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Dual-Resource Constrained Flexible Job Shop Scheduling Problem with Weighted Superposition Attraction Algorithm

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Abstract – Flexible job shop scheduling problem (FJSSP) contains two sub-problems, that is, routing and scheduling. Each operation is assigned to a machine among a set of alternative machines in the routing sub-problem, whereas the assigned operations on all machines are sequenced in the scheduling sub-problem to construct a feasible schedule. The operations cannot be processed without a qualified worker, but the worker constraint is usually ignored in the literature. The FJSSP which also considers the worker resource constraints is called the dual resource constrained FJSSP. Dual resource constrained FJSSP deals with machine assignment, order sequencing and worker assignment all together. Weighted Superposition Attraction (WSA), a recent metaheuristic approach is based on two basic mechanisms, 'superposition' and 'attracted movement of agents' for solving complex optimization problems algorithm is proposed to solve the dual resource constrained FJSSP with makespan minimization. Computational experiments performed in order to test the performance of the proposed WSA algorithm. The result of the WSA algorithm is compared with the results of the dispatching rule based approaches and greedy randomized adaptive search algorithm. The obtained results show that the WSA based algorithm is able to provide good quality solutions in reasonable time limits.

Keywords – Combinatorial Optimization, Flexible Job Shop Scheduling, Resource Constraints, Weighted Superposition Attraction Algorithm

I. INTRODUCTION

The flexible job shop scheduling problem (FJSSP) is one of the most popular scheduling problem in the literature. The FJSSP is NP-hard [1]. In the FJSSP, one operation can be processed in more than one machine and this problem deals with the assignment of operations to one of the candidate machine and providing sequence for the operations on machines to fulfill the predefined objective(s).

Machine flexibility is considered in the FJSSP. Most of the scheduling problems in the literature ignore worker resources. Machine and worker constraints are potential capacity constraint in a typical shop floor. Just as the machine constraint affects the performance of the problem, so do worker. Each worker's performance is different. This affects the processing time of the operations. The efficiency of the worker and the effectiveness of worker/machine assignment affect the shop floor performance.

The Dual resource constrained flexible job shop scheduling problem (DRC-FJSSP) includes worker and machine constraints and consists of three sub-problems: assigning the operations of jobs to machines; assigning the operations to workers; sequencing the assigned operations on the assigned machines considering the worker constraint in order to optimize the predefined objective function. The DRC-FJSSP is formulated as a set of n independent jobs $J=\{J_1, J_2, \ldots, J_n\}$, a set of m machines $M=\{M_1, M_2, \ldots M_m\}$, and a set of l workers $W=\{W_1, W_2, \ldots, W_l\}$. A job J_i has a sequence of r operations $\{O_{i1}, O_{i2}, \ldots, O_{ir}\}$ to be processed one after another according to the precedence constraints. Each operation O_{ij}, namely, the jth operation of J_i, must be executed on a given machine which is chosen from the given machine set M. Each machine M_i must be operated by a given worker chosen from the given worker set W. The number of workers l is less than the number of machines m [2].

The DRC-FJSSP is common in real life, but it is rarely addressed in the literature. Hybrid genetic algorithm [3], hybrid discrete particle swarm algorithm ([4],[5]), simulated annealing and vibration damping optimization [6], knowledge-guided fruit fly optimisation algorithm [7] and variable neighbourhood search algorithm [8] are used to solve the DRC-FJSSP in the literature. In this paper, Weighted Superposition Attraction algorithm and greedy randomized adaptive search algorithm are proposed for solving the DRC-FJSSP under makespan minimization.

II. MATERIALS AND METHOD

Weighted Superpostion Attraction (WSA) is a swarm based metaheuristic algorithm which is recently proposed for solving continuous optimization problems by [9], [10]. Performance of WSA was extensively tested with many constrained and unconstrained optimization test problems. Due to its competitive performance on the continuous optimization problem, we motivated to apply it to present problem.

WSA is based on two principles 'superposition' and 'attraction movement of agents' that are noticeable in many

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natural systems. In WSA an agent, refer to a solution of the optimization problem. An agent can be delineated through its own position and quality of its current position, on the other hand, a solution of an optimization problem can be delineated through its location and fitness value . The main steps of the WSA algorithm is shown in Fig. 1 [12]. For details of WSA refer to [9,10,12].

```
1. Initialize the algorithm parameters, the best solution and the best
   fitness
2. Generate a pre-defined number of initial solutions
3. Evaluate fitness values of the initial solutions, and update the best
   solution and the best fitness
4. Iteration = 1
     while Iteration <= Maxiter
        • rank solutions according to their fitness values
        • assign a weight to each solution by considering their ranks
        • determine a target point (superposition) to move the solutions
          towards it
        • evaluate the fitness value of the target point
        • determine search directions for each solution by considering the
          target point and its fitness value
        • move each solution towards its determined direction
        • evaluate fitness values of each solution, and update the best
          solution and the best fitness
       Iteration = Iteration + 1
     end while
```

Fig. 1. Main steps of the WSA algorithm [9,12]

The present problem is an example of combinatorial optimization problem. Therefore, combinatorial version of WSA is utilized in this study, the details of combinatorial WSA is recently presented in [12]. Combinatorial WSA differs from the continuous version of WSA in some characteristics (superposition determination, movement of agents etc.), however, general flow of the algorithm is same.

Combinatorial WSA contains three different/modified mechanisms which are named as *'creation of agent swarm'*, '*determination of superposition(target)*' and '*determining agents next moves*'. Fig. 2 presents the procedure of combinatorial WSA [12].

```
Randolmy generate initial agent population
Sort the population according to fitness value
while iteration < maximum iteration
        Determine the superposition
        Calculate the superposition'fitness
        Maintain the best superposition
                for each agent in the population
                        if      agent fitness < superposition's fitness
                                Apply one of the neighborhood mechanisms
                        else
                                Crossover with superposition
                        end if
                end for
                Sort population according to fitness values
end while
return best_fitness
end Procedure
```

Fig. 2 Procedure of combinatorial WSA [12]

According to the characteristic of the dual-resource constrained job shop-scheduling model, we designed a three dimensional coding scheme (Fig. 3). A complete chromosome is consisted of three parts: process coding, machine coding and worker coding.

process coding	2	2	1	3	4	2	4	5	3	3	1	5	2	3	4	1	2	2
machine coding	7	6	7	4	1	4	7	5	2	2	2	8	5	6	4	4	4	8
worker coding	6	5	6	3	1	3	6	4	2	2	2	6	4	5	3	3	3	6

Fig. 3. Three-dimensional coding scheme

Corresponding to the sequence of process chromosome, machine chromosome and worker chromosome, the top three position corresponding to the process coding are decoded as follows: (O21, M7, W6),(O22, M6, W5).

The efficiency of the model and the algorithm is tested by an application to a mechanical processing workshop. This workshop plans to use 8 machines and 6 workers to process five kinds of jobs with multiple working procedures respectively. The assumptions of the problem are the following: One job can be processed only on one machine at a time. Processing times are considered as deterministic and Table 1 shows the detailed parameters of each job. The processing time includes setup time and transportation time. Preemption is not allowed. The performance of workers is not identical. Table 2 presents the worker set for each machine and the worker set for each machine.

Table 1. Detailed processing parameters of each job

Job no.	Operation	M1	M2	M3	M4	M5	M6
J1	O11	-	2	1	-	-	5
	O12	3	-	-	-	7	-
	O13	-	6	-	2	-	-
	O14	1	-	-	7	-	-
	O15	-	-	9	-	-	3
	O16	-	4	-	-	6	-
J2	O21	-	8	-	2	-	-
	O22	2	-	5	-	1	-
	O23	-	6	-	-	10	-
	O24	-	4	-	-	-	10
	O25	10	-	-	3	-	-
	O26	-	6	-	4	-	-
J3	O31	-	-	5	-	-	3
	O32	3	5	-	4	-	-
	O33	-	-	-	7	-	8
	O34	9	-	6	-	-	-
	O35	-	1	-	-	4	-
	O36	10	-	2	-	7	-
J4	O41	-	5	-	-	3	-
	O42	5	-	-	8	-	-
	O43	7	-	5	-	-	-
	O44	-	2	-	3	-	-
	O45	9	-	-	-	8	-
	O46	-	8	-	2	-	9
J5	O51	-	-	9	-	10	-
	O52	-	3	-	7	-	-
	O53	2	-	6	-	5	-
	O54	-	8	-	-	-	4
	O55	3	-	-	7	-	-
	O56	-	4	-	1	-	-
J6	O61	-	3	-	-	6	-
	O62	9	-	-	3	-	-
	O63	-	5	-	-	-	9
	O64	10	-	-	8	-	-
	O65	-	7	-	-	4	-
	O66	2	-	1	6	-	-

Table 2. Worker set corresponding to each machine

Worker/Machine	M1	M2	M3	M4	M5	M6
W1	√	√			√	√
W2	√	√	√	√		
W3		√	√	√		√
W4				√	√	√

III. RESULTS

Computational experiments is performed in order to test the performance of the proposed WSA algorithm. The result of the WSA algorithm is compared with the results of the shortest processing time, the longest processing time, Giffler and Thompson (G&T) algorithm with shortest processing time, G&T algorithm with longest processing time and greedy randomized adaptive search algorithm [11].

We use three indices ARPD, MRPD and SRPD to compare the performance difference among all algorithms. Each algorithm runs 20 times for the instance. MRPD, APRD and SRPD are the minimum value, average value and standard variance of 20 values.

Table 3. Results for workers with different operational efficiency

	MRPD	**APRD**	**SRPD**
SPT	91	121	240
LPT	96	121	247
GT_SPT	62	84	140
GT_LPT	52	59	69
GRASP	35	37	1,98
WSA	35	36	1,1

IV. DISCUSSION

Makespan is chosen as the performance measure. The machine and worker Gantt charts is shown in Fig. 3 and Fig. 4 respectively. In Fig. 3, X-axis demonstrates the processing time of operations and Y-axis demonstrates machine number. The three number present each operation in Fig. 3. These numbers are job number, operation number and worker number, respectively. For example, the first operation on machine 2 is ‘613’ and this means that the first operation of job 6 is processed on machine 2 by worker 3. In Fig. 4, X-axis represents the processing time of operations; Y-axis represents worker number. The first operation of worker 1 is ‘415’ and it means that the first operation of job 4 is done on machine 5 by worker 1. The optimal value of the make-span is 35. The result is in according with the optimal value.

V. CONCLUSIONS

The combinatorial WSA algorithm is used to solve the Dual Resource Constrained Flexible Job Shop Scheduling Problem in this paper. The results of the numerical simulations depict that the proposed algorithm has competitive performance. Moreover, the results of the proposed algorithm is also compared with the results of the GRASP algorithm. The obtained results show that the WSA based algorithm is able to provide better quality solutions in reasonable time limits.

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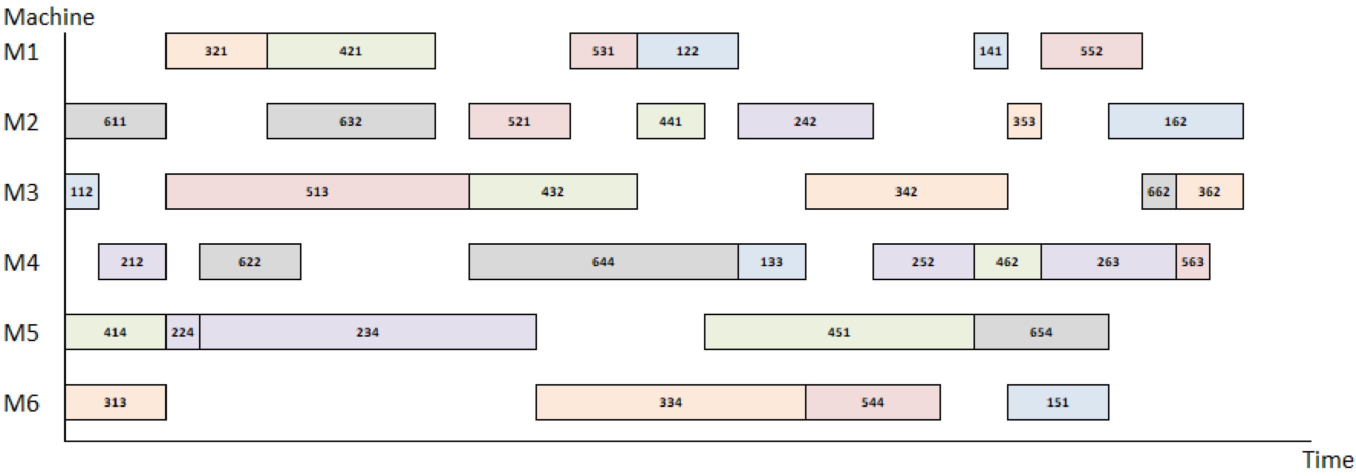

Fig. 3. Machine Gantt Chart of DRC-FJSSP

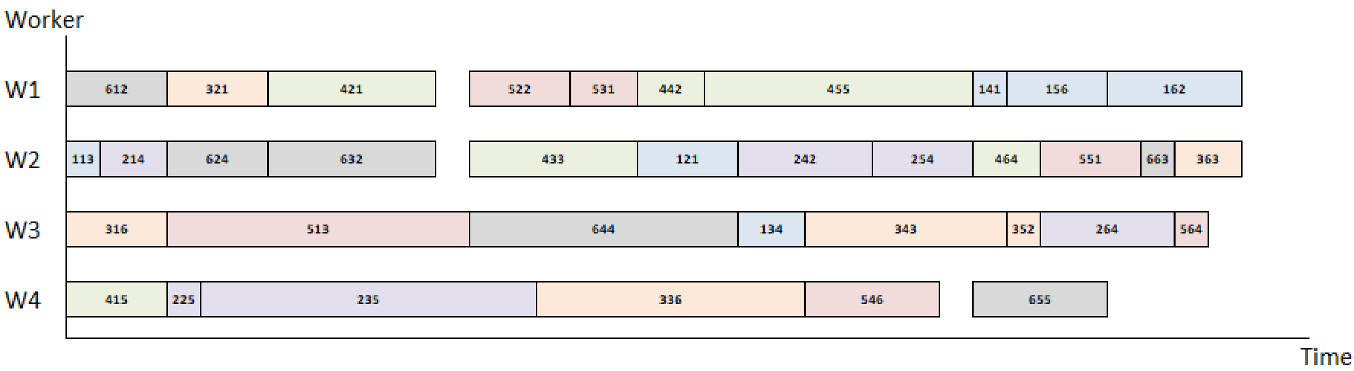

Fig. 4. Worker Gantt Chart of DRC-FJSSP