A Hybrid Algorithm for Multi Objective Flexible Job Shop Scheduling Problem

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Abstract

Flexible job shop scheduling problem (FJSP) is one of the most important issues in different areas of production management and manufacturing systems and currently many researchers in the field of optimization issues consider it.This study includes FJSP problem with three objective functions minimization for makespan, maximum workload and total workload of machines. In this study a hybrid metaheuristich algorithm based on tabu search, simulated annealing and genetic algorithms with suitable parameters for solving is presented, So that the targeted and effective combination of random solutions with the results from SA, TS and TSA algorithms are considered to initial population for genetic algorithm. Also in genetic algorithm, a multivariate equation with minimum square error by using regression equations in SPSS software is introduced, which obtains effective numbers of each mutation, crossover, reproduction(Elite-oriented algorithm) operators to produce new generation. In order to evaluate the effectiveness and efficiency of proposed algorithm, obtained results are compared with optimal solutions obtained through solving mathematic model and KACO, PSO, SA, GA and local approach methods. Results of experiments and computational analysis show that the proposed algorithm in this study has ability to achieve close to optimal points at suitable time for different issues in different sizes.

Key Words
Flexible jobshop scheduling problem, Multi objective function, HGA, Regression equation.

1.Introduction

FJSP is an extension of classic jobshop systems problem. it has more usage than jobshop systems problem and through that we can use for increasing production, solving bottleneck problem, or use as a competitive issue in economic environment. In recent years many Meta heuristic algorithms has been used in jobshop scheduling. Bruker and Schile[9] in 1990, were the first people that discussed about this problem. They provided a multifaceted algorithm with two works for solving jobshop scheduling problem. In 1993, Brandimarte[2] was the first man who used hierarchical approach about FJSP. In 1999 Bayiz and sabuncouglu[6] have used branch search algorithm in two modes of mean time to delay and end time for all works objective function.

Choi and choi[11] in 2002 presented a local search algorithm for job shop scheduling problem. In 2004 Boryczka[7] used ant colony algorithm in orders to solve job shop scheduling problem.Weiijun[5] in 2005 concentrated on flexibility of job shop scheduling problem. After that Fattahi and et al.[10] searched integrated and hierarchical theories about jobshop shechuling problem. They presented and compared six combinative algorithms based on these theories, TS and SA Meta heuristic algorithms.

O'Leary and Vokurka[1] in 2000 developed flexible manufacturing and production systems to fifteen type. In 2002 Kacem and et al.[4] presented a Pareto optimization approach for multi objective functions. They presented a local approach for solving multi objective optimization problem based on combination of fuzzy logic (FL) and evolutionary algorithm (EAS). In 2005, Xia and Wu[5] presented an optimization and hybrid approach for flexible multi objective FJSP problem. They combined Particle Swarm Optimization and SA algorithm for optimization in FJSP problem. In 2007, Chen and et al.[18] developed a scheduling algorithm for the job shop scheduling problem with parallel machines and reentrant process. Xing and et al in 2008-9[15] solved FJSP issue using ant colony algorithms and hierarchical attitudes. In 2009 Ozguven and et al.[3] solved flexible jobshop scheduling problem through optimization of NP-hard problems separately. Xing and et al.[14] in 2009-2010 applied ant colony algorithm and effective articles related to FJSP using multi objective functions. In 2010, Moslehi and et al[21] presented a new approach based on a hybridization of the particle swarm and local search algorithm to solve the multi-objective flexible job-shop scheduling problem. Yazdani and et al.[22] in 2010 proposed a parallel variable neighborhood search (PVNS) algorithm that solves the FJSP to minimize makespan time.

In recent years also due to be efficient genetic algorithm in solving FJSP, many researchers have been used this algorithm and been presented more optimal solutions that Davis[8] in 1985 was the first one who used genetic algorithm for solving job shop scheduling problem. Petrovic and et.al.[23] in 2007 presented a new tool for multi-objective job shop scheduling problems. The tool encompasses an interactive fuzzy multi-objective genetic algorithm (GA) which considers aspiration levels set by the decision maker (DM) for all the objectives. In 2007 and 2008 Jie Gao and et al.[13] modeled for combinative algorithms FJSP problems and they used Genetic and TS algorithms as combinative, for providing better solutions. They also utilized variable neighboring and obstacles transmission for presentating solutions through two separate articles including three objective function. In 2008, Pezzella and et al.[16] presented a genetic algorithm for the Flexible Job-shop Scheduling Problem (FJSP). The algorithm integrates different strategies for generating the initial population, selecting the individuals for reproduction and reproducing new individuals. Giovanni and et al[17] in 2010 presented an improved genetic algorithm to solve jobshop scheduling problem and data distribution.

Reviewing of literatures and records of previous similar researches has approved valuable topics and potential problems in this field, as in most researches ,because of complexity of jobshop scheduling problem ,we don't observe any development in this field. So, researcher has tired to define jobshop scheduling problem by considering flexibility of operations and multi objective function along with applied limitations, and used Hybrid genetic algorithm. For Genetic algorithm initial population, purposive combination of metaheuristich algorithm outputs of SA,TA and hybride TSA are used .This research is a form of hierarchical model of genetic algorithms and this algorithm is accepted in other problems because of its success.

In section 2, we will describe mathematical model .Then in section 3, we will present proposed algorithms and in section 4 we will introduce regression equation and in section 5 we present results from proposed algorithm in which programmed software is shown. Finally in chapter 6, we will discuss about conclusion and suggestions for future research.

2. Problem definition and mathematical modeling

This problem is a FJSP problem with multi objective function that includes the following objectives:

Min $C_{\max}$ (C_m), Min total workload (Wt), Min Maximal workload (Wm).

The assumptions considered for this problem includes following cases:

- Each similar operation can be performed on each machine from a set of predefined machines.
- Each machine can do up to one work at any time.
- setup time is independent of the sequence and in processing time is considered.
- Processing times, are Known, fixed and definite.
- Production machinery are always available and there is no failure and there is no operation cutoff.

Mathematical model of this problem is as combination of integer and liner programming. This problem includes n works and m machines. Each work includes a sequence of operations $O_{j,h}$. In the set, machine M is as M = (M_1, M_2, ... M_1) that $M_{j,h}$ are a subset of M that ability to performing operation h belonging to j on the subset is possible and the subset can be assigned to $O_{j,h}$ .The Set of $O_{j,h}$ is defined by using binary variable $a_{i,j,h}$. If the value is one, this means that machine i has ability to perform operation $O_{j,h}$. Each of the assignable machines for performing operation $O_{j,h}$ will be including the specific processing time that will be displayed as $p_{i,j,h}$. After assignment machines to operation the time is shown by $Pt_{j,h}$.

To assign, the binary variable $y_{i,j,h}$ is used that the value of that is obtained through solving the model. In fact it shows that which machine do each operations. $X_{i,j,h,k}$ is a binary variable for showing the solution of sequence problem that the value of that is obtained through solving the model. It shows priorities in each operation by desired machine. If the value of this variable is one, it means that operation $O_{j,h}$ have done on machine i, in turn k. Also for sequence problem we have considered two variable $Tm_{i,k}$, $t_{j,h}$ that their value are gained through solving the model that respectively, indicate start processing time operation $O_{j,h}$ and start working time for machine i in sequence k. They respectively, indicate the first and the second sequence and sequence scheduling.

3. The proposed algorithm

In this study a combination of tabu search algorithm, simulated annealing algorithm, TSA algorithm and genetic algorithm have been used for obtaining acceptable solutions. Therefore, in this study a hierarchical genetic algorithm with combination of sequence of operations problem and assignment machinery is used that the volume of calculations required is very less and it has a high speed in calculations. Although we may not get the optimum answer necessarily, but they reach an acceptable approximation, is considered the optimum, but their solution with acceptable approximation, is considered optimal.
It is necessary to explain that obtained solutions through solving SA, TS, TSA algorithms and random method are intervals of primary populations for genetic algorithm, and obtained solutions of them have special properties and they have important rule to convergency of genetic algorithm into suitable solutions at reasonable time.
Other important parameters for proposed algorithm, that it is important to reach quality solutions, is optimal and suitable combination of obtained solutions through solving per algorithm.
It is an important agent for helping to achieve optimal solutions at suitable times by genetic algorithm. Since the elitist property are used through solving genetic algorithm, So it remains better solutions of other algorithms.
In this model that has been formulated based on the genetic algorithm, a multiple regression equation based on the solutions close to the optimum solution is obtained that it is function of number of population in per generation toward percent of optimum combination of the gained solutions from 3 operator (fusion, cross over, mutation). The equation specifies desired and optimum percent to produce the next generation.

3.1 Fusion

Fusion operator in this section is the same way with increased colony that in fact certain percentage of last population move to the next generation. In order to enhance the quality of solutions, this percent is chosen from between the best solutions that in fact it is what we call the elite-oriented algorithm.

3.2 Cross over

Transplant operation between two chromosomes and the reproductive of next generation occurs by the intersection operator or the transplantation. Considered intersection for this study is obtained from OPX[1] method that it is a good cross over. This method has a method of healing in the form of lies and in fact, it does the repair operation during the cross over very well. Method related to this intersection is that after selecting two parent chromosomes, we select two points during the string randomly. Then we insert the numbers under the string between two points created from the first parent, in primary son situations from left to right in according to numerical values of the second parent, respectively. Then we delete the numbers from first parent and put the rest of the remaining numbers from left to right in the empty blank of primary son respectively. We do this method for creating the second son according to the above method.

3.3 Mutation

In nature mutations is a process that in which a part of a gene is randomly changed. This operator also ensures that regardless of the initial population distribution, probability of search at each point of the problem space would be never zero. This paper is based on permutation coding and mutation give new values to variables in their allowed limit, so that it replaces place of two random points obtained in a chromosome.

Steps of the proposed algorithm is given in the form of a schematic below:

1.Combined order and position-based crossover

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Create the  obtained solution  from SA algorithm
Create the obtained solution  from TS algorithm
Create the obtained solution  from TSA algorithm
Create the obtained solution  randomly
Make the primary population from above steps
For nas=1:NASL
Put F% of the best previous population chromosomes in the new population.
  Select two parent chromosomes.
     If  Pc<=CR
Do the cross over process.
                Calculate obtained solutions from cross over (OP3, OP4)
If (OP3>OP1) or (OP3>OP2) or (OP4>OP1) or (OP4>OP2)
     Insert OP3 or OP4 in new populations
                                   else
        Repeat the previous step.
                                   end
           Select a chromosome
                                    if Pm<MU
              Do the process of mutation
                                    else
                    Repeat the previous step.
                     end
end
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3.4 Command for the end of algorithm

Since the genetic algorithm is a random search method, presenting a special formula for the end of that is difficult. A common way for ending the algorithm, is stopping the algorithm, after production certain numbers of generations. Since in this proposed combination algorithm we need to know total number of generations as some other algorithms, therefore, this approach seems suitable.

4. Extract the linear regression equation for the optimum combination of the three above-mentioned operator

In order to extract the appropriate combination of the three reproduction operator, (Elite-oriented algorithm), cross over and mutation, the proposed algorithm is encoded in Matlab programming 7.4.0 software. Different combinations of operators on FJSP problems with objective function minimization for makespan and with different dimensions has been tested. Then the most suitable numeric combinations of operators that the most optimal solutions were obtained by them, has been entered in SPSS software. Finally a linear regression equation with the minimum square error is obtained. The details of the results is given in equation (1). We know that:
Cr = Cross over operator number
mu = Mutation operator number
el = Elite-oriented reproduction operator number
po = Population number of each generation
F = Certain percentage of the previous generation
So:

$$Cr + 1.585mu - 2.835el = 3.55 \qquad \text{equation (1)}$$

On the other hand we know that total number of three mentioned operator is equal with population of each generation. Because in the proposed algorithm number of population in different generations is constant. we will:

$$Cr + mu = po - el \qquad \text{equation (2)}$$

Also, as we said in the previous chapter, reproductive function, includes the certain percentage of the previous population. Therefore, we will:

$$el = po \times F$$

As a result of combination of above equations, we will have:

$$cr + 1.585mu - 2.835po \times F - 3.551 = 0 \qquad \text{equation (3)}$$

$$cr + mu - po\,(1-F) = 0$$

Therefore in equation (3) by considering certain percentage of the population of the previous generation to produce the next generations and inserting them in equation (3), We can determine suitable combination of operators and insert in the proposed algorithm to achieve the high quality solutions in appropriate times.

$$po\,(4.835 \times F - 1.585) + 3.551 < 0 \qquad \text{equation (4)}$$

5. Numerical calculations and experiments

To evaluate the performance of proposed algorithm, obtained result from proposed algorithm is tested on a number of problems with different dimensions, after the programming on lingo11.0 software in table (1). Then they are compared with other similar research results that results are shown in tables (2), (3) ,(4)and (5).

Table (1)

Dimension of problem	Number of jobs	Number of machines	Total number of operations	Cmax		Wt		Wm		CPU time of lingo software (sec)	CPU time of our algorithm (sec)
				Lingo	our algorithm	Lingo	our algorithm	Lingo	our algorithm		
2*2	2	2	4	25	25	36	36	25	25	3	8
2*3	2	3	4	8	8	9	9	4	4	2	11
3*2	3	2	5	31	31	61	61	31	31	11	12
2*4	2	4	5	8	8	11	11	5	5	13	10
3*3	3	3	7	14	14	21	21	9	9	285	68
4*2	4	2	8	18	18	30	30	16	16	457	98
4*3	4	3	9	21	21	32	32	14	14	1324	120
4*4	4	4	10	10	10	18	10	6	6	3011	389
5*3	5	3	11	N/A	9	N/A	20	N/A	8	-	371
4*4	4	4	13	N/A	14	N/A	38	N/A	14	-	450
5*4	5	4	17	N/A	12	N/A	36	N/A	10	-	574
5*4	5	4	19	N/A	31	N/A	78	N/A	22	-	789

By considering the Table (1) we see that the proposed algorithm has the needed efficiency for solving the considered problem. It is observed that the solution time for problem increases increasingly with small variations in the size of the problem by lingo software that these times in solving scheduling problems are important and they confirm the efficiency of our algorithm. $C_{\max}$, W_t and W_m coefficients have been considered 0.5, 0.2 and 0.3 respectively.

Table (2)The obtained results for Problem 8 × 8 with 27 operations

	Temporal Decomposition	classical GA	Approach by Localization	AL+CGA		PSO+SA		KACO	Our algorithm
Cmax	19	16	16	15	16	15	16	14	14
Wt	91	77	75	79	75	75	73	77	77
Wm	19	11	13	---	---	12	13	12	12
OBJ	33.4	26.7	26.9	---	---	26.1	26.5	26	26

Table(2),(3) show our algorithm's effectiveness by comparison with other algorithms. The column labeled 'Temporal Decomposition' refers to F. Chetouane's method (Kacem et al, 2002a) [20] and the next column labeled 'classical GA' refers to classical genetic algorithm. 'Approach by Localization' and 'AL+CGA' are two algorithms by Kacem et al. (2002a,2002b) [4,20]. 'PSO+SA' is proposed by Xia and Wu (2005) [5].KACO is proposed by Xing et al. (2008) [24]. From Table (2), we know the new our algorithm and KACO method make us reduce the objective (26.5 instead of 26) and get the decline in terms of objective function value. It is necessary to explain that with proposed algorithm number 26 is obtained that it is the absolute optimum solution of problem.
From Table (3), we know the new our algorithm make us reduce the objective (13.9 instead of 13.7) and get the decline in terms of objective function value.

Table (3)The obtained results for Problem 10 × 10 with 30 operations

	Temporal Decomposition	classical GA	Approach by Localization	AL+CGA	PSO+SA	KACO	Our algorithm
Cmax	16	7	8	7	7	7	7
Wt	59	53	46	45	44	43	42
Wm	16	7	6	5	6	6	6
OBJ	24.6	16.2	15	14	14.1	13.9	13.7

$C_{\max}$, W_t and W_m coefficients have been considered 0.5, 0.2 and 0.3 respectively.
To evaluate the effectiveness of our algorithm, we have applied it to the instance in Table (4).We present the comparison with the algorithms of Kacem et al. (2002b) [4] and Xia and Wu (2005) [5] and Xing et al.(2008) [24] in Table(4). From Table (4), we know the new our algorithm make us reduce the objective (27.4 instead of 27.2) and get the decline in terms of objective function value.

Table (4) the obtained results for Problem 15 × 10 with 56 operations

	AL+CGA	PSO+SA	KACO	Our algorithm
Cmax	24	12	11	11
Wt	95 91	91	93	92
Wm	11 11	11	11	11
OBJ	33.8 33.5	27.5	27.4	27.2

$C_{\max}$, W_t and W_m coefficients have been considered 0.5, 0.2 and 0.3 respectively.

Table(5) Experimental results of the DLACO for solving 2 instances

FJSP Instance	Objective (DLACO)			Objective (Our algorithm)		
	Cmax	Wt	Wm	Cmax	Wt	Wm
Case 1	12	32	8	11	31	7
Case 2 Case 2	11 11	61 62	11 10	11	60	10

In Table(5) we compare results of our algorithm with algorithm of Xing et al.(DLACO) [15]. In DLACO method more than one optimization result islisted. However; our algorithm obtained better result than all of them.

Table (6) compares our algorithm with the algorithms proposed by Chen et al[25]; Ho, Tay, Jia et al[19]; and Pezzella et al.[16] on 10 FJSP problem instances from Brandimarte. The first column reports the instance name; the second columns report the number of jobs and the number of machines for each instance, respectively. The third column reports Pezzella[16] best makespan over five runs of GA. The fourth column reports the best results of Chen algorithm[25]. The fifth column reports the best results of Ho and Tay algorithm[19]. The sixth column reports the best results of Jia algorithm[26]. The seventh column reports the best results of Pezzella[16] algorithm and eighth column reports the best results of our algorithm. Result shows that the quality of solutions is comparable.

Table(6)

Name	Dimension of problem	GA	Chen	GENACE	Jia	M.G	Our proposed algorithm
MK01	10*6	40	40	41	40	40	39
MK02	10*6	26	29	29	28	26	26
MK03	15*8	204	204	204	204	204	204
MK04	15*8	60	63	67	61	60	54
MK05	15*4	173	181	176	176	173	171
MK06	10*15	63	60	68	62	58	52
MK07	20*5	139	148	148	145	144	138
MK08	20*10	523	523	523	523	523	523
MK09	20*10	311	308	328	310	307	305
MK10	20*15	212	212	231	216	198	178

6- Conclusion

This study includes the flexible jobshop scheduling problem (FJSP) with multi objective function minimization for makespan, total work load and maximal workload of machines. For solving NP- HARD problem, presenting capable algorithm based on hybrid genetic with obtained initial population from random solutions, SA, TS and TSA algorithms with obtained suitable parameters is considered. So that it can produce high-quality solutions in the fastest possible time, leaded us to define the optimum numbers of different genetic algorithm operators for FJSP problems. Therefore, in this study, a multiple regression equation with minimum square error according to three operator reproduction (Elite-oriented), cross over and mutation in SPSS software is main contribution of paper ($cr + 1.585mu - 2.835po \times F - 3.551 = 0$, $cr + mu - po(1-F) = 0$, $po(4.835 \times F - 1.585) + 3.551 < 0$) and researcher by using this equation can achieve the most optimal combination of operators with determining the desired population size and desired percentage from the optimal solutions of previous generation. Accordingly, we tested our proposed algorithm for different problems that obtained result in order to review of effectiveness and efficiency of the proposed algorithm, were compared with optimal solutions obtained through the Lingo Software and the results of other similar researches. KACO algorithm is one of the best algorithms that obtains good solution for FJSP that with our algorithm number 26,13.7 and 27.2 is obtained that they get the decline in terms of objective function value and time. Results of experiments and computational analysis show that the proposed algorithm in this study has ability to achieve close to optimal points at suitable time for different issues in different sizes.

In this paper coefficients is assumed fix and it will be usufull sensitive analysis to obtain solutions for different decision makers. Effort to obtain nonlinear, exponential, logarithmic regression relations and other relations between the operators of genetic algorithm or purposive combination of SA, TS, TSA, random solution and other effective metaheuristich algoritms for making initial population that it can compare their efficiency with relation obtained in this research, can be one of the future suggestions for this study. Also, Using Fuzzy logic to obtain fuzzy regression equations and comparing possible results can be analyzed.

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