Available online at www.sciencedirect.com
ScienceDirect
Computers & Industrial Engineering 50 (2006) 286–295
computers & industrial engineering
www.elsevier.com/locate/dsw

Three-machine flowshop with two operations per job to minimize makespan

Ling-Huey Su *, Cheng-Te Lin

Department of Industrial Engineering, Chung-Yuan Christian University, Chung-Li, Taiwan, ROC

Received 14 February 2006; received in revised form 8 June 2006; accepted 8 June 2006
Available online 18 July 2006

Abstract

This work studies three variants of a three-machine flowshop problem with two operations per job to minimize makespan ($F3/o=2/C_{\max}$). A set of n jobs are classified into three mutually exclusive families A, B and C. The families A, B and C are defined as the set of jobs that is scheduled in machine sequence (M_1, M_2), (M_1, M_3) and (M_1, M_3), respectively, where (M_x, M_y) specifies the machine sequence for the job that is processed first on M_x, and then on M_y. Specifically, jobs with the same route (machine sequence) are classified into the same family. Three variants of $F3/o=2/C_{\max}$ are studied. First, $F3$/GT, no-idle, $o=2/C_{\max}$, in which both machine no-idle and GT restrictions are considered. The GT assumption requires that all jobs in the same family are processed contiguously on the machine and the machine no-idle assumption requires that all machines work continuously without idle time. Second, the problem $F3$/GT, $o=2/C_{\max}$, in which the machine no-idle restriction in the first variant is relaxed, is considered. Third, the problem $F3$/no-idle, $o=2/C_{\max}$ with the GT assumption in the first variant relaxed is considered. Based on the dominance conditions developed, the optimal solution is polynomially derived for each variant. These results may narrow down the gap between easy and hard cases of the general problem.

Keywords: Scheduling; No-idle; Group assumption; Three-machine flow shop; Two operations per job; Makespan

1. Introduction

This work discusses three variants of a three-machine flowshop problem with two operations per job to minimize makespan ($F3/o=2/C_{\max}$). Let M_j, $j=1$, 2 and 3, be machine 1, 2 and 3, respectively. The set of n jobs is classified into three mutually exclusive families A, B and C. Jobs that are scheduled in the same route (machine sequence) are classified as belonging to the same family. The families A, B and C are defined as the set of jobs that is scheduled with machine sequence (M_1, M_2), (M_1, M_3) and (M_2, M_3), respectively, where (M_x, M_y) specifies the machine sequence of a job that is processed first on M_x and then on M_y. Three variants, according to the imposition of GT or the no-idle restriction, are proposed. The GT restriction requires that all

* Corresponding author.
E-mail address: linghuey@cycu.edu.tw (L.-H. Su).

0360-8352/$ - see front matter
doi:10.1016/j.cie.2006.06.001

jobs in the same family are contiguously processed. Such a requirement may reflect the fact that the setup times are much longer than the job processing times, or the minimization of the time spent on setup in situations where capacity is scarce, or the need simply to make the problem more tractable. The no-idle restriction means that each machine must process jobs without any interruption from the start of processing the first job to the completion of the last job. The three cases are as follows. First, the $F3$/GT, no-idle, $o = 2/C_{\max}$ problem in which both machine no-idle and the GT restriction are imposed. Then, the $F3$/GT, $o = 2/C_{\max}$ problem in which machine no-idle restriction in the first case is relaxed, is considered. Finally, the $F3$/no-idle, $o = 2/C_{\max}$ problem with the GT restriction of the first variant is relaxed is considered. The first known polynomial time schemes for these three cases are presented.

Various applications of the proposed flowshop model are encountered in the testing process in semiconductor manufacturing, in which an IC is processed through burn-in, testing and packing (including baking). However, some of these operations may be omitted at the request of the customer for all reasons. For instance, a DRAM IC needs burn-in, testing and packing, while a FLASH IC needs only testing and packing. Besides, the packing is not always necessary if the IC is to be used in the affiliated company, or the quality of the compound in the surface of an IC is rather high such that baking is unnecessary.

The minimization of makespan for scheduling n jobs on m machines in a flow shop has received considerable attention. When m equals 2, the application of Johnson's rule (1954) yields the minimum makespan. Unfortunately, Johnson's rule cannot be extended to three machines unless that the second machine is not the "bottleneck." Garey, Johnson, and Sethi (1976) proved the NP-hardness of the $F3//C_{\max}$ problem. Gonzalez and Sahni (1978) showed that $F3/o \leqslant 2/C_{\max}$ was ordinary NP-hard.

Adiri and Pohoryles (1982) were the first to discuss the idea of the no-idle schedule. They studied $F/\text{no-idle}/\sum_i C_i$ and $F/\text{no-wait}/\sum_i C_i$ problems, and showed that the $F2//C_{\max}$ problem was equivalent to the $F2/\text{no-idle}/C_{\max}$ problem. Riane, Artiba, and Elmaghraby (1998) studied the problem of scheduling n jobs on a three stages hybrid flowshop of a particular structure, one machine in each the first stage and the third stage, and two dedicated machines in the second stage to minimize the makespan. Two heuristics procedures have been proposed to solve the problem. Baptiste and Hguny (1997) developed a branch and bound algorithm to solve the $Fm/\text{no-idle}/C_{\max}$ problem. Saadani, Guinet, and Moalla (2003) then proposed an $O(n\log n)$ heuristic for solving $F3/\text{no-idle}/C_{\max}$ problem. Kamburowski (2004) identified a simple network representation for the same problem and revealed a certain anomaly that results from the no-idle condition, and lead to some dominance relations among the machines under which the problem became efficiently solvable. They extended their work to m-machine no-idle flowshops were also included. Saadani, Guinet, and Moalla (2005) recently proposed the well-known nearest insertion rule to solve the $F/\text{no-idle}/C_{\max}$ problem based on the idea that this problem could be modeled as a traveling salesman problem.

Liaee and Emmons (1997) considered the processing of families of jobs on single or parallel facilities, a setup time was incurred whenever a switch was made from the processing of a job in one family to that of a job in another family. They also considered cases based on the group technology assumption. Yang and Chern (2000) considered a two-machine flowshop group scheduling problem. The jobs were classified into groups; jobs in the same group must be processed consecutively. Each group involves a setup time and a removal time for both machines. A transportation time was required to move the jobs from M_1 to M_2. A polynomial time algorithm has been proposed to minimize the makespan. Lin and Cheng (2001) considered a batch scheduling in the no-wait two machine flow shop to minimize the makespan. They showed that the problem is strongly NP-hard and designed methods for solving the two restricted cases $F2$/no-wait, batch, $p_i = q_i = p/C_{\max}$ and $F2$/no-wait, batch, $p_i = q_i$, $q_i = q/C_{\max}$, where p_i and q_i are the processing time of job i on M_1 and M_2, respectively. Andres, Albarracin, Tormo, and Vicens (2005) considered the problem of a three-stage hybrid flow shop problem with sequence dependent and separable setup time. They applied the model to the tile industry to identify a set of families that are integrated by products that have a common feature.

These particular classes of $F3/o = 2/C_{\max}$ problems were (i) to establish methods for solving simple problems in order to generalize them to solve complex problems. (ii) to identify special cases which were tractable in polynomial time. These results may narrow down the gap between easy and hard cases of the general problem.