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Solving a bi-objective flowshop scheduling problem by a Multi-objective Immune System and comparing with SPEA2+ and SPGA

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ABSTRACT

This paper presents a bi-objective flowshop scheduling problem with sequence-dependent setup times. The objective functions are to minimize the total completion time and the total earliness/tardiness for all jobs. An integer programming model is developed for the given problem that belongs to an NP-hard class. Thus, an algorithm based on a Multi-objective Immune System (MOIS) is proposed to find a locally Pareto-optimal frontier of the problem. To prove the efficiency of the proposed MOIS, different test problems are solved. Based on some comparison metrics, the computational results of the proposed MOIS is compared with the results obtained using two well-established multi-objective genetic algorithms, namely SPEA2+ and SPGA. The related results show that the proposed MOIS outperforms genetic algorithms, especially for the large-sized problems.

1. Introduction

In the operations research literature, flowshop scheduling is one of the most well-known problems in the area of scheduling. Flowshops are useful tools in modeling manufacturing processes. A permutation flowshop is a job processing facility which consists of several machines and jobs to be processed on the machines. In a permutation flowshop, all jobs follow the same machine or processing order and job processing is not interrupted once started. The objective is to find a sequence for the jobs so that the makespan or the completion time is a minimum. The majority of articles on the flowshop scheduling problems have concentrated on single-criterion problems.

Varadharajan and Rajendran [1] considered a permutation flowshop scheduling problem with the objectives of minimizing the makespan and total flow times of jobs, and presented a Multi-objective Simulated Annealing (MOSA) algorithm. Neppalli et al. [2] considered a two-stage bi-criteria flowshop scheduling problem with the objective of minimizing the total flow time while obtaining the optimal sequence. In view of the NP-hard nature of the problem, two genetic algorithms (GA)-based solutions are proposed. Framinan and Leisten [3] tackled the problem of the makespan minimization in a permutation flowshop where the maximum tardiness is limited by a given upper bound. They focused on approximate approaches that yield good heuristic solutions. T'kindt and Billaut [4] considered a flow shop problem that minimizes the maximum completion time and total tardiness. Basseur et al. [5] used an innovative Multi-objective Genetic Memetic Algorithm (MGMA) for a flow shop problem. They used specific hybrid techniques to replace the local search realized during the memetic algorithm. Beside the criterion of the maximum completion time, in multi-objective problems, the most usable function is the criteria of the total completion time. Ravindran et al. [6] dealt with the multi-criteria approach to flow shop scheduling (FSS) problems by considering the makespan and the total flow time. Three heuristic algorithms, namely HAMC1 (Hybrid Algorithm for Multi Criteria), HAMC2 and HAMC3, have been proposed to the problem. They compared their proposed algorithms with another heuristic method and reported better results. Qian et al. [7] proposed an effective hybrid algorithm based on Differential Evolution, namely HDE, to solve a Multi-objective Permutation Flow Shop Scheduling Problem (MPFSSP) with limited buffers between consecutive machines. Eren and Güner [8] tackled a tri-criteria two-machine flowshop scheduling problem. The objective is to minimize the total weighted of the completion times, total tardiness, and makespan. Yagmahan and Yenisey [9] considered the flow shop scheduling problem with multi-objectives of the makespan, total flow time, and total machine idle time. Their proposed algorithm is based on Ant Colony System algorithm (ACS). Rahimi-Vahed et al. [10] considered a bi-criteria no-wait flowshop scheduling problem that minimizes the weighted mean completion time and weighted mean tardiness. They proposed a new

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Multi-objective Scatter Search (MOSS) and compared the related results with Strength Pareto Evolutionary Algorithm II (SPEA-II). Tavakkoli-Moghaddam et al. [11] proposed a new multi-objective model for a no-wait flow shop scheduling problem that minimizes both the weighted mean completion time and weighted mean tardiness. They proposed a Hybrid Multi-objective Immune Algorithm (HMOIA) and compared the related results with five prominent multi-objective evolutionary algorithms: namely PS-NC GA (Pareto Stratum-Niche Cubicle Genetic Algorithm), NSGA-II (Non-dominated Sorting Genetic Algorithm II), SPEA-II, MOIA (Multi-objective Immune Algorithm), and MISA (Multi-objective Immune System Algorithm).

Recently, the scheduling issue of incorporating the earliness/tardiness (E/T) measure has been attracting intensive research interest. This measure is, in fact, compatible with the concept of just-in-time (JIT) production inventory control [12]. Many scheduling investigations considering the E/T measure have been reported in the literature. Most of them have considered only a single or parallel discrete processing machine cases. These studies are traced back to the late 1970s and early 1980s as shown in the literature survey by Baker and Scudder [12]. Radhakrishnan and Ventura [13] studied the Parallel machine Earliness/Tardiness Scheduling Problem (PETNDDSP) with Non-common Due Date, sequence-dependent setup times and varying processing times, where the objective is to minimize the sum of the absolute deviations of completion times from their corresponding due dates. A literature review shows only a few papers of E/T that consider the issue of scheduling the tasks on multiple non-identical machines with the objective of minimizing the total cost of earliness and tardiness, and also consider the sequence-dependent setup time for machines [14].

In this paper, we deal with a bi-objective permutation flowshop scheduling problem with setup times is considered. The objective function of the problem is to minimize the sum of the weighted completion time and the total weighted earliness/tardiness for all jobs. An effective Multi-objective Immune System (MOIS) is used to find locally Pareto-optimal frontier of the problem. The rest of this paper is organized as follows: Section 2 gives the problem definition. Section 3 surveys the Multi-objective Genetic Algorithm (MOGA) review. In Section 4, the proposed MOIS algorithm is given. The experimental results are provided in Section 5. Finally, Section 6 consists of conclusions.

2. Problem definition

The objective in flowshop scheduling problems is to find a sequence for processing all jobs on machines so that a given objective is optimized. In the literature search, we could not locate any article which explained the cost of earliness/tardiness along with another objective. Also there were only a few studies that considered sequence-dependent setup times. In this paper, we consider these objectives, and bring this problem closer to real-life conditions.

P_{ij}	processing time of job j on machine i
S_{ijk}	setup time on machine i if job j is sequenced before job k
d_j	due date for job j
α	penalty cost of stopping job j
β	tardiness and earliness cost for any job
C_{ik}	completion time of a job that positioned in sequence k on machine i
W_{jk}=	$\begin{cases} 1 & \text{if job } j \text{ is assigned to machine } k \\ 0 & \text{otherwise} \end{cases}$
$C_j = C_{mj}$	completion time of job j

The first considered objective function is the minimization of the total completion time. This objective can be computed by the following equation:

$$\min Z_1 = \sum_{j=1}^{n} C_j$$

The second objective function is to minimize of the total earliness/tardiness of all jobs. To compute the objective function value, the subsequent equation is used:

$$\min Z_2 = \sum_{j=1}^{n} (H_j(E_j) + H'_j(T_j))$$

A job is to be processed on one machine at a time without preemption and a machine processes no more than one job at a time.

$$\sum_{j=1}^{n} W_{jk} = 1, \quad \forall k \in (1, 2, \ldots, n) \tag{1}$$

$$\sum_{k=1}^{n} W_{jk} = 1, \quad \forall j \in (1, 2, \ldots, n) \tag{2}$$

The completion times for the jobs on the machines are computed by:

$$C_{11} = \sum_{j=1}^{n} W_{j1} \times P_{1j} \tag{3}$$

$$C_{1k} = \sum_{j_1=1}^{n} \sum_{j_2=1}^{n} W_{j_1,k} W_{j_2,k-1} (C_{1,j_2} + S_{1,j_2,j_1} + P_{1,j_1}), \quad \forall k \in (2, 3, \ldots, n) \ \& \ j_1 \neq j_2 \tag{4}$$

$$C_{i1} = \sum_{j=1}^{n} W_{j1} (C_{i-1,j} + P_{ij}), \quad \forall i \in (2, 3, \ldots, m) \tag{5}$$

$$C_{ik} = \sum_{j_1=1}^{n} \sum_{j_2=1}^{n} W_{j_1,k} W_{j_2,k-1} (\max\{C_{i,j_2} + S_{i,j_2,j_1}, C_{i-1,j_1}\} + P_{i,j_1}, \quad \forall i \in (2, 3 \ldots, m), \quad \forall k \in (2, 3, \ldots, n) \tag{6}$$

$$E_j = \max\{d_j - C_{mj}, 0\}, \quad \forall j \in (1, 2, \ldots, n) \tag{7}$$

$$T_j = \max\{C_{mj} - d_j, 0\}, \quad \forall j \in (1, 2, \ldots, n) \tag{8}$$

$$j_1, j_2 \in (1, 2, \ldots, n) \quad \& \ j_1 \neq j_2 \tag{9}$$

$$W_{jk} : \text{Binary} \ \& \ C_{ik} \geqslant 0 \tag{10}$$

The earliness and tardiness of job j are given by Constraints 7 and 8.

3. Multi-objective genetic algorithms

3.1. Multi-objective optimization problem

The multi-objective optimization problem is to minimize or maximize multiple evaluation criteria that conflict with each other. It is difficult to say that the solution that is an optimum for one criterion is the optimal solution for multi-objective optimization, because the multiple criteria have trade-off relationships with each other. Therefore, in multi-objective optimization, the concept of a Pareto-optimal solution is used in the search. In a Pareto optimal solution, there are multiple, or sometimes an infinite number of solutions. In multi-objective optimization, obtaining a Pareto-optimal solution is one of the goals, and an approach to obtain a wide range of Pareto optimal solutions at equal intervals is required.