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Non-dominated sorting biogeography-based optimization for bi-objective reentrant flexible manufacturing system scheduling

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ABSTRACT

Scheduling in flexible manufacturing systems (FMS) is described as an NP-Hard problem. Its complexity has increased significantly in line with the development of FMS over the past years. This paper presents a non-dominated sorting biogeography-based optimization (NSBBO) for scheduling problem of FMS having multi loading-unloading and shortcuts infused in the reentrant characteristics. This model is formulated to identify the near optimal trade-off solutions capable of addressing the bi-objectives of minimization of makespan and total earliness. The goal is to simultaneously determine the best machine assignment and job sequencing to satisfy both objectives. We propose the development of NSBBO by substituting the standard linear function of emigration-immigration rate with three approaches based on sinusoidal, quadratic and trapezoidal models. A selection of test problems was examined to analyze the effectiveness, efficiency and diversity levels of the proposed approaches as compared to standard NSBBO and NSGA-II. The results have shown that the NSBBO-trapezoidal model performed favorably and is comparable to current existing models. We conclude that the developed NSBBO and its variants are suitable alternative methods to achieve the bi-objective satisfaction of reentrant FMS scheduling problem.

1. Introduction

Flexible manufacturing systems (FMS) have become an important part of modern production environment due to its ability in responding quickly to the dynamics of demand [1]. The flexibility in FMS enables the production system to share its resources in processing a wide array of products at the same time, thus reducing the overall production costs. However, the planning and scheduling in FMS are mostly composed of NP hard combinatorial problems which are difficult to solve and develop the relevant optimal polynomial algorithm [2].

This study considers the scheduling problem in reentrant FMS with multi loading-unloading and shortcuts, two characteristics which increase the complication significantly [3]. The problem covers two decisions: 1) determining the sequence of jobs to start the operation, and 2) to determine the machine assignment for each operation and subsequently set the routing path for each job. Both problems need to be considered simultaneously to satisfy the bi-objective of minimizing makespan and total earliness. Minimizing makespan is closely related to maximizing the productivity and reducing production cost. It is the most commonly used objective in FMS scheduling, even in recent publications [4–7]. Decreasing the makespan means that more time can be saved in manufacturing certain amount of products, with the implication that the job can be completed earlier than scheduled.

Alongside maximizing productivity, the just-in-time (JIT) philosophy is another popular objective in production systems. JIT mechanism advocates that products are produced only when they are needed, so both early and tardy results are undesirable [8]. Thus, the optimum production schedule is when all jobs are completed on their due times. JIT eases the supply chain in coordinating material flows from the suppliers to costumers, as well as reducing undesired inventory cost which is then regarded as waste. JIT approach has been considered for various types of scheduling problems, i.e. in flexible job-shop [9], single machine scheduling [10], and parallel machine scheduling [11]. The proposed makespan-earliness

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pair is intended to achieve the balance between increasing productivity and JIT production. Since these objectives are contradictive in nature, conforming both objectives are the key to obtain the optimized trade-off solutions.

Since the problem is classified as an NP hard, the use of metaheuristics is obliged. Godinho Filho et al. [12] have reviewed the use of Genetic Algorithm (GA) and its derivative, concluding that GA is still the most popular method for solving FMS scheduling problems. Kim et al. [13] developed a Network-based hybrid GA, incorporating a neighborhood search technique in the mutation operation. The inclusion is intended to improve the solution and to enhance the performance of the genetic search process. Similarly, Prakash et al. [14] have included knowledge management into a knowledge based Genetic Algorithm (KBGA), whereas Burnwal and Deb [15] developed a cuckoo search based approach to minimize penalty costs due to delay in manufacturing and maximizing the machine utilization time. Newly proposed methods would be typically compared to traditional methods of Shortest Processing Time, Longest Processing Time, GA and Particle Swarm Optimization (PSO). Erol et al. [16], in their proposal of a new multi-agent based approach for dynamic scheduling of automated guided vehicles and machines, tested the working methods on off-line scheduling problems and compared the results obtained with existing optimization methods and dispatching rules.

In recent years, the development of new algorithms was encouraged. A novel biogeography-based optimization (BBO) method has been developed recently and is gaining popularity due to its good performance on both benchmark functions and real-world optimization [17]. The method, as proposed by Simon [18], is an evolutionary algorithm modeled after biogeography evolution driven by the process of emigration and immigration of species between habitats. BBO uses information sharing between candidate solutions, allowing suitable habitats to share its feature with unsuitable habitats. The effectiveness of BBO has been demonstrated in many studies of various applications. Zheng et al. [19] developed a hybrid BBO for emergency railway wagon scheduling to minimize the weighted times for delivering all the required supplies to target stations. The results showed that the proposed hybrid BBO was able to deliver good solutions, especially for large-scale emergent operations. Lin [20] proposed a hybrid BBO for solving a fuzzy flexible job-shop problem by utilizing an algorithm with path relinking technique as migration operation, and insertion-based local search heuristic to modify the mutation operator. The hybrid BBO technique was able to outperform some state-of-the-art methods, such as co-evolutionary GA, estimation of distribution algorithm, hybrid artificial bee colony and teaching-learning-based optimization.

Rahmati and Zandieh [21] developed the BBO for flexible job shop scheduling problem. Three objectives were considered: makespan, critical machine work load, and total workload of the machine. Wang and Duan [22] presented a hybrid BBO algorithm for job shop scheduling, and its validation of method was compared with CPLEX, GA, SA, PSO and basic BBO. Paslar et al. [23] developed a BBO where different types of mutation operators were employed for the instances with different sizes and degree of complexity for the FMS scheduling problem. The goal was solving the integrated mathematical model of machine loading, part routing, sequencing and scheduling. The proposed approach considered three objectives: minimizing longest completion time, minimizing total processing cost, and concurrently minimizing maximum completion time, total processing time and the number of part movement. Berghida and Boukra [24] improved BBO for a vehicle routing problem.

More recently, Ma et al. [25] constructed an ensemble multi-objective BBO for solving automated warehouse scheduling problems. Its performance was tested on a set of ten unconstrained multi-objective benchmark functions and ten constrained multi-objective benchmark functions from the 2009 Congress on Evolutionary Computation and emerged as among the best algorithm presented. Lin and Zhang [26] presented a newly effective BBO combined with a novel local search for distributed assembly permutation flow-shop scheduling problem. Rabiee et al. [27] developed a BBO to minimize the mean tardiness for exploring a no-wait hybrid flow shop scheduling problem with realistic assumptions involving unrelated parallel machines at each stage, machine eligibility, sequence-dependent setup times and various ready times. To record the development of algorithms, Chaudhry and Khan [28] conducted a survey of flexible job shop scheduling techniques, and Danping and Lee [29] reviewed the research methods of the reentrant scheduling problem.

As FMS scheduling involves multiple objectives, it is essential to consider the issue of non-dominated properties. In scalar objective optimization, a complete order to differentiate all feasible solutions would naturally exist, i.e., for any two feasible solutions x and y, either $f(x) \leq f(y)$ or $f(y) \leq f(x)$. However, in multi-objective optimization, the Pareto dominance, $\prec$, only defines a partial order in the objective space, and not all feasible solutions can be compared to one another [30]. Therefore, the main purpose of algorithms now has shifted to obtain Pareto-optimal sets and to assist decision makers in selecting suitable compromised solutions with respect to the space of the feasible solutions. For example, recent literature has documented the use of multi-objective biogeography-based optimizations (MOBBO) to solve a variety of multi-objective problems. Yang et al. [31] design an improved MOBBO to solve the hard approximating optimization model in multi-objective supply chain network design problem with uncertain transportation costs and customer demands. Other applications can be found in indoor wireless heterogeneous network planning problem [32] and virtual machine placement problem [33]. Simon [34] further reviewed an improved BBO for multi-objective optimization called the non-dominated sorting biogeography-based optimization (NSBBO) which combined BBO with non-dominated sorting genetic algorithm (NSGA).

The previous literatures have shown that BBO was able to outperform other existing methods in various optimization problems with the ability in producing solutions with better convergence and diversity. Based on these observations, we propose a modified and improved version of NSBBO to solve reentrant FMS scheduling problems. The significances of this study include: a) Based on the literature review that has been conducted, to our best knowledge, there is no published work addressing the application of BBO in FMS scheduling with reentrant characteristic; b) The proposed method incorporates the non-dominated sorting and crowding distance sorting feature of NSGA-II for selecting new habitats; c) Three migration models, namely sinusoidal, quadratic, and trapezoidal migration models are proposed as alternatives to substitute the current linear model in the NSBBO framework; d) It was noted that the immigration-emigration rates play a central role in BBO. The migration models guiding these rates were previously observed to have good performances in different problems [35]. As each migration model has its distinct characteristic, we examined the effect and performance of each model in producing solutions based on four criteria: effectiveness, robustness, efficiency, and ability to generate diverse solutions.

The rest of the paper is organized as follows. Section 2 presents the reentrant FMS scheduling problem. Section 3 describes the procedures in NSBBO including the linear and the three non-traditional migration models. The experiments and performance analysis of the algorithms are discussed in Section 4. The conclusions are presented in Section 5.