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Multi-objective fuzzy multiprocessor flowshop scheduling

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ABSTRACT

This paper considers a bi-objective hybrid flowshop scheduling problems with fuzzy tasks' operation times, due dates and sequence-dependent setup times. To solve this problem, we propose a bi-level algorithm to minimize two criteria, namely makespan, and sum of the earliness and tardiness, simultaneously. In the first level, the population will be decomposed into several sub-populations in parallel and each sub-population is designed for a scalar bi-objective. In the second level, non-dominant solutions obtained from sub-population bi-objective random key genetic algorithm (SBG) in the first level will be unified as one big population. In the second level, for improving the Pareto-front obtained by SBG, based on the search in Pareto space concept, a particle swarm optimization (PSO) is proposed. We use a defuzzification function to rank the Bell-shaped fuzzy numbers. The non-dominated sets obtained from each of levels and an algorithm presented previously in literature are compared. The computational results showed that PSO performs better than others and obtained superior results.

1. Introduction

Scheduling problems are the allocation of machines to perform a set of jobs in a period of time. In general, scheduling requires both sequencing and machine allocation decisions. When there is only one machine, the allocation of that machine is completely determined by sequencing decisions. As a consequence, in the single-machine model, no distinction exists between sequencing and machine allocation. To appreciate that distinction, we must examine models with more than one machine. A hybrid flowshop scheduling (HFS) problem, as described by Linn and Zhang [1], consists of a series of production stages, each of which has several machines operating in parallel. Some stages may have only one machine, but at least one stage must have multiple machines. The HFS is an adequate model for several industrial settings such as semiconductors, electronics manufacturing, airplane engine production, and petrochemical production [2]. The flow of products in the plant is unidirectional. Each product is processed at only one facility in each stage and at one or more stages before it exits the plant. The machines in stages can be identical, uniform, or unrelated and each job is processed by at most one machine at each stage.

Many real-world problems involve simultaneous optimization of several objective functions. In general, these functions often compete and conflict with themselves [3]. Many industries such as aircraft, electronics, semiconductors manufacturing, etc., have tradeoffs in their scheduling problems where multiple objectives need to be considered in order to optimize the overall performance of system. For reflecting real-world situation adequately, we formulate the scheduling problems as bi-objective ones that simultaneously minimize the maximum completion time (makespan), and the sum of the earliness and tardiness (ET) of jobs. The use of both objectives is well-justified in the practice, as makespan minimization implies the maximization of the throughput and the second objective comes from the make-to-order philosophy in management and production theory: an item should be delivered exactly when it is required by the customer. Therefore, both early and tardy delivery of a task with respect to its due date is penalized. Interestingly, the objective of the ET problem fits perfectly to just-in-time (JIT) production control policy where an early or a late delivery of an order results in an increase in the production costs.

Fuzzy set theory has been studied extensively over the past 40 years and many approaches have been proposed in this field. Most of the early interest in fuzzy set theory pertained to representing uncertainty in the human cognitive processes. Fuzzy set theory is now applied to problems in the various sciences and it is being recognized as an important problem modeling and solution technique [4]. Several successful applications and implementations of fuzzy set theory in the production management have also been reported. Fuzzy scheduling is a very important research topic not

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only because of the fuzzy nature of most real-world problems, but also because there are still many open questions in this area.

Four important motivations that fuzzy set theory is relevant to scheduling are as follows [5].

- In the scheduling environment, the information required to formulate an objective function, decision variables, constraints and parameters may be vague or not precisely measurable.
- Third, imprecision and vagueness as a result of personal bias and subjective opinion may further dampen the quality and quantity of available information.
- A fuzzy scheduling algorithm constructs the real system flexibility and models the uncertainty inherent in real environments.

This notice has led to the development of fuzzy scheduling. The "most obvious place" to introduce fuzzy concepts for modeling uncertainty in scheduling algorithms is with a task's operation and due date time. Typical scheduling algorithms assume this information to be crisp value; this may or may not be reliable. By modeling these times of a task with a fuzzy number, a system designer can build flexibility into the scheduling algorithm and reach to better solution.

Machine setup time is a significant factor for production scheduling in many factories. In sequence-dependent scheduling, the length of time required to do the setup depends on both the prior and the current job to be processed [6]. Due to great saving when setup times are explicitly included in scheduling decisions, we take into account the existence of sequence-dependent setup times in our problem. Sequence-dependent setup times (SDST) hybrid flowshop scheduling can be found in a vast number of industries. Numerous examples are given in the literature, including the plastics manufacturing, rolling slitting in the paper industry [7] and wafer testing in semiconductor manufacturing [8]. Since recently, considering SDST becomes popular researches' area [9], according to taxonomy of Quadt and Kuhn [10] only few studies considered setup times.

Our goal in this paper is to develop a two level algorithm to bi-objective fuzzy hybrid flowshop that gives a set of compromise (non-dominated) solutions, so that, these solutions should represent a good approximation to the Pareto optimal front.

The paper has the following structure. Section 2 gives literature review. Section 3 presents mathematical modeling. Section 4 is the bell-shaped fuzzy number description and its arithmetic. Section 5 introduces the two-level algorithm and characteristics of the proposed algorithms. Section 6 presents the experimental design which compares the algorithms' results. Finally, Section 7 is devoted to conclusions and future works.

2. Literature review

Ishibuchi and Murata [11] fuzzified the due dates of jobs. In their work, the satisfaction degrees for job completion times are described using fuzzy sets, and the objective is to obtain a job sequence whose completion time has a maximum degree of satisfaction. In that study, a multi-objective genetic algorithm is developed to handle these fuzzy scheduling objectives. The uncertainty of processing time has been described as triangle fuzzy numbers by Liu and Gu [12] in the flowshop scheduling environment under uncertainty on fuzzy programming theory. Balasubramanian and Grossmann [13] presented a mixed integer linear programming models for the flowshop scheduling problems with uncertainty in the processing time. The uncertainty of task durations used from the fuzzy set theory concepts. They predict the optimistic and pessimistic values of makespan. Peng and Song [14] proposed a hybrid intelligent algorithm to solve three types of fuzzy flowshop scheduling models. In that study the authors aimed to demonstrate how the hybrid intelligent algorithm can be used for managing fuzzy scheduling on the flowshop problems. Celano et al. [15] used a concept of agreement index to solve the scheduling problems with fuzzy due dates considering the fuzzy-sum and fuzzy maximum among triangular fuzzy numbers.

Zheng and Gu [16] considered no-wait flowshop production scheduling within finite intermediate storage under uncertainty in which fuzzy processing time was conducted. The maximum membership function of mean value was applied to convert the fuzzy scheduling model to an accurate optimization problem. An improved simulated annealing algorithm was proposed to verify and optimize the scheduling model. Wu and Gu [17] used the fuzzy numbers to denote the uncertainty of processing time in flowshop scheduling problem, and developed the multiple objectives scheduling model for flowshop scheduling problems with fuzzy processing time. In that research, the multiple objectives are converted into single one by weighted method, and the fuzzy optimal problem then transformed to determinate one by Zimmermann algorithm. Finally, Wu and Gu [17] proposed a genetic algorithm for solving the problems. Temiz and Erol [18] applied fuzzy concept to the flowshop scheduling problems. A branch-and-bound algorithm was used for three-machine flowshop problems with fuzzy processing time. In that study, fuzzy arithmetic on fuzzy numbers is used to determine the minimum completion time. Proposed algorithm gets a scheduling result with a membership function for the final completion time. Wang et al. [19] considered the fuzzy flowshop scheduling problem with distinct due window. For the fuzzy flowshop scheduling, first the authors applied triangular fuzzy number as processing time and established a fuzzy programming model. Then they transformed fuzzy objection function into deterministic function. In that paper, a genetic algorithm based on the fuzzy logic controller is developed. Xu and Gu [20] considered a fuzzy scheduling model for flowshop problems with uncertain processing time based on fuzzy programming theory, in which the uncertain processing can be dealt with by the fuzzy operators and fuzzy model can be transformed to the optimal programming. For solving the scheduling problem, they combined an immune algorithm and a branch and bound method in a hybrid algorithm. Petrovic and Song [21] proposed a new approach based on Johnson's algorithm for the two-machine flowshop problem in the presence of uncertainty. It is assumed that the processing times of jobs on the machines are described by triangular fuzzy sets and used α-cuts of the fuzzy processing times. Kilic [22] proposed an ant colony optimization metaheuristic in the flowshop scheduling problem with fuzzy processing times and flexible due dates. Wang and Yang [23] proposed a particle swarm optimization algorithm for the flowshop scheduling problems with uncertain processing times. In that study, the uncertain processing times are represented by triangular fuzzy numbers. They designed an integrated objective function to embody the bi-criteria schedule, which involves the fuzzy makespan and the robustness of makespan. The scheduling problem with fuzzy processing times and fuzzy due dates are concerned in Lai and Shu [24] study. To obtain an optimal schedule which minimizes tardiness fuzzy-valued objective functions, they invoked the ant colony algorithm to solve the optimal problem. Bozejko et al. [25] proposed a genetic algorithm for the problems with fuzzy data and block properties, which enable the inter-island genetic operator to distribute calculations and use local search process apart of classic operators. Javadi et al. [26] developed a fuzzy multi-objective linear programming model for solving the multi-objective no-wait flowshop scheduling problem in a fuzzy environment. The proposed model in this paper attempts to simultaneously minimize the weighted mean completion time and the weighted mean earliness. Zhou and Gu [27] considered a type of no-wait flowshop scheduling problem with fuzzy due date. For