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Flexible job shop scheduling problem for parallel batch processing machine with compatible job families

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ABSTRACT

Flexible Job-Shop Scheduling Problem (FJSP) with Parallel Batch processing Machine (PBM) is studied. First, a Mixed Integer Programming (MIP) formulation is proposed for the first time. In order to address an NP-hard structure of this problem, the formulation is modified to *selectively* schedule jobs. Although there are many jobs on a given floor, semiconductor manufacturing is most challenged by priority jobs that promise a significant amount of financial compensation in exchange for an expedited delivery. This modification could leave some non-priority jobs unscheduled. However, it vastly expedites the discovery of improving solutions by first branching on integer variables with higher priority jobs. This study then turns job-dependent processing times into job-independent ones by assuming a machine has an equal processing time on different jobs. This assumption is roughly true or acceptable for the sake of the reduced computational time in the industry. These changes significantly reduce computational time compared to the original model when tested on a set of common problem instances from the literature. Computational results show that this proposed model can generate an effective schedule for large problems. Author encourages other researchers to propose an improved MIP model.

1. Introduction

In the semiconductor industry, researchers have exploited the performance of local production areas like lithography, diffusion, etch, and implanter for the last decades by using advanced scheduling/dispatching systems. Now, there is a growing need for orchestrating a whole factory to seek a global optimization. While flexible job shop scheduling problem (FJSP) with 3000-job (assuming 50 K monthly wafers output and 45 days cycle time), 1000-machine, 500-step, 40-product is unlikely to be solved in reasonable time, linking and orchestrating multiple consecutive steps seem to be approachable.

One application is a wet-diffusion area scheduling problem which has 2–4 consecutive steps with parallel batching machines [1–3]. Another application is to schedule jobs having the time constraint between consecutive process steps [4–7]. The last application which has not yet been studied in the literature is to schedule priority jobs which are often introduced into the factory for new product development or business considerations. A typical priority job travels on such an irregular process flow that it disrupts normal production and creates an inconsistent cycle. Furthermore, a floor supervisor often takes an extreme measure letting some ports of machine empty as the priority job is approaching from upstream steps due to the non-preemptive nature of machines in the industry. This results in a productivity loss. The industry calls it *priority job scheduler* (PJS). This study tackles this PJS problem in the context of FJSP with batching.

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Table 1
The articles related FJSP mathematical models.

Ref.	Year	Highlights	Journal
[15]	1997	sequence dependent setup times	EJOR
[16]	1999	process plan flexibility	IJPR
[17]	2001	alternative process plan	IJPE
[8]	2001	sequence dependent setup times	IJPR
[18]	2001	sequence dependent setup times	IEEE
[19]	2002	process plan flexibility	C&IE
[20]	2005	homogenous machines	IJPE
[21]	2006	sequence dependent setup times	IEEE
[22]	2006	sequence independent setup times	C&OR
[23]	2006	flexible preventive maintenance	JIM
[10]	2007	–	JIM
[24]	2007	sequence dependent setup times	IJAMT
[25]	2009	–	C&IE
[26]	2009	sequence independent setup times	SETP
[27]	2009	overlapping	AMM
[28]	2010	process plan flexibility	AMM
[29]	2010	disturbances	JMST
[30]	2010	–	IJPR
[31]	2011	preventive maintenance	ESA
[32]	2012	transportation constraints	C&OR
[9]	2013	evaluation of MIP models	AMM
[33]	2015	sequence dependent setup times	JIM
[34]	2016	With transportation times	AMM

Considerable research has been devoted to FJSP in the literature. However, in consideration of the fact that there is no earlier work concerning FJSP with parallel batch processing machine (PBM), this paper attempts to propose an MIP model for FJSP with batching constraint for the first time and suggest a couple of modifications to reduce computational time. The rest of this paper is organized as follows: a literature review is presented in Section 2, and the proposed MIP model is developed in Section 3. Computational results are reported in Section 4, and finally Section 5 covers the conclusion.

2. Previous related work

2.1. Flexible job-shop scheduling problem

The classical JSP schedules a set of jobs on a set of machines with the objective to minimize a maximum completion time over all jobs (*Cmax*), subjected to the constraint that each job has an ordered set of operations, each of which must be processed on a predefined machine, whereas FJSP allows an operation to be processed on a machine out of a set of alternatives, which adds another dimension of complexity.

Researchers have addressed the FJSP mostly using heuristics. Despite the fact that these heuristics may generate fast and effective solutions, they are usually tailor-made. The best combination of parameters, which lead to effective solutions, is difficult to find so researchers conduct extensive experiments solely for that purpose. Namely, the efficiency of these techniques strongly depends on a proper implementation and fine tuning of parameters since they combine a problem representation and a solution strategy into a single framework. In contrast, mathematical modeling approach separates a problem representation from a solution strategy [13]. Furthermore, as computer hardware and solvers have improved, practitioners have been able to formulate increasingly detailed and complex problems. Therefore, this study explores a mathematical modeling approach.

Table 1 shows an overview of FJSP mathematical models in the literature. The overview table created by Demir and İşleyen [9] is slightly modified. A vast number of studies have addressed FJSP and its variants like plan flexibility, setup, overlapping, preventive maintenance, etc. However, to the best of our knowledge to date, no published work has dealt with the FJSP with batching.

They also categorize FJSP mathematical formulations into three different types: sequence-position variable based, precedence variable based, and time-indexed. Our proposed model is based on the sequence-position variable.

2.2. Priority job scheduler

Business requirements drive the need for a small number of jobs to be run through the factory as fast as possible. Various manual and automated schemes have been tried to keep the priority jobs from “queuing at the machine”. These schemes involve idling machines ahead of the arrival of priority jobs and trading machine utilization for priority jobs cycle time [3].

The main contributions of this paper can be summarized as follows. This study proposes a mathematical formulation of FJSP with batching constraint for the first time and makes a couple of modifications to reduce computational time for the PJS problem encountered at semiconductor manufacturing.