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Mathematical modeling and multi-objective evolutionary algorithms applied to dynamic flexible job shop scheduling problems

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ABSTRACT

Dynamic flexible job shop scheduling is of significant importance to the implementation of real-world manufacturing systems. In order to capture the dynamic and multi-objective nature of flexible job shop scheduling, and provide different trade-offs among objectives, this paper develops a multi-objective evolutionary algorithm (MOEA)-based proactive–reactive method. The novelty of our method is that it is able to handle multiple objectives including efficiency and stability simultaneously, adapt to the new environment quickly by incorporating heuristic dynamic optimization strategies, and deal with two scheduling policies of machine assignment and operation sequencing together. Besides, a new mathematical model for the multi-objective dynamic flexible job shop scheduling problem (MODFJSSP) is constructed. With the aim of selecting one solution that fits into the decision maker's preferences from the trade-off solution set found by MOEA, a dynamic decision making procedure is designed. Experimental results in a simulated dynamic flexible job shop show that our method can achieve much better performances than combinations of existing scheduling rules. Three MOEA-based rescheduling methods are compared. The modified ε-MOEA has the best overall performance in dynamic environments, and its computational time is much less than two others (i.e., NSGA-II and SPEA2). Utilities of introducing the stability objective, heuristic initialization strategies and the decision making approach are also validated.

1. Introduction

Job shop scheduling problem (JSSP) is well-known as a strongly NP-hard combinational optimization problem [17], which mainly deals with finding out the best sequences for processing jobs on each operable machine to achieve the required objectives subject to precedence and processing time constraints. In JSSP, each operation of a job should be processed on a predefined machine only once in a fixed operation sequence. However, the wide employment of multi-purpose machines in the real-world job shop makes it more general that an operation can be managed by several machines, i.e., there are alternative routings, which is the so-called flexible job shop scheduling problem (FJSSP). FJSSP is a generalization of JSSP. It has more complexity than JSSP because the machine assignment problem which selects an alternative machine for each operation should also be addressed, besides the sequencing problem. Hence, FJSSP is also considered to be strongly NP-hard [15].

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In real-world manufacturing systems, it is often the case that the working environment changes dynamically by unpredictable real-time events, such as one machine fails to work suddenly, and new jobs arrive in a stochastic way. A previously optimal schedule may get poor system performance or even becomes infeasible in the new environment. Moreover, some information about the job shop is previously unknown. For example, the due date and processing time of the new job are not given until the job arrives. This kind of problems is generally known as dynamic scheduling [14]. As indicated in [29], dynamic scheduling is of great importance to the successful implementation of real-world manufacturing systems.

In the literature reported, there are mainly three categories of dynamic scheduling technologies, which are completely reactive, predictive–reactive, and pro-active scheduling [29]. Among them, predictive–reactive scheduling is the most commonly used. It has a scheduling/rescheduling process where previous schedules are revised to adapt to the new environment caused by dynamic events. Most of the existing research generated a new schedule by minimizing the effect of disruption on shop efficiency like make-span [2,5]. However, it may produce a new schedule totally different from the original one. For example, some remaining operations in the previous schedule which have not begun processing at the time of rescheduling may have their starting time accelerated or delayed. It has a serious impact on other production activities planned based on the original schedule, and brings instability and lack of continuity in the shop system [33]. Thus, both the performances of efficiency and stability should be considered in predictive–reactive scheduling. Above all, FJSSP in the real world has the dynamic and multi-objective nature.

A few literatures have rescheduled dynamic job shops based on multiple objectives. Some of them only considered the performances of efficiency [2,5,32], e.g. make-span and tardiness. The others incorporated both efficiency and stability [14,33,62]. All the above studies used a weighted sum approach to convert multiple objectives to a single function. However, in most real-world cases, it would be difficult to identify suitable weights for each objective. On the other hand, multiple objectives such as make-span, tardiness and stability are usually conflicted with each other. It is better to handle multiple objectives with knowledge about their Pareto front. The various trade-offs among different objectives provided by the Pareto front is very useful in making an informed decision in dynamic scheduling. Evolutionary algorithms (EAs) have been recognized to be well suited for multi-objective optimization problems due to their capability to evolve a set of solutions simultaneously in one run. In the past 20 years, MOEA received much attention, and lots of success has been achieved [39].

So far, various EAs have been applied to solve manufacturing optimization problems. To optimize cutting parameters in the multi-pass turning operations, a comparative study of ten population-based optimization algorithms was performed in [47], and an artificial bee colony algorithm [48] and a hybrid Taguchi-differential evolution algorithm [49] were proposed, respectively. To select optimal machining parameters in milling operations, a hybrid differential evolution algorithm and a cuckoo search algorithm were presented in [50,51], respectively. As to the structural and shape design optimization problem, different EAs have been investigated, such as the hybrid of immune algorithm and Taguchi method [52], the hybrid differential evolution algorithm [53], the harmony search algorithm [54], the hybrid particle swarm optimization algorithm [55–57], Cuckoo search algorithm [13], genetic algorithm [58], the immune algorithm combined with a hill climbing local search [59,60], and the hybrid of immune and simulated annealing algorithm [61].

To our best knowledge, in the literature reported, MOEA has not yet been adopted to regenerate new schedules in a predictive–reactive way when shop environments change. The primary aim of this paper is to solve MODFJSSP based on an MOEA in a modified predictive–reactive scheduling manner. With the aim of covering the shortage of existing methods, three aspects are studied: (i) the mathematical model for MODFJSSP is constructed. In the model, four objectives including both the performances of efficiency and stability are considered simultaneously. Besides, constraints to the search space change dynamically when real-time events occur, which are also addressed in the model developed; (ii) a new MOEA-based rescheduling method is proposed, which do not regenerate a new schedule from scratch, but incorporate several heuristic methods in creating the initial population, and use problem specific genetic operators for variation; and (iii) in order to select one appropriate solution from the trade-off solution set found by an MOEA, a dynamic decision making procedure is designed. To evaluate the effectiveness of the proposed methods, a realistic dynamic flexible job shop is simulated with three purposes: (1) comparing the job shop performance produced by the MOEA-based rescheduling method to that of the combinations of existing heuristic rules and that of the existing static algorithms; (2) analyzing different trade-offs among the four objectives, and comparing the overall performances in dynamic environments produced by three MOEAs (ε-MOEA [9], NSGA-II [10], SPEA2 [64]); and (3) investigating the impact and utility of the stability objective, heuristic initialization strategies and the decision making approach.

The remainder of this paper is organized as follows. Section 2 presents a short overview of the existing related work. Section 3 describes the problem formulation which introduces the rescheduling mode and constructs the mathematical model of MODFJSSP. In Section 4, the new MOEA-based rescheduling method for MODFJSSP and the dynamic decision making approach are described in detail. Experimental results are discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. Related work

Mathematical model is very useful for understanding the problem structure, thus a few literature have focused on mathematical formulations for static FJSSP. A mathematical model was presented in [15] to achieve optimal solution for small size problems. A mixed-integer linear programming model was developed for FJSSP in [30]. In [12], models formulated for FJSSP in literature were reviewed which categorized them as sequence-position variable based model, precedence variable based model, and time indexed model. As to the dynamic flexible job shop scheduling problem (DFJSSP), there have been few