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A hybrid discrete firefly algorithm for multi-objective flexible job shop scheduling problems with maintenance activity

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Abstract. This paper presents a novel hybrid discrete firefly algorithm (HDFA) for solving the multi-objective flexible job shop scheduling problem with non fixed availability constraints (FJSP - nfa) due to maintenance activity. Three minimization objectives-the maximum completion time, the workload of the critical machine and the total workload of all machines are considered simultaneously. In this study, the discrete firefly algorithm is adopted to solve the problem, in which the machine assignment and operation sequence are processed by constructing a suitable conversion of the continuous functions as attractiveness, distance and movement, into new discrete functions. In addition the decoding mechanism considering the maintenance activity is presented. A neighbourhood based local search is hybridized to enhance the exploitation capability. Representative benchmark problems are solved in order to evaluate and study the performance of the proposed algorithm.

Introduction

The flexible job shop scheduling problem (FJSP) is an extension of the classical job shop problem, which allows one operation to be processed on one machine from a set of alternative machines. Most existing literature considers the fixed machine availability constraint, that is, the starting time and the end time of maintenance activities are pre-determined in maintenance planning. However, in practice, preventive maintenance tasks would impose non-fixed availability constraints on the machine in that the starting time of these maintenance tasks is generally flexible [1]. This means that the starting time of the unavailable periods is not known in advance and has to be determined within the given time window during the scheduling process. Gao et al. [1] proposed a hybridization of GA and local search method for solving the multi-objective FJSPs with preventive maintenance (PM) tasks. Wang and Yu [2] investigated a filtered beam search (FBS) based algorithm for FJSPs with PM tasks. Rajkumar et al [3] proposed a GRASP algorithm for solving the multi-objective FJSP with non-fixed availability constraints. Li & Pan [4] proposed an effective discrete chemical-reaction optimization (DCRO) algorithm for solving the flexible job shop scheduling problem with maintenance activity.

Firefly algorithm (FA) is one of the nature-inspired metaheuristic algorithms developed by X.S.Yang [5], for solving continuous optimization problems [6]. However, FA can be discretized to solve a permutation problem, such as flow shop scheduling problems [7]. In this study, a hybrid discrete firefly algorithm is adopted to solve the multi-objective flexible job shop scheduling problem with non-fixed availability constraints.

Problem formulation

The flexible job-shop scheduling problem with non-fixed availability constraints that we addressed here belongs to the broad field of the deterministic scheduling with machine availability constraints, and it can be normally described as follows. There are m machines and n jobs. Each job J_i ($1 \leq i \leq n$

) consists of a sequence of n_i operations. Each operation O_{ij} (i = 1,2,...,n; j = 1,2,...,n_i) of job (J_i) can be processed by one machine m_{ij} in the set of eligible machines M_{ij}. The processing time of an operation O_{ij} on the machine M_k is p_{ijk} ($M_k \in M_{ij} \subseteq M$). PM_{kl} represent the lth preventive maintenance tasks on machine k (k =1, 2,..., m ,l =1,2,...,L_k). L_k is the total number of preventive maintenance tasks on machine k. Duration of the maintenance task PM_{kl} is d_{kl}. c_{ij} is the completion time of the operation O_{ij}. $[t_{kl}^E, t_{kl}^L]$ is the time window associated with PM_{kl} where t_{kl}^E is the early starting time and t_{kl}^L is the late completion time.

The mathematical model for the problem is defined as follows.

$$min f_1 = \max_{1\le i\le n}\left(c_{in_i}\right) \quad (1)$$

$$min f_2 = \max_{1\le k\le m}\left\{\sum_{i=1}^{n}\sum_{j=1}^{n_i} x_{ijk}\cdot p_{ijk} + \sum_{l=1}^{L_k} d_{kl}\right\} \quad (2)$$

$$min f_3 = \sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{n_i} x_{ijk}\cdot p_{ijk} + \sum_{k=1}^{m}\sum_{l=1}^{L_k} d_{kl} \quad (3)$$

The weighted sum of the above three objective values are taken as the combined objective function:

$$\text{Minimise } F(c) = W_1 \times f_1 + W_2 \times f_2 + W_3 \times f_3 \quad (4)$$

$$\text{Subject to: } W_1 + W_2 + W_3 = 1, \qquad 0 \le W_1, W_2, W_3 \le 1 \quad (5)$$

Where $F(c)$ denotes the combined objective function value of a schedule, f_1,f_2, and f_3 which denotes the makespan (C_m), maximal machine workload (W_{max}) and total workload of machines (W_t) respectively. W_1, W_2 and W_3 represent the weight coefficient for the three objective values, which could be set for different values depending upon the requirement.

Hybrid discrete firefly Algorithm

The firefly algorithm has been originally developed for solving continuous optimization problems. The firefly algorithm cannot be applied directly to solve the discrete optimization problems. In this study, we propose a possible way that can be modified to solve the class of discrete problems, where the solutions are based on discrete job permutations.

Solution Representation. In the proposed algorithm, each solution contains two components, i.e., the machine assignment component and the operation scheduling component. Each element in the machine assignment component gives the selected machine for corresponding operation, while each element in the scheduling component denotes the job number being operated. One example solution is {1,2,2,1,1,2,1,1| 1,1,2,2,1,2,3,3}. The first part is the machine assignment component while the second part is the scheduling component. In this study, the maintenance tasks are scheduled using the heuristic presented by Li & Pan [4]. The decoding of the machine assignment, operation scheduling and maintenance tasks for the example solution can be represented as a following schedule, with starting and completion time of each operation on its assigned machine. S_1 = {(O_{11}, M_1: 0-2), (O_{12}, M_2: 2-5), (O_{21}, M_1: 5-7), (O_{22}, M_1: 7-9), (O_{13}, M_2: 8-9), (O_{23}, M_2: 9-11), (O_{31}, M_1: 9-14), (O_{32}, M_1: 14-15), (PM_{11}: 2-5), (PM_{21}: 5-8)}. Fig. 1 gives the Gantt chart of the above mentioned schedule.

Population Initialization. To consider both the problem features and solution quality, in the first part of the population, machine assignment components and scheduling components are generated according to percentage of population size given for machine assignment component rules (R_{ma1}-minimum processing time rule [8], R_{ma2}-global workload balance rule [9]) and scheduling component rules (R_{sc1}-most work remaining rule [10], R_{sc2}-most number of operations remaining rule [8]) respectively. All other solutions in the initial population are generated randomly to enhance the diversity of the population.

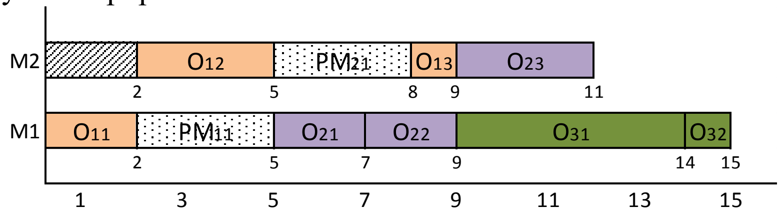

Fig.1. Gantt chart (C_m =15, W_{max} = 15, W_t = 24)

Firefly Evaluation The objective function value of each firefly is associated with the light intensity of the corresponding firefly. In this work, the evaluation of the goodness of schedule is measured by the combined objective function which can be calculated using equation (4). For example the combined objective function value for the schedule mentioned from the example problem is $F(c) = 15\times0.5 + 15\times0.3 + 24\times0.2 = 16.8$.

Solution Updation In firefly algorithm, firefly movement is based on light intensity and comparing it between two fireflies. The attractiveness of a firefly is determined by its brightness which in turn is associated with the encoded objective function. Thus for any two fireflies, the less bright one will move towards the brighter one. If no one is brighter than a particular firefly, it will move randomly.

Table 1: Illustration of Firefly Solution Updation

Solution vector	Machine Assignment	Operation Scheduling
Current firefly position (*P*)	1 2 2 1 1 2 1 1	1 2 4 5 3 6 7 8
Combined objective function	*F(c)* = 16.8	
Best firefly position (P_{best})	1 2 1 1 1 2 2 1	17 4 2 5 6 3 8
Combined objective function	*F(c)* = 13.0	
Difference between the elements *(d)*	{(3,1), (7,2),}	{(2,7), (4,7), (5,7)}
Hamming distance *(r)*	2	3
Attractiveness β – step: $\beta(r)\,\frac{\beta_0}{(1+\gamma.r^2)}$	0.71	0.53
rand ( ) between (0,1)	{ 0.64, 0.66}	{ 0.3,0.92, 0.06 }
Movement β – step	(3,1), (7,2)	(2,7), (5,7)
Firefly position after β – step	1 2 1 1 1 2 2 1	1 7 4 5 2 6 3 8
Attractiveness α – step: $\alpha(rand_{int})$	1 2 1 1 1 2 2 1	4 1 7 5 2 6 3 8
Combined objective function	*F(c)* = 13.0	

Table 1 illustrates the solution updating between the two fireflies using the modified functions for distance, attraction and movement. In this example the combined objective function value improves from 16.8 to 13.0, which indicates the movement from current position to the best firefly position for which the combined objective function value is 13.0. The procedure is repeated until the termination criterion is satisfied. In this study, the termination criterion is the total number of generations.

Local Search In each generation of the discrete firefly algorithm, we improve the quality of the solution (firefly) using a local search mechanism. In this hybrid algorithm we used the neighbourhood structures for machine assignment and scheduling component as presented by C. Zhang et al. [11]

Results and Discussions

One representative instance with PM tasks (denoted by problem *n x m*-m) is taken from Rajkumar et al. [3] and the remaining three instances from Gao et al. [1]. Each instance sets one or two PM activities on each machine in the planning horizon. The non-fixed availability constraint is set as the same as in Gao et al. [1]. Table 1 shows the comparison of results on four FJSP instances with PM tasks with other four algorithms. It can be seen from Table 1 that the make span value of the small scale instance 4 × 5-m is better than the GRASP algorithm. Then for the 8 × 8-m instance and the

10 × 10-m instance, the HDFA algorithm can obtain all the two non-dominated solutions, while the other algorithms except DCRO obtain only one optimal solution, respectively. For 15 × 10-m instance the optimal solution obtained is the same as in hGA and DCRO algorithm with less number of generations.

Table 1: Comparison of results on FJSP instances with PM Tasks

Algorithm	4 × 5-m			8 × 8-m			10 × 10-m			15 × 10-m		
	C_m	W_{max}	W_t	C_m	W_{max}	W_t	C_m	W_{max}	W_t	C_m	W_{max}	W_t
hGA [1]	-	-	-	17	15	105	8	7	61	12	12	107
GRASP [3]	16	9	40	18	16	103	9	7	60	-	-	-
FBS [2]	-	-	-	18	16	103	9	8	60	-	-	-
DCRO [4]	-	-	-	17 18	15 16	105 103	8 9	7 8	61 60	12	12	107
HDFA (Proposed)	13	9	40	17 18	15 16	105 103	8 9	7 8	61 60	12	12	107

Conclusion

In this paper, an effective hybrid discrete firefly algorithm (HDFA) has been proposed to solve multi-objective flexible job shop scheduling problem with non-fixed availability constraints due to maintenance activities. Instead of applying the standard firefly algorithm, we proposed the discrete version of the continuous function such as distance, attractiveness and movement to update a firefly position. A decoding method is used to consider the maintenance activities. In addition, two neighbourhood structures in relation to machine assignment and operation sequence were used in the algorithm to direct the local search to the more promising search space. The performance of the proposed algorithm is validated by comparing the results available in the literature for four representative instances.

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