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An improved migrating birds optimisation for a hybrid flowshop scheduling with total flowtime minimisation

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ABSTRACT

Migrating birds optimisation (MBO) is a new nature-inspired metaheuristic for combinatorial optimisation problems. This paper proposes an improved MBO to minimise the total flowtime for a hybrid flowshop scheduling problem, which has important practical applications in modern industry. A diversified method is presented to form an initial population spread out widely in solution space. A mixed neighbourhood is constructed for the leader and the following birds to easily find promising neighbouring solutions. A leaping mechanism is developed to help MBO escape from suboptimal solutions. Problem-specific heuristics and local search procedures are added to enhance the MBO's intensification capability. Extensive comparative evaluations are conducted with seven recently published algorithms in the literature. The results indicate that the proposed MBO is effective in comparison after comprehensive computational and statistical analyses.

1. Introduction

Scheduling is a type of decision-making process that plays a crucial role in the manufacturing and service industries [21,38,52]. This paper addresses a hybrid flowshop scheduling (HFS) problem that has a total flowtime criterion. Such a problem can be observed in a variety of modern industrial systems, including the glass, steel, paper and textile industries [1,35,40–42].

HFS problems have attracted extensive attention in recent years. Many solution approaches have been proposed in the literature. Because of the NP-hardness of the problems, exact algorithms such as branch-and-bound (B&B) and mixed-integer programming (MIP) can optimally solve only problems that are small or have a very simple scenario [4,5,28]. For decades, much more effort has been dedicated to finding high-quality solutions in a reasonable computational time by approximate methods instead of finding the optimal solution.

For the heuristics, Gupta [14] developed a simple heuristic to minimise the makespan for a two-stage HFS with only one machine at the second stage. Kim et al. [20] presented several heuristics for a similar two-stage HFS with release dates and a product-mix ration constraint. Riane et al. [39] presented two heuristics for a three-stage HFS with a particular structure. Soewandi and Elmaghraby [43] proposed several heuristics for a general three-stage HFS with a makespan criterion.

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Ruiz and Maroto [41] adapted the well-known NEH heuristic [27] to an m-stage problem with sequence-dependent setup times and machine eligibility. Paternina-Arboleda et al. [37] presented a heuristic based on the identification and exploitation of the bottleneck stage.

To attain a better quality solution, metaheuristics such as the tabu search algorithm [33], artificial immune approach [11], ant colony optimisation [2], genetic algorithm [18], simulated annealing method [17], quantum-inspired immune algorithm [32], and particle swarm optimisation [22] were applied to the HFS problems with the makespan criterion. For the HFS problem with more complex settings, Khaloui et al. [19] presented an ant colony optimisation with some heuristics that specifically accounted for both earliness and tardiness to compute the heuristic information values. Behnamian and Zandieh [3] proposed a discrete colonial competitive algorithm to minimise the sum of the linear earliness and quadratic tardiness while simultaneously considering the effects of sequence-dependent setup times and limited waiting time. Ruiz and Maroto [41] and Naderi et al. [25] provided a genetic algorithm to find a minimum makespan for a complex HFS problem with the additions of unrelated parallel machines at each stage, sequence-dependent setup times and machine eligibility. More recently, Naderi et al. [26] presented an improved simulated annealing method for an HFS problem that involved both sequence-dependent setup and transportation times to minimise the total completion time and total tardiness. In addition, neural-network and fuzzy logic approaches have been applied to the HFS problem, but not very often. A few examples can be found in Gupta et al. [15], Wang et al. [44], Tang et al. [49], and Hong and Wang [16].

Migrating birds optimisation (MBO) is a new metaheuristic that was presented by Duman et al. [10] for solving quadratic assignment problems. MBO is inspired from the V flight formation of migrating birds, which is a very effective formation in terms of energy minimisation. The authors showed that MBO could be an important player in a metaheuristic-based optimisation. Following its successful applications, this paper presents an improved MBO for the HFS problem with a total flowtime criterion. We introduce some advanced and effective technologies, including a diversified initialisation approach, a mixed neighbourhood structure, and a leaping mechanism. We demonstrate the effectiveness of the proposed MBO with extensive comparisons to several high-performing algorithms in the literature.

The remainder of this paper is organised as follows. In Section 2, the HFS problem is formulated. In Section 3, the basic MBO is introduced. Sections 4 and 5 propose an MBO and an improved MBO for the HFS with a total flowtime criterion, respectively. The computational results and comparisons are reported in Section 6. Finally, Section 7 provides concluding remarks and a number of future directions.

2. Hybrid flowshop scheduling problem

The hybrid flowshop is composed of a series of m production stages. Each stage k has τ_k identical parallel machines, and $\tau_k \geqslant 2$ for at least one stage. A set of jobs are required to be sequentially processed in the same production order, i.e., first on stage 1, then on stage 2, ..., and finally on stage m. At each stage k, job j can be processed on any machine $i \in \tau_k$. At any time, no job can be processed on more than one machine, and no machine can process more than one job simultaneously. All of the jobs are independent and available for processing at time 0. Job setup times and travel times between consecutive stages are included in the job processing times or can be negligible. The objective is then to find a schedule in which the total flowtime is minimised. A mathematical model for the HFS problem with a total flowtime criterion is given as follows.

2.1. Indices and parameters

- j, j': Job index; J: Set of all jobs; n: Number of jobs, $n = |J|$.
- k: Stage index; M: Set of all stages; m: Number of stages, $m = |M|$.
- i: Machine index.
- τ_k: Number of identical parallel machines at stage k.
- $p_{k,j}$: Processing time of job j at stage k.
- U: A very large positive number.

2.2. Decision variables

- $s_{k,j}$: Starting time of job j at stage k.
- $z_{k,j,i}$: If job j is assigned to machine i at stage k, then $z_{k,j,i} = 1$; otherwise, $z_{k,j,i} = 0$.
- $y_{k,j,j'}$: If job j is preceding job j' to be processed at stage k, then $y_{k,j,j'} = 1$; otherwise, $y_{k,j,j'} = 0$.

With the above symbol definitions, the HFS problem is formulated as follows:

$$\text{Minimise} \sum_{j=1}^{n} C_j = \sum_{j=1}^{n} (s_{m,j} + p_{m,j}) \tag{1}$$

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