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Full Length Research Paper

Scheduling in flexible job-shop manufacturing system by improved tabu search

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In modern manufacturing and production systems, flexibility has increased as a response mechanism toward changes. In such systems, a piece may have several flexible process programs. In this study, scheduling problem in flexible job-shop manufacturing production systems is studied with minimization objective function of make span (C_{max}) "and" average time in completion of pieces ($\bar{C}$) that is consistent with, just in time philosophy and management objectives of supply chain. Concerning problem being NP-hard, heuristic method is proposed to solve it based on tabu search algorithm which is compared with a hierarchical method. Performance criteria for comparison are "response quality" and "calculation time" in which results of numerical test approve the priority of tabu search algorithm in comparison to hierarchical method.

Key words: Flexibility, job-shop, sequencing, scheduling, tabu search, meta-heuristics.

INTRODUCTION

Principally, scheduling is resource allocation activity to tasks during the time. Range of scheduling theory does not limit to productive systems but it includes issues as transportation scheduling, human resources and project scheduling. The present study is limited to manufacturing production systems. In productive systems, machines and equipments have the role of resources and needed operations have the role of duties to manufacture any piece or order. The study defines general scheduling problem as; n is work (piece) and m is the present machine. Performance of each work requires a private operation set. Work processing of j_i by m_j machine is called o_{ij} operation. Processing duration of o_{ij} operation is definitep_{ij}. The movement order of each work, among different machines, is called "flow pattern" and "structure route". This route can be equal or different for various works. Each work has entrance time (r_i) and delivery time (d_i). Scheduling program is a program in which sequence of performing work operations on machines is determined during time. Feasible or acceptable program is a program in which technological limitations are considered and operations do not have temporal interference. In solving scheduling problem, the objective is to find a feasible timing program which optimizes one or several performances (McCarthy and Liu, 1993).

LITERATURE REVIEW

Hierarchical approach is used by Brandimarte to solve flexible job shop scheduling problem. In this approach, problem is partitioned in two sub-problems of routing and scheduling. Initially, routing sub-problem is solved by goal of machine allocation to each operation. Consequently, flexible job shop problem turns into classic job-shop timing program (JS), then it solves scheduling sub-problem. He proposes a tabu search algorithm to solve scheduling sub-problem. The hierarchical approach is designed in two versions. In the first version, there is a unilateral information process between routing and scheduling sub-problems, that is, from routing to scheduling. Firstly, a primary route is produced, using a proper preference rule. Then, result of job-shop problem is solved by tabu search algorithm. In the second version, information process is bilateral. In this state, terminating TS algorithm, the gained results from scheduling sub-problem effect on new route selection in routing sub-problem and new route is produced based on scheduling

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results. He solves flexible job shop problem via C_{max} criterion by each version. Numerical test results approve the priority of bilateral approach toward unilateral approach from answer quality viewpoint. (Brandimarte, 1993)

Chamber and Barnes (1996) solved flexible job shop using tabu search algorithm. The principal difference of their proposed tabu search algorithm with Brandimarte (1993) is in the strategy of adjacent production. In this method, adjacent changes are exerted on scheduling and routing problems concurrently. In each tabu search iteration, two kinds of motion are considered for adjacent production: Replacement of operation pair located in outset and terminal of a block in critical route and allocation of operation located on critical route to a feasible situation in another machine. In design stage of test problems, they turn three measure of job-shop present problem to flexible job shop via 6 kinds of various strategy in order to repeat machines which have highest processing time of operation or there on highest number of critical operation on them. In accordance with acquired results, flexibility of manufacture route toward job-shop state improves standard classic C_{max} between 0/32% up to 6/48%. (Chamber and Barnes, 1996).Chambers and Barnes (1998) suggests another tabu search algorithm for C_{max} minimization in flexible job shop problems. The main difference of this algorithm with algorithm of Chambers and Barnes (1996) is in the status of determining tabu list length. In new algorithm, there is dynamic tabu list length in order to exit from local optima and/or prevent from iteration of answers. It alters based on a definite strategy (Chamber and Barnes, 1998).

PROBLEM DESCRIPTION

Manufacturing and production is composed of receiving some distinct orders which should be produced in a multi-project area. Order of each product reaches to assembly unit with definite delivery deadline on behalf of customer. Assembly in each order requires manufacture of a set of pieces which is ordered to manufacture unit. Manufacture of each part needs specific operations. There are definite prerequisite relations between operations of each piece which will be represented by a graph. Graph is prerequisite relations for each definite piece. A piece may have several sequences for various operations. One or some operations are available for implementing each operation. There is different and definite processing time length of each operation in machines' alternatives. Due to focus of the research on timing and programming of manufacture unit, the study therefore prevents entering in details of other part of chain. Supposing a definite time length for assembly process, it specifies a delivery deadline for each piece in manufacturing part by subtracting this time from final delivery deadline. The study can use outer resources to access timing objectives. It supposes that, outer resources are analyzed in charges and are chosen. If the study uses outer resources, cycle time will be added to processing time of operation. The goal is to represent an efficient model for timing in manufacture unit in order to fulfill technological limitations and resources and optimize problem objectives. In this model, it is required to decide about determination of operation sequence in each work, allocation of machine to each operation, timing and outer source-finding (Figure 1). In figure 1, the structure of Manufacturing and production supply chain in a flexible industrial process is described and in the manufacture department, each piece may have multiple operation sequence.

C_{max} minimization objective function results in increase of efficiency of machines impliedly; on the other hand efficiency of pharyngeal or near-pharyngeal equipments is related to type output system. Therefore, C_{max} decrease can result in increase of utility of resources, speed increase of manufacturing and production process and increase of output rate (Cochran, 2003).

MATHEMATICAL MODEL OF PROBLEM

The problem is modeled as integer programming of zero and one. The proposed model is based on model of Baker (1974). In Baker mode, we suppose that operation sequence of each piece is definite and unique. Therefore, there is no flexibility in operation sequence and process program. In existing program, each piece has multiple operation sequence and a set of machines with various processing times that are available for implementing each operation. In represented model of the article, the flexibility is entered using two types of decision variables of zero and one. One of them is related to determination of operation sequence and the other is related to allocation of machines to each operation. In the model, it is possible to use outer resources as well. We suppose that, a set of all possible sequences between operations of piece is determined in accordance with the graph of prerequisite relation and is a part of model inputs.

Model explanation

$$\text{[illegible]}_{\text{[illegible]}} = \text{[illegible]} \qquad (1)$$

$$\text{[illegible]}\bar{\text{[illegible]}} = \frac{1}{\text{[illegible]}}\sum_{\text{[illegible]}=1}^{\text{[illegible]}} \text{[illegible]} \qquad (2)$$

Subject to:

$$\text{[illegible]}^{(\text{[illegible]})}_{(\text{[illegible]}+1)\text{[illegible]}} - \text{[illegible]}^{(\text{[illegible]})}_{\text{[illegible]}} + \text{[illegible]}\Big(1 - \text{[illegible]}^{(\text{[illegible]})}_{(\text{[illegible]}+1)\text{[illegible]}}\,\text{[illegible]}^{(\text{[illegible]})}_{(\text{[illegible]}+1)\text{[illegible]}} \geq \text{[illegible]}^{(\text{[illegible]})}_{(\text{[illegible]}+1)\text{[illegible]}} + \text{[illegible]} + \text{[illegible]} \qquad (3)$$

$$\mathrm{Ft}^{(\text{[illegible]})}_{\text{[illegible]}} - \text{[illegible]}^{(\text{[illegible]})}_{\text{[illegible]}} + \text{[illegible]} \times \text{[illegible]}^{(\text{[illegible]})(\text{[illegible]})}_{\text{[illegible]}} \geq \text{[illegible]}^{(\text{[illegible]})}_{\text{[illegible]}}\,\text{[illegible]}^{(\text{[illegible]})}_{\text{[illegible]}} \qquad (4)$$

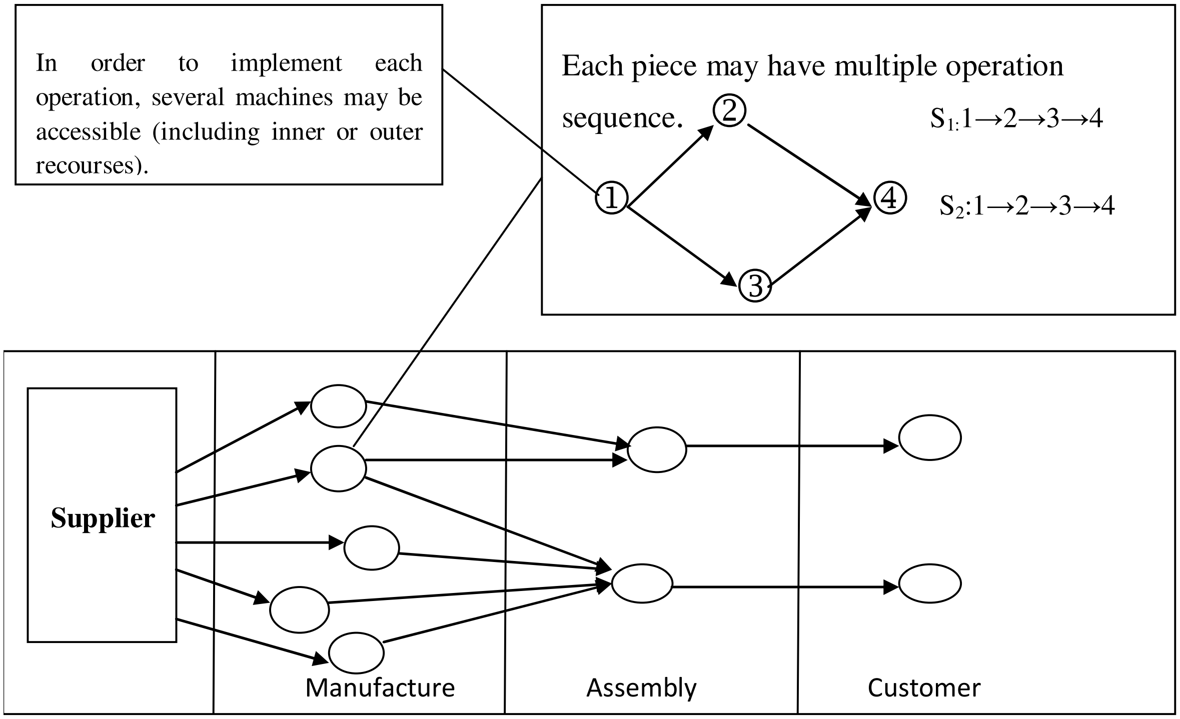

Figure 1. Manufacturing and production supply chain in a flexible industrial process (Lee et al., 2002).

$$\sum_{\square_{\square}=1}^{\square_{\square}} \square_{\square\square_{\square}} = 1 \tag{5}$$

$$\sum_{\square=1}^{\square} \square_{\square\square\square}^{(\square,\square_{\square})} \square_{\square\square\square}^{(\square,\square_{\square})} = \square_{\square\square_{\square}} \tag{6}$$

$$\square\square\square_{\square\square\square}^{(\square,\square_{\square})} \geq \left(\square_{\square}\square_{\square} + \square\square\square_{\square\square\square}^{(\square,\square_{\square})}\right) \square_{\square\square\square}^{(\square,\square_{\square})} \tag{7}$$

$$\square\square\square_{\square\square\square}^{(\square,\square_{\square})} \leq \square \times \square_{\square\square\square}^{(\square,\square_{\square})} \tag{8}$$

$$\square_{\square} \geq \sum_{\square=1}^{\square} \sum_{\square\square=1}^{\square_{\square}} \left(\square\square\square_{\square_{\square}\square}^{(\square,\square_{\square})} + \square_{\square}\square_{\square}\right) \square_{\square_{\square}\square}^{(\square,\square_{\square})} \tag{9}$$

$$\square\square\square_{\square\square\square}^{(\square,\square_{\square})} \geq 0\ ;\ \square_{\square\square_{\square}} = 0,1\ ;\ \square_{\square\square\square}^{(\square,\square_{\square})} = 0,1 \tag{10}$$

$$\square_{\square\square\square\square\square}^{(\square,\square_{\square})(\square,\square_{\square})} = 0,1 \tag{11}$$

N: set of pieces (works) $i = 1,\dots,N$
M: set of machines (including inner and outer resources) $K = 1,\dots,M$
Pi: set of possible operation sequences for i piece $S_i = 1,\dots,P_i$
Ni: operation number of i piece $j = 1,\dots,n_i$

Parameters

$Pt_{jk}^{(i,s_i)}$: Time length of Jth operation processing of (i, s_i) on k machine.
T_k: time length of piece transport from workshop to X outer resource (or vice versa)

$$Z_k = \begin{Bmatrix} 1 & \text{k machine is an outsource} \\ 0 & \text{otherwise} \end{Bmatrix}$$

$$a_{jk}^{(\square s_i)} = \begin{Bmatrix} 1 & \text{K machine is a part of possible machines' alternatives for j operation} \\ & \text{from } (\square s_i) \text{combination} \\ 0 & \text{otherwise} \end{Bmatrix}$$

L is a very big amount

Variables

$Ft_{jk}^{(i,s_i)}$ = terminal time of j operation of (i, s_i) combination on K machine.

$$Y_{is_i} = \begin{Bmatrix} 1 & \text{Si operation sequence is used for i piece.} \\ 0 & \text{otherwise} \end{Bmatrix}$$

Table 1. Solution structure (Sample problem)

Operation number	1	2	3	4	5	6
Priority	4	3	5	2	6	1
Machine	2	6	4	3	1	5

$$X_{jk}^{(i,s_i)} = \left\{\begin{array}{ll} 1 & \text{j operation of } (i,s_i) \text{ combination performes on k machine} \\ 0 & \text{otherwise} \end{array}\right\}$$

$$R_{jqk}^{(i,s_i)(r,s_r)} = \left\{\begin{array}{ll} 1 & \text{j operation of } (i,s_i) \text{ combination which performes before} \\ & \quad \text{qth of } (r,s_r) \text{ combination on k machine} \\ 0 & \text{otherwise} \end{array}\right\}$$

Relation 3 ensures that set of Si sequence operations have no time interference for i piece, on the other words, each operation of a sequence starts when its preceding operation was completed. Also, the relation assures that if implementation of an operation is allocated to outsources, we consider transportation time. Relation numbers (4) and (5) simultaneously assures that operation set which is performed on a machine has no interference time. Relation number (6) assures that we allocate only one operation sequence from possible sequences for each piece. Relation number (7) assures that each operation of one piece is only allocated to one of possible machines' alternatives for it. Relation number (8) assures that completion time of the first operation from Si sequence for i piece is bigger and equal to processing time length. We consider zero for j operation on the machine. Relation number (9) computes completion time for each variable. Relation numbers (10) and (11) determine type of variables.

SOLUTION APPROACH: TABU SEARCH

Here, the study introduces structure of proposed tabu search algorithm for solution of one objective scheduling problem. Tabu search algorithm is a parametric method and its parameters should be arranged properly. After arranging proposed algorithm parameters, the study compares algorithm operation toward common hierarchical method based on two standards of C_{max} and $\overline{C}$.

Structure of proposed tabu search algorithm

Scheduling problem includes 3 sub-problems:

i. Sub-problem of determination of operation sequence for each piece.
ii. Sub-problem of allocation of machines to each operation.
iii. Sub-problem of scheduling.

The proposed algorithm is composed of two search loops. The outer search loop using a production function of specific neighboring, researches the best operation sequence of each piece and the best scheduling program correspondent to it. The inner loop is recalled into outer loop and its duty is to search the best machine allocation program correspondent to defined operation sequence in outer loop. Both loops are designed based on principles of tabu search algorithm.

Each solution defines with two dimensions array. In Table 1, array length is the number of operations. First row represents allocated priority to each operation and second row determines allocated machine number to operations. Outer loop works with first row and inner loop works with second row.

Structure of tabu list

Each loop has a tabu list and its structure relies on movement type.

Outer loop

If displacement of priority, figure of two i and j operations will be accepted as the best movement, number of the two operations will be inserted to the tabu list in form of a pair figure. Hereafter, replacement of priority figure of the two operations is tabu and is possible only if satisfaction level will be fulfilled on effect of this movement.

Inner loop

If the movement related to alteration of allocated machine of an operation would be accepted, operation number and prior allocated machine number insert into tabu list as a pair figure. Hereafter allocation of the operation to the intended machine is accepted only if satisfaction level would be accepted.

Tabu list length

Tabu list length is supposed as a measure function of the problem that is equal to half of the total number of operations based on primary numerical test results. If tabu list is filled and a new element enters then the first element of list removed based on Fifo rule and a new element sets at the end of the list (Rossi, 2008).

Ideal level

The primary amount of ideal level is equal to primary amount of objective function. If and when the best achieved amount of objective function improves at the end of each iteration, ideal level will be set timely and equal to this amount.

Stoppage criterion

A stoppage criterion is defined for each loop. Considering unknown optimum amount of objective functions, we suppose stoppage criterion of each loop equal to maximum times of consecutive iteration of that loop without improvement in objective function. This amount is different for each loop and according to primary numerical test results, it is equal to:

i. Maximum times of consecutive iteration of outer loop without improvement in objective function (inner-max-iter): sum of operation numbers.
ii. Maximum times of consecutive iteration of inner loop without improvement in objective function (inner-max-iter): one third of products of operation numbers' sum in machine alternative maximum to perform each operation.

RESEARCH PROCESS

Search process starts with a random primary answer(s) as core. The outer loop works on first array and inner loop works on second array. In other words, the two inner/outer loops try to optimize the objective function respectively by alternation of operation sequence of piece and alternation of machine allocation program. Thus, neighboring set of S answer core will be produced ($N_{(s)}^{outer}$) by using neighboring function of outer loop. Then, inner loop is recalled for each neighbor of S core ($n_i^{\circ} \in N^{outer}$). In fact, each neighbor answer of S core n_i° has the role of initial core answer for inner loop. The inner loop creates this core answer using neighboring function of own neighboring set. The study computes timing program and amount of analogous objective function for each inner neighboring by ($N^{inner}(n_i^{\circ})$) and by recalling timing approach. The study chose the best inner neighbor which is not tabu or fulfils the ideal level and replaces it in inner core and inner core continues till arriving to its own stoppage criterion. By fulfilling stoppage criteria in inner loop, the best gained answer is returned to outer loop via this loop. In fact, this answer is the best found machine allocation program for each n_i° neighbor from neighboring set of S core in outer loop. Recall process of inner core repeats for all neighboring answers of S core ($N_{(s)}^{outer}$). Ultimately, the best S neighboring answer is chosen which is not tabu or satisfies ideal level and replaces in S core. In this step, the study knows the new core as the best researched answer up to this step, when objective function is improved. Thus, research process in outer loop continues until it arrives to stoppage criteria. Tabu list and ideal level of that loop updates at the end of each iteration in inner loop or outer loop. The study has pseudo code of proposed tabu search algorithm that is given below (algorithm 1):

Algorithm 1: Pseudo code of proposed tabu search algorithm.

Begin:

```
    Randomly generate an initial feasible solution(s).
    Calculate the objective function for s.
    s→$s^{best}$ and f(s) →f($s^{best}$).
    Initialize outer-TL,outer-AL,inner-TL and inner-AL.
    Set outer-max-iter and inner-max-iter.
Outer loop
    Outer-niter-without-improvement=0
   Do {
        Generate priority numbers neighborhood solutions by outer neighboring function ($N^{outer}(s)$).
         For (all priority numbers neighborhood solutions)
             Recall inner loop.
         Select the best priority numbers neighborhood solution, which is not tabu or satisfies outer-AL,
         If (there is an improvement in the objective function) {
           Outer-niter-without-improvement=0
           Update the best solution.
         }
         Else  outer-niter-without-improvement=outer-niter-without-impronement+1
         Update outer-TL and outer-AL.
    } while (Outer-niter-without-improvement<outer-max-iter)
    Report the best solution founds, which includes the best known process plan for each part the best known assignment machine for each operation and the best known schedule)
```

Inner loop

```
Inner-niter-without-improvement=0
     Do {
        Generate machine assignment neighborhood solutions by inner neighboring function ($N^{inner}(n_i^o)$).
         For (all machine assignment neighborhood solutions)
             Recall scheduling.
         Select the best machine assignment neighborhood solution, whitch is not tabu or satisfies inner-AL,
         If (ther is an improvement in the objective function) {
           Inner-niter-without-improvement=0
           Update the best solution.
         }
         Else  inner-niter-without-improvement=inner-niter-without-impronement+1
         Update inner -TL and inner -AL.
    } while (inner -niter-without-improvement< inner -max-iter)
    Return the best inner solution founds.
```

Scheduling

Initialize:

```
        $s_1 = \{\frac{o_i}{o_i} has\ no\ predecessors\}$
        $s_2 = \{all\ operations\ minus\ s_1\}$
Do{
Select the operation ($O^*$) with higher priority among members o s1.schedule $O^*$ on its assignment machine in possible earliest time. delete $O^*$ from s1.
   If there is any operation in s2 for which $O^*$ is its predecessors and all of its predecessors are scheduled, then delete it from s2 and add to s1.
      } while (s1 is not empty)
Calculate the objective function for the obtained schedule.
     Return (the best function).
```

ARRANGEMENT OF PROPOSED ALGORITHM PARAMETERS

Tabu search algorithm is parametric algorithm. Among

Table 2. Arrangement of proposed algorithm parameters: tabu length and stoppage criteria (Cambers et al., 1996).

Class	State	Outer-loop		Inner-loop	
		Max-iter	LTL	Max-iter	LTL
C1	S1-S4	ir	i:	i1	
C2	S5-S10	ir	i:	ir	
C3	S11-S14	TOR	i:	i1	
C4	S15-S18	ir	i:	i1	

TPR: total of precedence relations; TOR: total of operations; MNAM: maximum number of alternative machines; a, b, c, d: reduction factor; LTL: length of tabu list; Max-iter: maximum sequential iterations without improvement.

these parameters, tabu list length and stoppage criteria are significant and effective parameters in answer quality and implementation time. While we design a tabu search algorithm, it is a significant and underlying step in arrangement status of these parameters. Concerning problem's structure of neighboring functions in proposed algorithm, the initial supposition is that, amounts of the parameters are related to dimensions of problem and flexibility degree. In proposed relation, we used total of operations (TOR) as measurement index of problem's dimensions and maximum number of alternative machines (MNAM) and total of precedence relation (TPR) as measurement index of flexibility degree.

According to Table 2, 18 different position proposed for adjustment of this two parameters affect on algorithm performance by experiment design.

To assess algorithm performance, we use criteria that represent time and solution quality and they are discussed further.

Average percentage of relative error (ARE)

This criterion sets the answer distance from the best amount of objective function in each sample problem as comparison base. Average percentage of relative error for each problem set is computed by underneath relation in which P is number of each sample problem in each set and mean is average gained answer resulted from 25 times implementation of i sample and $best_i$ is the best known amount for objective function in this sample (Zampieri, 2006).

$$ARE = \frac{1}{p}\sum_{i=1}^{p}\frac{mean_i - best_i}{best_i}\times 100$$

Answer variance (VAR)

Average answer variance for each problem set.

Implementation time (CPU)

Average implementation time for each problem set.

Performance evaluation of proposed algorithm

In this step, proposed algorithm is evaluated toward different objective functions. We perform numerical tests concerning C_{max} and $\bar{C}$ are normal criterion .In this state, performance of proposed algorithm is compared with hierarchical method. Selection criteria of these methods are logical employment possibility of studied method for solution.

COMPARISON WITH HIERARCHICAL METHOD

Hierarchical method is an approach broadly applied for solving problems which are composed of some sub-problems related to each other (Kim et al. 2003). In this method, sub-problems are sorted in precedence and will be solved respectively. Each sub-problem has specific objective function and solution method. By solving each sub-problem, a section of decision variables are determined and answer of each input sub-problem will be the next problem. Here, we divide scheduling problem into two sub-problems. The first sub-problem is allocation or routing that determines movement route of each point between machines via allocation of operations to different machines. Objective function of this sub-problem is minimization of $\sum_k |w_k - \overline{w}|$. w_k is work load of k machine and $\overline{w}$ is average work load of machines. Allocating machines to each operation by objective of balancing work load of machines results in utility increase of resources. On the other hand, both C_{max} and $\bar{C}$ mineralize functions have direct relation with utility increase of resources (Kim et al, 2003). Therefore,

Table 3. Characteristics of sample problem (Kim et al., 2003).

Problem	N	TOR	MNAM	Min-or	Max-or
1	5	20	3	4	4
2	8	20	3	1	5
3	10	40	3	1	4
4	16	40	3	1	5
5	20	60	6	2	5
6	32	80	3	2	5
7	50	100	6	1	5

Table 4. Arrangement of proposed algorithm parameters for prior table problems.

Problem	Outer-Loop		Inner-Loop	
	Max-iter	LTL	Max-iter	LTL
1	20	7	30	7
2	20	7	30	7
3	40	13	60	13
4	40	13	60	13
5	60	20	180	20
6	80	27	120	27
7	100	33	300	33

selection of this objective function is to solve logical allocation sub-problem and is related to main objective function of problem. After solving the first sub-problem, we solve sequence determination and timing sub-problems under limitation of gained answer for the first sub-problem. In this step, mineralization objective function is C_{max} and $\bar{C}$ objective criteria. The applied hierarchical method for solution follows the manufacture of Tabu search algorithm. In order to perform a just comparison, its parameters are similarly arranged by parameters of proposed Tabu search algorithm. The study considers 7 groups of sample problem as shown in Tables 3 and 4. The study supposes that all the resources are internal. Therefore, we ignore transportation time.

The proposed tabu search algorithm and hierarchical method are coded with Borland C language and implement by 2000 MH2 and Pentium④ PC system. Each problem group includes 5 random samples. It solve 5 times for each answer using two methods and with 5 different initial answers. Initial answers are produced randomly but it is the same for each method. Parameters amounts are determined based on numerical tests. In each 25 implementations, a sample problem records by each of these methods; average answer, best answer and standard deviation. Evaluation criteria are answer improvement rate and average percentage of relative error.

As shown in Table 5, results improvement rate (column 10) is a positive figure in all of the problems. In other words, in all of the samples, answer of proposed tabu search algorithm has improved in comparison to answer of hierarchical method. Therefore, proposed tabu search algorithm is prior in comparison to hierarchical method. The cause of this priority is that, in proposed tabu search algorithm in each iteration, decision in sequence determination of pieces operation, machine allocation and scheduling program are made simultaneously and with mutual interrelation, while a section of answer area omits by solving allocation sub-problem and proving pieces' route in hierarchical method. Therefore, research continues in remained area. Indeed, answer quality and time criterion destroys a little toward this improvement in proposed algorithm. Owing to the fact that implementation time is about 6 min in the worst state, this time increase is acceptable concerning problem dimensions and rate of answer improvement.

Diagrams compare proposed tabu search algorithm and hierarchical method respectively for two objectives of C_{max} and $\bar{C}$ based on average percentage of relative error as shown in Figures 2 and 3.

i) Proposed Tabu search algorithm has less average percentage of relative error in comparison to hierarchical method.

ii) Behavior of Tabu search algorithm is stable while enlarging problem dimensions of a problem.

ii) In group of P5 and P7 sample problems, in which flexibility degree is more than other problems, average percentage of relative error has increased severely in hierarchical method. The study deduces from diagram behavior that by increasing flexibility and enlarging

Table 5. Result of proposed tabu search algorithm and hierarchical approach (C_{max} Objective function)

Problem	Sample no.	Initial mean	Hierarchical app.			Proposed TS			Improved rate (%)	Cput.(s)
			Best	Mean	S.D	Best	Mean	S.D		
1	1	41.4	16	21	2.4	14	16.3	1.3	22.1	0.2
	2	33.8	14	19.2	2.4	13	14.6	1.2	23.9	0.1
	3	29.8	17	20.2	1.5	15	16.6	0.8	18	0.2
	4	41.6	18	21.5	3.1	18	20.9	1.3	3	0.2
	5	31	14	16.7	2.5	15	16.4	1.4	2.2	0.1
Average					2.4			1.2	13.8	0.2
2	1	25.68	12.12	14.02	1.2	11.62	12.16	0.4	13.3	0.3
	2	31.35	13.25	14.58	0.8	12.25	13.14	0.6	9.9	0.3
	3	25.97	10.12	11.56	1.0	9.12	9.57	0.3	17.2	0.3
	4	22.73	10.00	11.32	1.7	7.38	7.83	0.3	30.9	0.4
	5	25	11.25	15.65	1.9	10.62	11.24	0.4	28.2	0.3
Average					1.3			0.4	19.9	0.3
3	1	37.06	18.20	20.78	1.4	16.70	18.20	0.8	12.4	3.7
	2	38.44	17.50	21.00	1.7	16.20	18.24	1.1	13.1	4.1
	3	36.78	17.70	19.82	1.2	16.80	18.12	0.8	8.6	3.8
	4	44.52	18.10	20.08	1.3	15.20	17.08	0.7	14.9	4.7
	5	41.724	15.80	17.54	1.2	15.50	17.17	0.9	2.1	4.0
Average					1.4			0.8	10.2	4.0
4	1	46.49	23.38	27.12	2.1	21.75	23.43	1.2	13.6	4.5
	2	51.89	25.69	27.43	1.3	25.81	27.30	1.0	0.5	4.4
	3	51.63	24.69	26.92	1.6	23.06	25.07	1.2	6.9	4.9
	4	54.60	24.12	26.58	2.1	21.19	22.87	1.2	13.9	5.0
	5	46.17	23.12	24.95	1.4	20.25	21.81	1.2	12.6	5.0
Average					1.7			1.2	9.5	4.8
5	1	85.36	31.05	36.95	3.8	26.75	29.08	1.2	21.3	38.3
	2	79.14	36.30	39.80	3.8	27.95	30.83	1.8	22.5	37.8
	3	74.35	32.65	37.13	2.8	25.60	27.41	1.8	26.2	37.0
	4	79.94	31.50	37.13	4.1	25.60	28.60	2.1	23.0	35.9
	5	69.32	33.95	35.61	1.2	24.55	27.40	1.7	23.0	39.8
Average					3.1			1.7	23.2	37.8
6	1	79.74	42.66	45.16	2.6	36.41	40.22	2.1	10.9	109.1
	2	96.36	42.56	46.80	2.4	35.59	40.33	1.7	13.8	111.5
	3	80.06	40.78	46.69	3.2	39.12	41.95	1.6	10.1	110.6
	4	94.36	42.06	46.27	2.2	37.03	39.88	1.5	13.8	116.0
	5	83.76	40.69	44.46	2.0	36.53	39.89	1.9	10.3	118.9
Average					2.5			1.8	11.8	113.2
7	1	96.78	38.58	42.21	2.5	29.30	30.90	1.1	26.8	608.3
	2	86.57	36.78	41.30	5.2	28.40	30.13	1.1	27.1	563.7
	3	91.18	38.12	40.58	5.2	28.34	30.63	1.1	24.5	585.7
	4	92.66	38.16	40.90	1.9	27.50	29.58	1.1	27.7	656.5
	5	88.73	39.42	43.43	2.7	28.96	31.69	1.4	27	692.7
Average					3.5			1.2	26.6	621.4

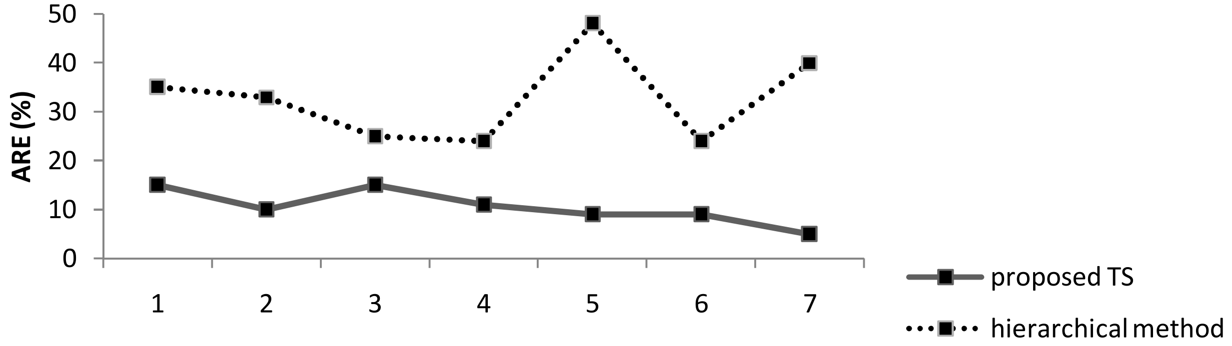

Figure 2. Compare proposed tabu search algorithm and hierarchical method based on average percentage of relative error (objective function:C_{max}).

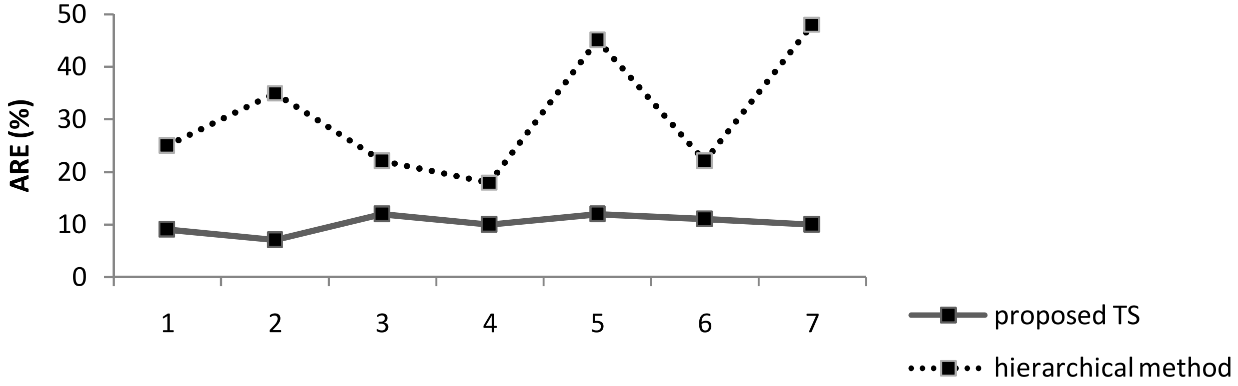

Figure 3. Compare proposed tabu search algorithm and hierarchical method based on average percentage of relative error (objective function: $\bar{C}$).

search area, hierarchical method is a dependable method in no way.

Conclusion

The study summarizes the achieved results from analysis of numerical tests on two performance criteria ($\bar{C}$, C_{max}) as follows: Considering each performance criteria ($\bar{C}$, C_{max}), proposed tabu search algorithm is able to solve scheduling in flexible job shop manufacturing and production system and presents an acceptable answer which fulfils related limitations to prerequisite and scheduling relations in an acceptable time. Comparison of average initial amount with average of the best amount gained for it represents a considerable amount for each objective function of various problems. Considering improvement mechanism in proposed algorithm, using flexibility chance (operation sequential alteration of pieces, alteration of machines allocation and alteration of scheduling program), results of numerical test approve the priority of proposed tabu search algorithm in comparison to hierarchical method basis on "response quality" and "calculation time."

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