Improved tabu search for early/tardy scheduling problem with customer delivery times

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Abstract: Delivery deadline of pieces is one essential data for implementation of Early/Tardy maximum objective function. Delivery deadline is a significant input which has a direct effect on objective function. If we don't consider the necessary accuracy at production time of delivery deadline, it is possible that a good or bad performance of an algorithm be affected by setting delivery deadlines in limit state. Scheduling studies in which objective function is related to delivery deadline are divisible into two groups. In the first group, delivery deadline of pieces is an input parameter. In this state, there isn't a specific standard for producing parameter of delivery deadline and different functions and relations are used in various references. In second group of researches, delivery deadline is a decision variable that determination of its optimum amount is one of problem objectives. In present research, we supposed that delivery deadline is an input variable. Considering solution of Scheduling problem with Early/Tardy maximum objective function has no prior background, therefore, there is no standard problem or significant pattern for data production. In this step of tests, we use two various rules in order to produce parameter of delivery deadline for studied sample problems. Then we study the effect of parameter of delivery deadline on Early/Tardy maximum delivery deadline. Then a new composition of improved Tabu search algorithm is introduced.

[Seyed Ahmad Sheibat Alhamdy, Mohammad Taghi Honari, Ardeshir Shaabani , Ali Akbar Beigi Yazdi. **Improved tabu search for early/tardy scheduling problem with customer delivery times.** *Life Sci J* 2013;10(1):1621-1630] (ISSN: 1097-8135). http://www.lifesciencesite.com. 239

Keywords: scheduling, delivery times, tabu search, job-shop

1. 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 having the role of resources and needed operations having the role of duties to manufacture any piece or order. We define general scheduling problem as follows: 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 definite p_{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 don't have temporal interference. In solving scheduling problem, objective is to find a feasible timing program which optimizes one or several performance criteria4 (McCarthy and Liu, 1993). 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-hop 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 first version, there is a unilateral information process between routing and scheduling sub-problems that is from routing to scheduling. First, a primary route is produced, using a proper preference rule. Then, result of job-shop problem is solved by tabu search algorithm. In 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 results. He solves flexible job shop problem via C_{max} Criterion by each two 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) in 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, 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 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)

2. Material and Methods 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 (figure 1). 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, therefore, we prevent from entering in details of other part of chain. Supposing a definite time length for assembly process, we specify a delivery deadline for each piece in manufacture part by subtracting this time from final delivery deadline. We can use outer resources to access timing objectives. We suppose that outer resources are analyzed in charges and are chosen. If we use outer resources, cycle time will be added to processing time of operation. Our 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.

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).

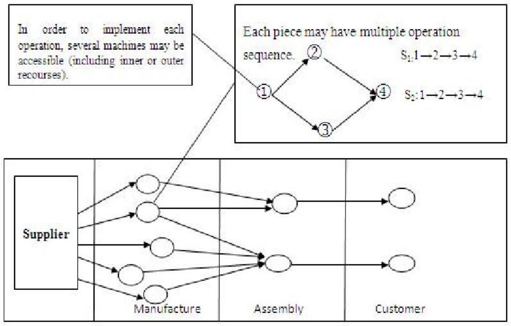

Figure 1 - Manufacturing and production supply chain in a flexible industrial process (Lee et al. 2002).

3. 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 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 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:

$$Min\ ETmax = Max(Ei, Ti) = Max[\alpha_i(D_i - C_i), \beta_i(C_i - D_i)] \quad (1)$$

Subject to:

$${}^{(i,s_i)}_{j+1)k} - Ft^{(i,s_i)}_{jm} + L(1 - a^{(i,s_i)}_{(j+1)k} X^{(i,s_i)}_{(j+1)k} \geq Pt^{(i,s_i)}_{(j+1)k} + T_k Z_k + T_m Z_m \quad (3)$$

Ft

$${}^{(i,s_i)}_{jk} - Ft^{(r,s_r)}_{qk} + L \times R^{(i,s_i)(r,s_r)}_{jqk} \geq Pt^{(i,s_i)}_{jk} X^{(i,s_i)}_{jk} \quad (4)$$

$$\sum_{s_i=1}^{P_i} Y_{is_i} = 1 \quad (5)$$

$$\sum_{k=1}^{M} a^{(i,s_i)}_{jk} X^{(i,s_i)}_{jk} = Y_{is_i} \quad (6)$$

$$Ft^{(i,s_i)}_{lk} \geq (T_k Z_k + Pt^{(i,s_i)}_{lk}) X^{(i,s_i)}_{lk} \quad (7)$$

$$Ft^{(i,s_i)}_{jk} \leq L \times X^{(i,s_i)}_{lk} \quad (8)$$

$$C_i \geq \sum_{k=1}^{M} \sum_{si=1}^{P_i} (Ft^{(i,s_i)}_{n_i k} + T_k Z_k) X^{(i,s_i)}_{n_i k} \quad (9)$$

$$Ft^{(i,s_i)}_{jk} \geq 0 ; Y_{is_i} = 0,1 ; X^{(i,s_i)}_{jk} = 0,1 \quad (11)$$

N: set of pieces (works) $i = 1, \ldots, N$

M: set of machines (including inner and outer resources) $K = 1, \ldots, M$

Pi: set of possible operation sequences for i piece $S_i = 1, \ldots, P_i$

Ni: operation number of i piece $j = 1, \ldots, n_i$

Parameters

$Pt^{(i,s_i)}_{jk}$: 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)

D_i: Delivery time of piece

α_i: Penalty of earliness

β_i: Penalty of tardiness

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

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

L is a very big amount

Variables

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

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

$$X^{(i,s_i)}_{jk} = \begin{cases} 1 & \text{j operation of } (i,s_i) \text{ combination performes on k machine} \\ 0 & \text{otherwise} \end{cases}$$

$$R^{(i,s_i)(r,s_r)}_{jqk} = \begin{cases} 1 & \text{j operation of } (i,s_i) \text{ combination which performes before qth of } (r,s_r) \text{ combination on k machine} \\ 0 & \text{otherwise} \end{cases}$$

(3) Relation 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 number (4) and (5) simultaneously assure 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 number (10) and (11) determine type of variables.

4. Solution approach: tabu search

In this section, we introduce 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.

Structure of proposed tabu search algorithm:

Scheduling problem includes 3 sub-problems:

Sub-problem of determination of operation sequence for each piece

Sub-problem of allocation of machines to each operation

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 of loops are designed based on principles of tabu search algorithm.

Each solution defines with two dimensions array. In figure 2 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.

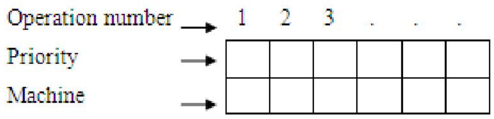

Figure 2: solution structure

Structure of tabu list:

Each loop has a tabu list that 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 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:

Maximum times of consecutive iteration of outer loop without improvement in objective function (inner-max-iter): sum of operation numbers

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

5. 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 the 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 $(N^{outer}_{(S)})$ by using neighboring function of outer loop. Then inner loop is recalled for each neighbor of S core $(n^{o}_{i} \in N^{outer})$.

In fact each neighbor answer of S core n^{o}_{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. We compute timing program and amount of analogous objective function for each inner neighboring by $(N^{inner}(n^{o}_{i}))$ and by recalling timing approach. We chose the best inner neighbor which is not Tabu or fulfils the ideal level and replace 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^o 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, we know 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. In figure 3 we have pseudo code of proposed Tabu search algorithm in beneath column.

Tabu search algorithm is parametric algorithm. Among 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 1, 18diferent position proposed for adjustment of this two parameters that affect on algorithm performance by experiment design.

To assessment algorithm performance, we use tree bellow criteria that representative time and solution quality: 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.

```
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
0    Outer-niter-without-improvement=
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) {
0           Outer-niter-without-improvement=
            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
 0    Inner-niter-without-improvement=
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, which is not tabu or satisfies inner-AL,
        If (there is an improvement in the objective function) {
0           Inner-niter-without-improvement=
            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:
            $s_1 = \{o_i \text{ has no predecessors}\}$
            $s_2 = \{\text{all operations minus } s_1\}$
    Do {
            Select the operation ($O^*$) with higher priority among members o s1.schedule $O^*$ on its assignment machine in possible earliest time.delet $O^*$ 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)
```

Figure 3: solution

Table 1. Arrangment of proposed algorithm parameters: tabu length and stoppage criteria

class	state	Outer-loop		Inner-loop	
		Max-iter	LTL	Max-iter	LTL
C1	S1-S4	$int[\frac{TOR\times(TOR-1)}{2\times(TPR+1)}]$	$int[\frac{TOR}{b}]$	$int[\frac{TOR\times MNAM}{c}]$	$int[\frac{TOR}{d}]$
C2	S5-S10	$int[\frac{TOR\times(TOR-1)}{2\times a}]$	$int[\frac{TOR}{b}]$	$int\left[\frac{TOR\times MNAM}{c}\right]$	$int[\frac{TOR}{d}]$
C3	S11-S14	TOR	$int[\frac{TOR}{b}]$	$int[\frac{TOR\times MNAM}{c}]$	$int[\frac{TOR}{d}]$
C4	S15-S18	$int[\frac{TOR\times(TOR-1)}{2\times(TOR+1)}]$	$int[\frac{TOR}{b}]$	$int[\frac{TOR\times MNAM}{c}]$	$int[\frac{TOR}{d}]$

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

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.

6. 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 of C_{max} and $\bar{C}$ mineralize functions have direct relation with utility increase of resources (Kim et al, 2003). Therefore 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. We consider 5 groups of sample problem according to table 2. We suppose 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 two methods. 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.

Table2: Characteristics of sample problem

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

7. Results

Two various rules are used to determine delivery deadline in trial problems:

The first rule: development of an existing rule in literature is for uni-machine problem with objective function of sum of precipitation and postponement (Ow and Morton, 1989). We use relation (1) in order to determine delivery time in uni-machine problem with objective of minimizing sum of gain weight of precipitation and postponement. In the relation, parameter of delivery deadline is controlled by two factors. The first factor is postponement factor and is shown with t. This factor determines average delivery deadline of works using relation (2). In this relation, Pi and $\bar{d}$ respectively represent average delivery deadline of works and processing time of work i. The second factor is range factor of delivery deadline and is represented with R.

$$U \sim \left[\bar{\mathrm{d}}(1-\frac{\mathrm{R}}{2}), \bar{\mathrm{d}}(1-\frac{\mathrm{R}}{2})\right] \qquad (1)$$

$$\bar{d} = (1-\tau)\sum P_i \qquad (2)$$

Zegori et al, 1995 turn relation (2) to underneath relation in order to produce parameter of delivery deadline in problem of ordinal workjob process (PFS).

$$\bar{d} = (1-\tau)\sum\sum P_{ij} \qquad (3)$$

If we use relation (3) in timing program, concerning any operation can be perform by various machines and with different processing times, sum of processing time enlarges pro rata. Accordingly delivery deadline of each work will enlarge in comparison to sum of needed time for its processing and therefore most of the works have unavoidable precipitation. Moslehi, 1377, entering a criticism to method of Zegori et al, 1995 write relation (2) in form of underneath relation (9). In his opinion, M parameter, in problem of uni-machine, is equal to completion time of lateral work in order or Cmax. in order to use relation (9) to produce parameter of delivery deadline in PFS problem, he uses Cmax amount instead of M for each random order in works.

$$\bar{d} = (1-\tau)M \qquad (4)$$

In present research, a similar method is used for producing parameter of delivery deadline in timing problem from Cmax average for each sample problem instead of M parameter in relation (4). Thus parameter of delivery deadline is determined for each piece by specifying M, T, R parameters and using relation (1) and (4). We consider t factor amount equal to 0.2 or 0.6 and factor amount of postponement equal to 0.6 or 1.6 as references (Zerogi et al, 1995) .Thus we will gain a set of delivery deadline for each sample problem for each of (0.2, 0.6), (0.2, 1.6), (0.6, 0.6), (0.6, 1.6) compositions.

Second rule: PR is a proposed rule. The rule is based on idea that each work has a share in comparison to average time of its processing from sum of work load of workshop and determination of its delivery deadline to this ratio can be realistic. Delivery time of I work in proposed rule is determined by using relation (5).

$$di = \frac{MPT_i}{TPT} \times WL \qquad (5)$$

In which MPTI and TPT are respectively average processing time of I work and sum of average processing time of works and is computed by relation (6) and (7).

$$MPT_i = \sum_{j=1}^{n_i} \frac{\sum_{KeKij} Pt_{ijk}}{\left|k_{ij}\right|} \qquad (6)$$

$$TPT = \sum_{i=1}^{N} MPT_i \qquad (7)$$

In above-mentioned relation, Ptijk is processing time j operation from I work on k machine and kij is set of possible machines for implementation of j operation in I work. WL parameter expresses sum of workshop work load that is equal to sum of completion time of works. Thus it is necessary to solve each sample problem first with $\bar{C}$ objective function and via using proposed algorithm and sum of completion time of its pieces are fulfilled averagely. By setting this amount in relation (5), delivery time of each piece is computable.

Study of parameter effect of delivery deadline on ETmax objective function:

By studying parameter effect of delivery deadline on ETmax objective function and selecting proper rule for parameter determination of delivery deadline, we select 5 problem groups P1, P2, P3, P4, P6 from table 2 and 5 random samples are produced from each set. Parameter of delivery deadline of pieces is produced for each sample problem using two defined rules in previous section. Considering that we gain a set of delivery deadline of pieces for each composition of (T,R) parameters, altogether there will be 5 sets of delivery deadline for each sample problem. Then each sample problem is solved with ETmax objective problem and for each of delivery deadline sets. Similar to prior tests, eah problem s solved with 5 primary random answers and 5 times for each answer (with various cores).

Figure (4) to (8) compare average ETmax for slelected problems' set in condition in which delivery deadline of pieces are produced via using the first rule with various compositions (T,R) or via proposed rule. Diagrams' behavior approves that production status of delivery deadline of pieces has a direct effect on ETmax objective function. On the other hand, we observe that while delivery deadline of pieces are determine using (PR) proposed rule, diagrams have a stable behavior in each 5 set of studied problem. In proposed rule, delivery deadline of each piece is fulfilled proper to requirements of piece and workshop but not in form of probability. In other words, the proposed rule is designed for determining parameters of delivery deadline proper to problem characteristics of flexible workshop production and therefore has more efficiency in comparison to the first rule. Here efficiency word means that if we use proposed rule, delivery deadline of limit states would not form.

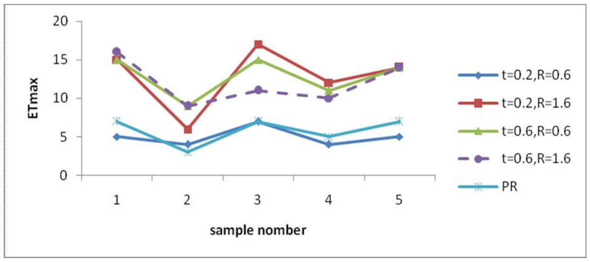

Figure 4: P1 problem

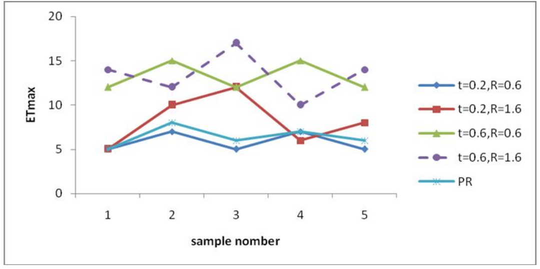

Figure 5: P2 problem

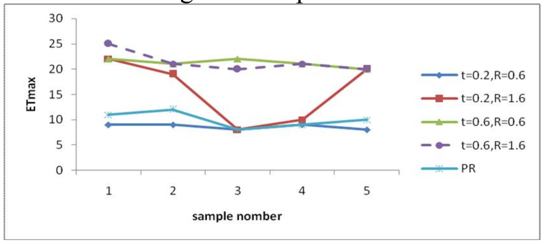

Figure 6: P3 problem

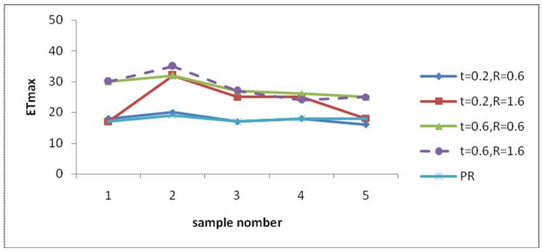

Figure 7: P4 problem

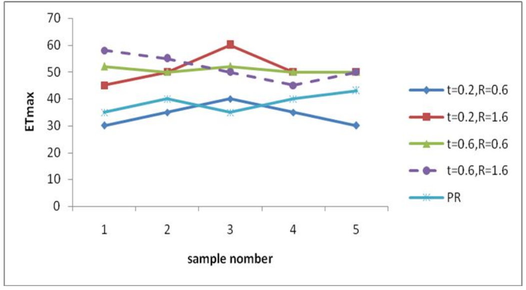

Figure 8: P5 problem

8. Discussions

We call proposed Tabu search algorithm as TS1 hereafter. Its structure is explained in previous section. In this algorithm, inner loop is in outer loop and it is recalled for each neighbor of neighboring set of core. In other words in TS1 composition of proposed algorithm, outer loop sets in higher level and inner loop sets in lower level (figure 9).

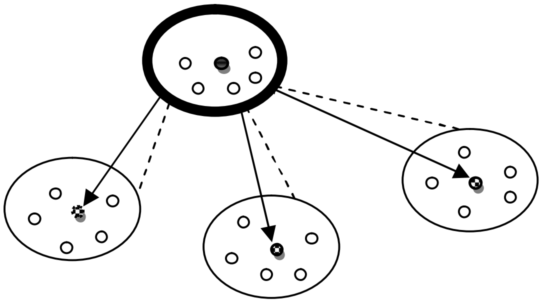

Figure 9: structure of proposed tabu search algorithm-connections between inner and outer loop

We use numerical tests with ETmax objective function on sample problems of table 3 shows numerical test results. The first and second columns, respectively, represent set code and sample number for each set. In the third column, we have initial amount of objective function and the best known amount in the forth column for objective function in each problem. The fifth columns up to eighth column, respectively, represent average, variance, frequency number that the best answer is achieved and average implementation time.

In table 3 an operation assessment of TS1 is basis of three criteria of average, variance and frequency number in finding the best amount (column 5 to 7). This quality improvement and time increase is because TS1 composition improves quickly in initial frequencies of answer and algorithm quickly falls on local optimization. Therefore we gain stoppage provision sooner and implementation time is shorter as a result.

Table 3: numerical test results on TS1

Problem	Sample no.	Mean init.	best	Ts1			
				mean	Var.	No.best	Cput.(s)
1	1	39.8	7	7.2	0.2	22	0.21
	2	24.0	2	4.2	1.7	3	0.15
	3	25.0	7	7.3	0.8	22	0.16
	4	26.4	1	3.0	1.0	2	0.18
	5	23.4	6	7.0	0.7	8	0.13
Total/average						57	0.17
2	1	34.6	3	5.7	1.8	0	0.18
	2	42.4	7	7.3	0.6	21	0.17
	3	37.0	5	6.8	1.4	6	0.23
	4	33.8	4	6.1	4.6	6	0.22
	5	33.2	3	6.2	1.8	0	0.18
Total/average						33	0.20
3	1	50.8	2	11.3	20.8	0	2.49
	2	62.6	4	12.4	7.2	0	2.87
	3	50.2	3	9.8	11.7	0	2.84
	4	63.6	3	10.5	11.4	0	3.39
	5	51.4	3	10.7	7.0	0	2.84
Total/average						0	2.88
4	1	85.0	3	15.8	20.8	0	3.24
	2	81.6	6	17.7	20.5	0	2.82
	3	71.8	6	17.7	20.9	0	3.50
	4	86.6	4	16.8	21.6	0	3.17
	5	61.0	5	19.0	16.0	0	3.07
Total/average						0	3.16
5	1	118.2	14	22.0	19.12	1	19.73
	2	106.4	14	20.7	8.39	0	18.79
	3	108.8	13	21.7	24.56	0	21.92
	4	115.8	12	26.4	13.67	0	18.25
	5	102.0	14	22.0	11.54	0	20.23
Total/average						1	19.78

Totalization and conclusion:

We summarize the achieved results from analysis of numerical tests on three performance criteria (ETmax,) as follows:

- Considering each three performance criteria (ETmax,), proposed Tabu search algorithm is able to solve scheduling in flexible job-shop manufacturing and production system untidily and presents an acceptable answer which fulfils related limitations to prerequisite and timing relations in an acceptable time.
- Comparison of average initial amount with average of the best amount gained for it represents a considerable mount for ETmax objective functions of various problems. For example amount of this improvement on ETmax objective function is averagely 80%. Considering improvement mechanism in proposed algorithm is using flexibility chance (operation sequential alteration of pieces, alteration of machines allocation and alteration of timing program), we result that
- integration of two operations of process timing and timing leads to significant objectives and improvement of system operation as a result, for example improvement of ETmax performance criteria i.e. accessing to on time production ideal and increase of satisfaction level of customer.
- Studying the effect of parameter of delivery deadline of pieces on ETmax objective function approves efficiency of (PR) proposed rule for producing parameter of delivery deadline in timing problem in comparison to two existing rules.

Performance comparison of two various composition of proposed Tabu search algorithm on ETmax represents priority of TS2 composition toward TS1 based on criterion of answer quality. As it is predicted, time increases versus improvement of quality that this amount of time increase is acceptable in comparison to improvement rate of answer versus rate of time increase.

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1/20/2013