flowshop scheduling with setup times and an availability constraint

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Abstract

This paper studies the two-machine permutation flowshop scheduling problem with anticipatory setup times and an availability constraint imposed only on the first machine. The objective is to minimize the makespan. Under the assumption that interrupted jobs can resume their operations, we present a polynomial-time approximation scheme for this problem.

Keywords: Flowshop scheduling; Approximation scheme; Availability constraint

1. Introduction

Machine scheduling problems with availability constraints have received increasing attention from researchers in the last decade. When scheduling jobs over a planning period, we need to take into consideration the unavailability of machines for processing, which arises due to such causes as scheduled preventive maintenance, prior assignment of some fixed jobs or overlapping with the previous planning period. Surveys of the latest research results on this subject have been given by Lee et al. [1], Sanlaville and Schmidt [2], and Schmidt [3].

Although the classical two-machine flowshop scheduling problem with the objective of minimizing the makespan is polynomial-time solvable, the problem even with an unavailable interval becomes NP-hard (see [4]). Under the assumption that the jobs are resumable, i.e., an unfinished job can continue after the machine becomes available again, Lee [4] proposed pseudo-polynomial dynamic programming algorithms to solve the problem optimally. He also developed two heuristics with a worst-case error bound of 3/2 and 4/3 for the cases where the unavailable interval is on machines 1 and 2, respectively. Cheng and Wang [5] developed an improved heuristic with a worst-case bound of 4/3 for the problem with an unavailable interval on machine 1. Breit [6] presented an improved heuristic with a worst-case bound of 5/4 for the problem with an unavailable interval on machine 2. Ng and Kovalyov [7] provided fully polynomial-time approximation schemes for the problems with an unavailable interval on machine 1 or 2. Under the no-wait processing environment, Cheng and Liu [8] developed a Polynomial-time approximation Scheme (PTAS) for the problem.

The above-mentioned scheduling models only consider job processing times; in other words, setup times are assumed to be included in processing times. However, in many industrial settings it is necessary to treat setup times as separated

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from processing times. For example, the production of steel tubes mainly consists of two stages. First, pre-heated pillared billets are made into tubes by a rolling machine, which can control the outer-diameter and inner-diameter of the tubes by assembling different sizes of machine-frames and mandrels. Each order has special requirements for the outer-diameter and inner-diameter of the tubes. So setting the types of machine-frame and mandrel must be performed before fabricating the tubes. Once all the tubes of an order have been produced, a chemical disposal operation to remove the phosphor on the surface of the tubes is performed. So an order is taken as a job. Then a chasing lathe is used to make screw threads on the two ends of a steel tube and on the inner wall of a steel-hoop. The chasing lathe needs to have its tools adjusted before working on tubes in different diameters. Making adjustments of the tools may be anticipatory. In order to reduce intermediate inventories, orders are in turn processed in two stages. As a heavy machine, the rolling machine needs periodic maintenance such as replacing worn-out parts and lubricating the axles once a month. In the floor shop, a production plan usually spans two weeks. Thus, there exists at most an unavailable interval on the first machine over a scheduling period. To the best of our knowledge, only Wang and Cheng [9] have considered the scheduling problem with separated setups and availability constraints. In their paper, they studied two-machine flowshop scheduling with anticipatory setup times and a resumable availability constraint imposed on only one of the machines. They presented two heuristics and showed that their worst-case error bounds are no larger than 5/3.

Motivated by the above example, we consider the two-machine flowshop scheduling problem with anticipatory setup times, where an availability constraint is imposed only on the first machine. A setup is performed on a machine before processing a job. The setup times are anticipatory, i.e., the setup for the second operation of any job on machine 2 can start before the completion of its first operation on machine 1 whenever there is some idle time on machine 2. We assume that the processing order of the jobs is the same on each machine. That is, we confine ourselves to finding solutions that are permutation schedules for the problem. We also assume that all the jobs and their setups are resumable. The objective is to minimize the makespan. It is evident from Lee [4] that our problem is NP-hard. It is very unlikely to develop an algorithm for solving the problem optimally in polynomial time. In this paper we propose a PTAS for the problem.

The rest of this paper is organized as follows. In the next section, we introduce the notation and some preliminaries and investigate some optimal properties of the problem. In Section 3 we give an algorithm for a class of special instances of the problem and prove that it can generate an optimal schedule. In Section 4 we develop a PTAS based on the algorithm in Section 3 for our problem. Some conclusions are given in the last section.

2. Notation and preliminaries

For the problem under consideration, we first introduce the following notation to be used in this paper.

$N = \{J_1, \ldots, J_n\}$: a set of n jobs
M_1, M_2: machine 1 and machine 2
$\Delta_1 = t_2 - t_1$: the length of the unavailable interval on M_1, where M_1 is unavailable from time t_1 to t_2
s_i^1, s_i^2: setup times of J_i on M_1 and M_2, respectively
a_i, b_i: processing times of J_i on M_1 and M_2, respectively
X: the job set in which all the jobs are finished before the unavailable interval on M_1
$\bar{X}$: a sequence of X
Y: the job set in which all the jobs are finished after the unavailable interval on M_1
$\bar{Y}$: a sequence of Y
Φ: the empty set
π: a permutation schedule
$C_i(\pi)$: completion time of J_i on M_2 in schedule π
$C(\pi)$: the makespan of schedule π
C^*: the optimal makespan