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Parallel-machine scheduling to minimize makespan with fuzzy processing times and learning effects

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ABSTRACT

This paper addresses parallel machine scheduling with learning effects. The objective is to minimize the makespan. To satisfy reality, we consider the processing times as fuzzy numbers. To the best of our knowledge, scheduling with learning effects and fuzzy processing times on parallel machines has never been studied. The possibility measure will be used to rank the fuzzy numbers. Two heuristic algorithms, the simulated annealing algorithm and the genetic algorithm, are proposed. Computational experiments have been conducted to evaluate their performance.

1. Introduction

Traditionally, job processing times are assumed to be fixed and known over the entire process. In reality, the job processing times in many situations are not fully known in advance, and the efficiency of the production line improves continuously as firms produce more of a product and gain knowledge or experience. As a result, the production time of a given product is shorter if it is processed later. This phenomenon is known in literature as the "learning effect". Bachman and Janiak [2], Biskup [6], and Janiak and Rudek [19] have provided comprehensive reviews of scheduling models and problems with learning effects. For more recent papers, readers can refer to Lai and Lee [23], Lee [26], Zhang et al. [53], Cheng et al. [8], Kuo et al. [21], Lee and Wu [28], Yin et al. [47], Yin et al. [48], Rudek [38], Wang et al. [43], and Cheng et al. [9].

Most of the research on scheduling with learning effects focuses on the single machine environment and studies on parallel machines are relatively unexplored. Pinedo [36] noted that a bank of machines in parallel provides a setting that is important from both a theoretical and a practical point of view. From a theoretical viewpoint, a bank of machines in parallel is a generalization of the single machine and a special case of the flexible flowshop. From a practical point of view, a bank of machines in parallel is important because the occurrence of resources in parallel is very common in the real world. Techniques for machines in parallel are often used in decomposition procedures for multistage systems. In addition, many practical job shop and open shop scheduling problems can be treated as parallel machine scheduling problems under certain

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constraints [13,15,31,4]. The parallel machine environment exists not only in manufacturing but also has applications in the service sector or in information systems, i.e., parallel information processing and distributed computing.

To the best of our knowledge, Mosheiov [33] was the first author to study the learning effect on parallel machines. He showed that the total completion time problem on parallel identical machines is polynomially solvable under Biskup's [5] position-based learning effect model. Eren [11] studied a bi-criterion identical parallel machines scheduling problem with a learning effect of setup times and removal times. The objective was to minimize the weighted sum of total completion time and total tardiness. He provided a mathematical programming model to solve problems with up to 15 jobs and five machines and three heuristic approaches to solve problems with large numbers of jobs. Toksari and Guner [42] considered a parallel machine earliness/tardiness (ET) scheduling problem with different penalties based on the effects of position-based learning and linear or nonlinear deterioration. They showed that the optimal solution for the ET scheduling problem under effects of learning and deterioration is a V-shaped schedule under certain agreeable conditions. Furthermore, they developed a mathematical model, an algorithm and a lower bound procedure for problems with large numbers of jobs. Okołowski and Gawiejnowicz [34] considered a parallel-machine makespan problem under the general DeJong's learning curve. For the NP-hard problem, they proposed two exact algorithms, a sequential branch-and-bound algorithm and a parallel branch-and-bound algorithm. Hsu et al. [16] investigated an unrelated parallel-machine scheduling problem with past-sequence-dependent setup time and learning effects. They derived a polynomial time solution for the total completion time problem. Kuo et al. [22] studied unrelated parallel-machine scheduling problems with setup time and learning effects. The setup time is proportional to the length of the jobs already processed, and the objectives are to minimize the total absolute deviation of job completion times and the total load on all machines. They showed that both problems are polynomially solvable. Yang et al. [46] considered the parallel-machine scheduling problem with aging effects and multiple-maintenance activities. The objective was to find the optimal maintenance frequencies, the optimal positions of the maintenance activities, and the optimal job sequences. They provided an efficient algorithm to solve the problem when the maintenance frequencies on the machines were given.

In the literature on scheduling with the learning effect, it is assumed that the job processing time is a known constant which will be shortened due to the learning effect. However, there are situations in which the job processing times might not be fully known in advance. In many practical industrial applications, the data are usually recorded or collected under the influence of some unexpected noise. As a result, the processing time of a job cannot be measured precisely, and fuzzy set theory provides a convenient alternative framework for modeling real-world systems mathematically. Balin [4] noted several advantages of fuzzy numbers. For instance, fuzzy theory provides an efficient way to model imprecision [1]. Using fuzzy set theory decreases the computational complexity of the scheduling problem compared to the stochastic-probability theory [3]. Fuzzy theory enables the use of fuzzy rules in heuristic algorithms [39].

In practical industrial applications, the data are usually recorded or collected under the influence of unexpected noise, so the processing time of a job often cannot be measured precisely. In this event, perhaps a more reasonable statement is that "the processing time is approximately 2 h". The better way to model the phrase "approximately 2 h" would be to invoke a fuzzy number $\tilde{2}$. In this paper, we shall use the possibility and necessity frameworks and ranking concept proposed by Dubois and Prade [10], thus enabling us to optimize the objective functions as fuzzy makespans or total weighted fuzzy completion times.

Fuzzy scheduling problems have been explored for more than two decades. Though the possibility and necessity concept was proposed early by Dubois and Prade [10], the history of applying the ranking method based on possibility or necessity measure to fuzzy scheduling problems is shorter. To the best of our knowledge, Itoh and Ishii [18] made an early attempt to use the possibility measure to propose the concept of $\lambda - P$ tardiness. Chanas and Kasperski [7] later investigated the single machine fuzzy scheduling problem based on possibility and necessity indices. We refer to Lai and Wu [24] for details of other works. Peng and Liu [35] proposed a hybrid intelligent algorithm to solve three parallel machine scheduling problems with fuzzy processing times. Tavakkoli-Moghaddam et al. [41] proposed a fuzzy multi-objective linear programming problem to minimize the total weighted tardiness and makespan simultaneously in a fuzzy environment. Balin [4] proposed a genetic algorithm for minimizing the makespan of parallel machines where processing times are fuzzy. Huang et al. [17] considered a fuzzy time-dependent project scheduling problem and proposed three fuzzy programming models to address different situations of decision–making encountered in practice.

In nature, many factors are often imprecise or uncertain in real-world scheduling problems. Fuzzy set theory is suitable to address the uncertainties, and it offers a convenient framework for modeling real-world production systems mathematically. Moreover, the actual job processing time may be shortened due to the repetition of similar tasks. The classification of related work is given in Table 1. To best of our knowledge, the fuzzy set theory and the learning effect have never been studied simultaneously, especially in the parallel machine environment. In this paper, we study a parallel machine scheduling problem with learning effects and fuzzy processing times. The objective is to minimize the fuzzy makespan. We adopted

Table 1
Literature review about the learning effect and fuzzy number.

	Single machine	Parallel machine	Others
Learning effect	[2,5,8,9,19,23,38,47]	[11,16,22,33,34] [42,46]	[6,12,21,26,28,43,48,53]
Fuzzy number	[7,18,41]	[1,4,35]	[3,17,24,25,39]