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A heuristic for minimizing the makespan in no-idle permutation flow shops☆

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Abstract

The paper deals with the problem of finding a job sequence that minimizes the makespan in m-machine flow shops under the no-idle condition. This condition requires that each machine must process jobs without any interruption from the start of processing the first job to the completion of processing the last job. Since the problem is NP-hard, we propose a constructive heuristic for solving it that significantly outperforms heuristics known so far.

Keywords: Scheduling; Flow shop; No-idle machines; Makespan; Heuristics

1. Introduction

A set of n jobs, $\{1,2,\ldots,n\}$, available at time zero has to be processed in a shop with m-machines M_1, $M_2,\ldots,M_m$. Each job is processed first on M_1, next on M_2, and so on, and lastly on M_m. No machine can process more than one job at a time, no job preemption is allowed, and all setup times are included into the job processing times. The m-machine permutation flow shop problem, $Fm|\mathrm{prmu}|C_{\max}$, is to determine a job sequence that minimizes the makespan, that is, the completion time of the last job on M_m. If, in addition, each machine must process jobs without any interruption from the start of processing the first job to the completion of processing the last job, then the m-machine no-idle permutation flow

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shop problem, $Fm|\text{prmu,no-idle}|C_{\max}$, is defined. Baptiste and Lee (1997) showed that $F3|\text{prmu,no-idle}|C_{\max}$ is strongly NP-hard.

The no-idle condition is typically imposed when the machine idle time is extremely costly. For example, the furnace in the fiber glass processing, in which glass batches are reduced to molten, stays on throughout the entire production season as it takes three days to heat it back to the required temperature of 2800 °F. Saadani, Guinet, and Moalla (2003) presented a three-machine flow shop production of engine blocks in a foundry. It includes the casting of sand moulds and sand cores. The moulds are filled up with metal in fusion and the cores prevent the metal to fill some spaces in the mould. The casting machines work without idle times due to both economic and technological reasons.

As opposed to the flow shop problems under the blocking and no-wait conditions that attracted a great deal of attention, there are only few papers written on $Fm|\text{prmu,no-idle}|C_{\max}$. Adiri and Pohoryles (1982) were the first to observe that $F2|\text{prmu,no-idle}|C_{\max}$ and $F2|\text{prmu}|C_{\max}$ are equivalent, and therefore, $F2|\text{prmu,no-idle}|C_{\max}$ can be solved by Johnson's (1954) algorithm. Baptiste and Lee (1997) developed an integer linear programming model of $Fm|\text{prmu,no-idle}|C_{\max}$, and a corresponding branch and bound algorithm; see also Saadani, Baptiste, and Moalla (2005). Saadani, Guinet, and Moalla (2001) approximated $Fm|\text{prmu,no-idle}|C_{\max}$ by an instance of the shortest Hamiltonian path problem, and propose a heuristic similar to the insertion point traveling salesman problem heuristics. Saadani et al. (2003) presented a simple heuristic for solving $F3|\text{prmu,no-idle}|C_{\max}$, and examined its performance in comparison with their lower bound on the shortest makespan, as well as with the optimal solution found by Lingo for small instances. Kamburowski (2004) observed that, under the no-idle condition, the makespan is not an increasing function of the job processing times. He also identified some efficiently solvable special cases of $Fm|\text{prmu,no-idle}|C_{\max}$.

The purpose of this paper is to present a new $O(mn^2)$ constructive heuristic for minimizing the makespan in no-idle permutation flow shops that significantly outperforms the heuristic of Saadani et al. (2001). We also show that our heuristic outperforms even the famous NEH $Fm|\text{prmu}|C_{\max}$ heuristic of Nawaz, Enscore, and Ham (1983) when it is modified for solving $Fm|\text{prmu,no-idle}|C_{\max}$.

2. Background

Consider Johnson's flow shop with two artificial machines in series A and B, and let a_j and b_j be the processing times of job j on A and B, respectively. The makespan, $C_{\max}(\pi;A,B)$, of a job sequence $\pi = (\pi(1),\pi(2),\ldots,\pi(n))$ is the length of the critical (longest) path in the acyclic network depicted in Fig. 1; the nodes are numbered by the corresponding processing times. A job $\pi(k)$ for which $C_{\max}(\pi;A,B) =$

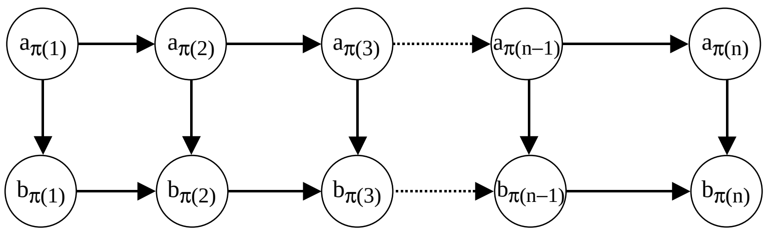

Fig. 1. Network for computing the makespan $C_{\max}(\pi;A,B)$ in $F2|\text{prmu}|C_{\max}$.