DYNAMIC BATCH JOB SHOP SCHEDULING
FOR MULTI ITEMS AND MULTI DUE DATES
WITH TOTAL ACTUAL FLOW TIME AS PERFORMANCE CRITERIA

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Abstract

Earliness and tardiness are two common problems on production activity. They are related to the due date and subsequently give disadvantages for both company and customer. The problems are caused by random production process and the changing order during a production period. This paper explores a scheduling model for job shop production system with total actual flow time as the performance criteria. The characteristic of production system is batch production with parallel machines, while the characteristics of customer order are multi due dates, multi parts, and dynamic. The objective function is to fulfill the order on the right time (just-in-time) and minimize both work in process and finished goods.

Keywords: Batch production, dynamic, multi parts, multi due dates, total actual flow time

I Introduction

Nowadays, production activity has become more complex. Therefore, it is necessary to consider due date from customer and number of items have to be produced every day. In some cases, random production schedule causes earliness and tardiness.

Tardiness occurs when number of items on the production floor do not comply customer order on a certain due date. While earliness occurs when number of items on the production floor exceed customer order. Earliness consists of work in process and finished goods.

This paper investigates how to make production schedule that minimizes the earliness and tardiness. The performance criteria is the total actual flow time. Total actual flow time is the total time that is required by all part started from the production process of first batch until the due date (Halim, 1993).

Object of this research is company that produces components for some Original Equipment Manufacturing (OEMs). The production system of the company is job shop, batch production, and uses parallel machine. Job shop is a pattern of flow production with different, unique, and not unidirectional process sequence (Baker, 1974). The working day of the company is six days a week and eight hours a day.

Batch production is a job production that is divided into several pieces. The determination of number of batch and size of batch affect the actual flow time (Halim, 1993). Parallel machine is a group of similar type of machines that produces same output with same processing time and setup time (Sarian, 2008).

During production process, the operator uses basket as tools of material handling. The basket is utilized to store and to move work-in-process and finished goods and it has limited capacity. This material handling process becomes important. This is due to the fact that in the common manufacturing strategy characteristics, when the order has a high probability of arriving before the procurement (material supply) process, the best manufacturing strategy is make to-order (MTO) and this condition also strengthens the procurement probability of components (Hidayat, et al., 2011).

Customer gives an initial order once a month. The order consists of multi parts and multi due dates. During the production period, customer is possible to change the order until the due date of delivery or until some number of order. The total number of order part is thirty six types and there is no addition of new part type. There are three due dates delivery for each week, namely Monday, Wednesday, and Friday.

There are some research related to this problem. Zaini (2001) do a research for a job shop production system with order changes during the production period (dynamic). The company uses single machine and the order has multi due dates. Zaini (2001) creates a scheduling model with the cost of earliness and tardiness as the performance criteria. This model does not compute the optimal number of batch and size of batch.

Ras (2002) performs a research for a dynamic job shop production system. The company uses single machine and the order has multi due dates. In this research, a scheduling model with total actual flow time as performance criteria is developed.

Sarian (2008) do a research for job shop production system with no order changes from the customer (static). The company uses heterogeneous machines and the order has a certain due date. In this research, a scheduling model with...
total actual flow time as performance criteria is developed.

Herlina (2010) carries out a research for dynamic job shop production system with order changes including the addition of new part type. The company uses heterogeneous machines and the order has multi due dates. In this research, a scheduling model with total actual flow time as performance criteria is developed.

All of the previous models use backward scheduling. They do not consider the tools capacity of material handling by assuming that there is no machine breakdown and use single or heterogeneous machine instead of parallel machines.

The problem in our paper refers to the scheduling problems in Herlina (2010). Therefore, we use it as basic model and add some modification. The modification consists of the usage of parallel machines, tools capacity of material handling as an additional constraint, and the additional new part type of order is not allowed.

**Batch Scheduling**

Production of job is divided into several parts of batch. Determination of batch number and batch size influence the actual flow time (Halim, 1993). Equation (1) is a formula of actual flow time:

\[ FJ^d[J] = d - BJ[J], \quad i = 1, 2, ..., b \]  

Where \( d \) is the common due date, \( BJ[J] \) is the start time of processing job \( J \) with position- \( i \), and \( FJ^d[J] \) is the actual flow time of job \( J \).

It is assumed that the setup time, \( s \), is constant and not included to the processing time, \( p \), as shown in Eq. (1) derived from (Halim, 1993):

\[ FJ^d[J] = \left\{ \sum_{j=1}^{i} (pj + s) \right\} - s, \quad i = 1, 2, ..., b \]  

Where \( p \) is the processing time of job \( J \), \( s \) is the setup time, and \( FJ^d[J] \) is the actual flow time of job \( J \). If the processing time \( p \) is replaced with the batch processing time, then the actual flow time \( L[i] \) is formulated in Eq. (3).

\[ FJ^d[J] = \sum_{j=1}^{i} (Qj[j] + s) - s, \quad i = 1, 2, ..., N \]  

Where \( Qj[j] \) is the notation for number of part that can be found on the batch \( L[i] \) position- \( i \), \( s \) is the setup time, \( t \) is the processing time, and \( N \) is the number of batch.

Total actual flow time for one part on batch \( L[i] \) is showed in Eq. (4).

\[ FJ^d[J] = \left\{ \sum_{j=1}^{i} (Qj[j] + s) \right\} - s, \quad i = 1, 2, ..., N \]  

Total actual flow time for every part is showed in Eq. (5).

\[ F^d = \sum_{i=1}^{N} \left\{ \sum_{j=1}^{i} (Qj[j] + s[j]) - si \right\} * Qj[j] \]  

**II Problem Formulation**

**Characteristics of Production System**

(1) The system consists of multiple stages with job shop and batch production system.

(2) Group of machines that are used are parallel machines.

(3) Transportation time of part is counted and depend on to the distance between machines.

(4) Processing time and setup time are fixed.

(5) Setup times are different for each part and each machine.

(6) Operation cannot be executed on more than one machine.

(7) Number of baskets on production floor is \( n - 1 \) (\( n \) is number of machines).

**Characteristics of Customer Order**

(1) Initial order is given by customer once a month

(2) Multi due dates and multi-parts are sent to the customer every Monday, Wednesday, Friday

(3) Multi parts: Total parts are 36 parts type, with 12-15 part types of order for every due date.

(4) Dynamic: customer is possible to change the amount of order or the due date.

**Parameter**

\( n_t \) = demand part \( i, i = 1, 2, ..., I \)

\( d_i \) = due date part \( i, i = 1, 2, ..., I \)

\( s_{im} \) = setup time at machine \( m \) before batch processing that contains part \( i, m = 1, 2, ..., M, i = 1, 2, ..., I \)

\( t_{ijk} \) = processing time of part \( i \) in operation \( j \) at workstation \( k \) using machine \( m \)

\( u \) = index for batch position, \( u = 1, 2, ..., N \)

**Decision Variable**

\( N_t \) = number of batch from part \( i, i = 1, 2, ..., I \)

\( Y_{mk}[u] \) = binary variable for the selection of machine \( m \) from work station \( k \) operation \( j \) and batch at position- \( u \)

\( Y_{mk}[u] = \)

\[ \begin{cases} 
1, & \text{if part } i \text{ is processed at machine } m \text{ from work station } k \\
0, & \text{if otherwise} 
\end{cases} \]

\( Q_{i[u]} \) = size of batch from part \( i \) that scheduled at position- \( u \) from due date (using backward scheduling)

\( B_{ijkm}[u] \) = starting time of batch production for part \( i \) on operation \( j \) at machine \( m \) and workstation \( k \) in the position- \( u \) from due date

**Model formulation**

Equation (6) explains the objective function. Objective function of this model is to minimize the total actual flow time.

\[ \min \ T = \sum_{j=1}^{I} \sum_{m=1}^{M} \sum_{n=1}^{N} (d_i - B_{ijkm}[u]) Q_{i[u]} \]  

Equation (7) defines the balance of material where the number of part produced for every part is equal to the number of that items.

\[ S.t.: \sum_{i=1}^{I} Q_{i[u]} = n_t \quad \forall i = 1, 2, ..., I \]  

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Equation (8) describes the start time of batch from the first operation for every part \(i\) in every work station and every machine (\(B_{i[i,u]}\)) at the time or after the starting point.

\[
B_{i[i,u]} \geq D_i \quad \forall i = 1,2,\ldots,I
\]  

Equation (9) explains the batch processing on a certain operation (\(B_{ijkm[u]}\)) that can be done if batch processing from the previous operation is completed.

\[
C_{ij[j-1]km[u]} - B_{ijkm[u]} \leq 0, \quad \forall i, j, k, m, u
\]  

Equation (10) shows that batch processing must be done immediately after the previous batch is completed.

\[
B_{ijkm[u]} \leq B_{ijkm[u-1]} - ((\sum_{k=1}^{K} \sum_{m=1}^{M} Y_{ijkm[u]} \times t_{ijk}) \times Q_{ij[u]}) - S_{im} \quad \forall i, j, k, m, u
\]  

Equation (11) describes that the last position for every part of batch on position-\(u\) must be completed strictly on the due date.

\[
B_{ij[u]} = d_i - (Q_{ij[u]} \times t_{ijkm}) \quad \forall i
\]  

Equation (12) explains the finish time of batch if there is still another batch to be scheduled on the same work station and machine.

\[
Z_{km} = \sum_{k=1}^{K} \sum_{m=1}^{M} Y_{ijkm[u]} D_{ijkm[u]} - s_i \quad \forall k, m
\]  

Equation (13) defines the value selection for finishing time of a batch if there is another batch to be scheduled on the same work station and machine.

\[
z_{km} = \begin{cases} \infty & \text{for } z_{km} < 0 \\ z_{km} & \text{for } z_{km} \geq 0 \end{cases}
\]  

Equation (14) describes batch on position-\(u\) at a stage that cannot be processed on more than one machine.

\[
\sum_{k=1}^{K} \sum_{m=1}^{M} Y_{ijkm[u]} = 1; \quad \forall j, u
\]  

Equation (15) explains the binary of decision variable for machine selection, 1 while selected, otherwise 0.

\[
Y_{ijkm[u]} = 0,1 \quad \forall j, i
\]  

Equation (16) shows that the size of batch must be positive.

\[
Q_{ij[u]} > 0
\]  

Equation (17) shows that the number of batch must be an integer.

\[
N_i \geq 1, \text{ integer}
\]  

According to Herlina (2010), the formulation of mathematical model above is too complex because of so many decision variables. Therefore, a heuristic approach has to be made to simplify the model. The heuristic approach for this model consists of three algorithms.

(1) Determination Number of Batch and Size of Batch Algorithm

(2) Static Batch Job Shop Scheduling Algorithm

(3) Dynamic Batch Job Shop Scheduling Algorithm

**First Algorithm: Determination Number of Batch and Size of Batch Algorithm**

Notations for the Determination Number of Batch and Size of Batch Algorithm:

(1) \(a\) = index sequence of part type, \(\alpha = 1,2,\ldots,A\)

(2) \(KM_a\) = set from work station and machine that is used for processing sequence of part type \(a\), \(\alpha = 1,2,\ldots,A\).

(3) \(F_a^a\) = flow time of sequence part \(a\), \(\alpha = 1,2,\ldots,A\)

(4) \(o\) = work station and machine that is a member of \(KM_a\)

(5) \(Q_{ake_m[u]}\) = size of batch from sequence part \(a\) at work station \(k\) machine \(m\) on position \(u\), \(\alpha = 1,2,\ldots,A\)

(6) \(F_{a0Va}\) = flow time at \(N_0\), \(\alpha = 1,2,\ldots,A\)

(7) \(F_{aVa}\) = flow time at \(N_a\), \(\alpha = 1,2,\ldots,A\)

(8) \(n_i\) = demand from part \(i\), \(i = 1,2,\ldots,I\)

(9) \(N_i\) = number of batch from part \(i\), \(i = 1,2,\ldots,I\)

(10) \(p_m\) = machine productivity, namely number of part that can be processed from \(m\) per time unit. \(p_m = \frac{1}{t_{ijkm}}, m = 1,2,\ldots,M, i = 1,2,\ldots,I, j = 1,2,\ldots,J, k = 1,2,\ldots,K\)

(11) \(s_m\) = setup time of machine \(m, m = 1,2,\ldots,M\)

(12) \(u\) = index for batch position, \(u = 1,2,\ldots,N\)

The procedure of Determination Number of Batch and Size of Batch Algorithm is given as follows:

Step 1: Determine work station and machine \(KM_a\), namely set from work station and machines that is used for processing part \(a\).

Step 2: Set \(N_a = 1\) and \(Q_a = n_a\)

Step 3: Schedule the operations backwardly at sequence part \(a\) at every work stations and machine member \(KM_a\) appropriate with routing operation. On this step, the selected machine is the one that has the shortest processing time. Compute \(F_{a0Va}\).

Step 4: Based on routing seto = first work station and machine that is member of \(KM_a\), use setup time and process time from that machine as a parameter.

Step 5: Divide batch for part \(a\) gradually, set \(N_a = 2\).

Step 6: On every machine and for batch \(u = 1\) until \(N_a\) compute size of batch \(Q_{ake_m[u]}\) using formula

\[
Q_{ake_m[u]} = \frac{(n_a/N_a) + (p_m/s_m)(N_a + 1)/2 - (p_m/s_m)\times u}{N_a}
\]

Step 7: Is \(Q_{ake_m[u]} > 0\)?

If yes, continue to Step 8.

If no, continue to Step 9.

Step 8: Compute \(F_{aVa}\) for every machine, select minimum \(F_{aVa}\).

Step 9: Is \(F_{aVa}\) selected < \(F_{aVa-1}\)?

If yes, continue to Step 10.

If no, set \(N_a(opp) = N_a - 1\). Get the value of decision variable \(Q_{ake_m[u]}\) on that work station and schedule
backwardly operations part $a$ at every work stations and machines member $K_{M_a}$ suitable to its routing. Compute $F_{ab}^{a}$, Continue to Step 11.

Step 10: Set $N_0 = N_a + 1$, and back to Step 6.

Step 11: Set $o = $ work station and machine that is member of $K_{M_o}$, use set up time and process time from that machine as parameter.

If $o$ is last work station, then Stop.

If $o$ is not last work station, back to Step 5.

Step 12: Choose the best solution for part $a$, namely solution with minimum value of $F_{ab}^{a}$ from several alternative of solutions and get every value of decision variable $\left( N_a \text{ and } Q_{ab}^{a} \right)$.


Second Algorithm: Static Batch Job Shop Scheduling Algorithm

This algorithm is used to determine schedule for initial order, namely order that is received firstly from the customer. The algorithm contains two functions, i.e. to determine number of batch and size of batch and to determine sequence of batch processing. The first function is shown by "Determination Number of Batch and Size of Batch" Algorithm and second function is shown by "Batch Job Shop (BJS) Scheduling Algorithm With Heterogeneous Machines".

These are the procedures of Static Batch Job Shop Scheduling Algorithm

Step 1: Sort parts based on due date, start with last due date. State part on v sequence, where $v = 1, 2, ..., V$

Step 2: Set $v = 1$

Step 3: Specify the number of batch and size of batch with Determination Number of Batch and Size of Batch Algorithm

Step 4: Set $v = v + 1$

If $v \leq V$ then back to Step 3.

If $v > V$ then Stop. Get the number of batch and size of batch that selected for every part $v$

Step 5: Do scheduling with Batch Job Shop (BJS) Scheduling Algorithm With Heterogeneous Machines

Step 6: Finish

Batch Job Shop (BJS) Scheduling Algorithm with Heterogeneous Machines

This algorithm is used after "Determination Number of Batch and Size of Batch" Algorithm. The function of this algorithm is to determine the sequence of batch processing for all parts. Notations that are used in Batch Job Shop (BJS) Scheduling Algorithm with Heterogeneous Machines namely:

$t = $ stage

$PS_t = $ set that contains batch processes scheduled on stage $t$

$S_t = $ set that contains batch processes that can be scheduled on stage $t$

$\delta_j = $ last time process $j$ can be done, with $\delta_j = 0^* - s$

$\theta_j = $ last time process $j$ can be began.

Following is procedure of Batch Job Shop (BJS) Scheduling Algorithm with Heterogeneous Machines

Step 1: Initialization $t = 0, PS_t = 0$, and $S_t$ is set that contains all processes that not have successor, namely last process on every batch $(j\mu)$. Set the latest value from last process every batch on every machine equal to due date from certain due date. $(\delta_{j\mu} = d)$ and $\theta_{j\mu} = \delta_{j\mu} - P_{j\mu}$

Step 2: Do backward pass to get the latest finish and the latest start value for every process on set $S_t$. Stack every process $j$ member $S_t$, begin at $\theta_j$ and finish at $\delta_j$

Step 3: Specify the position of work station and machine that can produce the latest start value for every batch $\theta_{j\mu} = max_{j\mu \in S_t} \{ \theta_j \}$. Specify $\theta^* = max_{j\mu \in S_t} \{ \theta_j \}$, work station $k^*$, and machine $m^*$, where $\theta^*$ must be done.

If $\theta^*$ can be found on several batches with different position $k^*$ and $m^*$, then specify one of the batch randomly. Based on routing, seto = first work station and machine that member of $K_{M_e}$, use setup time and process time from that machine as parameter. If $\theta^*$ can be found on several batches with same position $k^*$ and $m^*$ then:

- Compute actual flow time from that batch by putting one batch first and another batch after, both at same or different machine.

b. Schedule batch with the lower total actual flow time value.

Step 4: For every partial schedule that formed on Step 3, do:

- Discard selected $j$ batch process on Step 3 from $S_t$

b. Form $S_{t+1}$ by adding directly the predecessor $j$ batch process that is selected on $S_{t+1}$

Step 5: Increase $t: t = t + 1$. If $S_t = 0$, then stop; If not then back to Step 2 for every $PS_{t+1}$ that formed on Step 3 and continue until the schedule is accomplished.

Step 6: Finish

Third Algorithm: Dynamic Batch Job Shop (BJS) Scheduling Algorithm

This algorithm is used when customer makes change of order, either the change of order number or the change of order due date. The algorithm accommodates to add a new part type. For example, customer make an initial order for four parts type, namely part A, part B, part C, and part D. And in the middle of production period, the customer make an order of new part named part E.

Notations that used in Dynamic Batch Job Shop (BJS) Scheduling Algorithm are:

$S = $ initial schedule

$P = $ group of operations at start point and end point

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$S' = \text{new schedule}$  
$x = \text{index of operation sequence, } x = 1, 2, ..., y$  
$a = \text{sequence index of new order set according to sequence of due date with sort descending, } a = 1, 2, ..., A$  
$(T_{av})_m = \text{juncture when machine } m \text{ is available to do the next operation.}$  
$\theta_{a jkm} = \text{start time operation } j \text{ from batch part } a \text{ at work station } k \text{ machine } m$  
$T_1 = \text{new order received}$  
$T_2 = \text{new order rejected}$  

These are the procedure of Dynamic Batch Job Shop (BJS) Scheduling Algorithm  
Input: Initial schedule $S$, initial start, new order. Initial start is the time when new order comes.  
Step 1: Specify start point namely last completion time between operations, where the processing time is passed by the initial start.  
Step 2: Specify end point namely in which new order must be sent (due date of new order)  
Step 3: Specify $P$ is group of operations at start point and end point.  
Step 4: Operation on $P$ that set as new scheduling problem $S'$.  
Step 5: Specify number of new order and due date for each order. Sort new order with descending and give index $\alpha = 1, 2, ..., A$.  
Step 6: Set $a = 1$  
Step 7: Make separate schedule for new order with Static Batch Job Shop (BJS) Scheduling Algorithm  
Step 8: Combine the new schedule with previous schedule  
Step 9: Investigate schedule that produced on step 7 for every operation of batch part $a$ and operation batch part $a + 1$. Give index $x = 1, 2, ..., y$.  
Step 10: Set $x = 1$  
Step 11: Is schedule operation can be found on certain $t$?  
If yes, continue to Step 12.  
If no, schedule operation $j$ from batch part $a$ at work station $k$ machine $m$. Save start time that operation and state as $\theta_{a jkm}$. Continue to Step 14.  
Step 12:  
a) If operation that is scheduled is the last operation of batch part $a$, then proceed the operation for batch part $a + 1$ after last operation of batch part $a$ finishes or being moved to another machine. Choose position that produces the minimum total actual flow time.  
b) If operation that is scheduled is not the last operation, do insertion on possible position for operation $j$ or move one of operation $j$ to another machine. Choose position that produces the minimum total actual flow time.  
Note: insertion cannot be done between batch operations from same part  
Step 13: Schedule operation $j$ from batch part $a$ at work station $k$ machine $m$. Save start time that operation and state as $\theta_{a jkm}$  
Step 14: Set $x = x + 1$  
If $x \leq y$, back to Step 11.  
If $x > y$, continue to Step 15.  
Step 15: Evaluate value of $(T_{av})_m$ at every machine. Is $(T_{av})_m$ violated?  
If yes then reject new order.  
If no continue to Step 16.  
Step 16: Is $\theta_{a jkm} \geq \text{start point}$?  
If no then reject new order  
If yes than combine the schedule on every machine to form $S_{last}$  
Step 17: Set $a = a + 1$  
If $a \leq A$, back to Step 7.  
If $a > A$, continue to Step 18.  
Step 18: Classified new order received on $T_1$ and new order rejected on $T_2$. Display $S_{last}$.  
Note: $(T_{av})_m$ can be evaluated by checking machine availability at the time needed.

Scheduling Model Modification

The company on this research has parallel machines and uses basket as tool of material handling on its production activity. Also, the customer of the company is not allowed to add new type of part, while order changes are possible to be requested.  
It is different with condition on scheduling model Herlina (2010) where the model uses heterogeneous machines, do not consider the tool, and customer can add new type of part during production period. It is necessary to modify the model so that suitable with the real condition. Here is the explanation of the modification.

(1) Modification to Determination Number of Batch and Size of Batch Algorithm

Algorithm of Herlina (2010) does not consider tools of material handling. Subsequently, the production process cannot run smoothly because size of batch exceeds the tools capacity.  
Company in our research uses the tools on its production activity. It is assumed that the tools have limited capacity. Consequently, size of batch should not exceed tools capacity. The number of initial batch is stated with demand divided by the tools capacity.  
It is assumed that number of basket is $n-1$ where $n$ is number of machines on production floor. In order to approach the real condition, transportation time of part should be counted and combine with setup time and processing time.  
Figure 1 shows the illustration basket usage between machines

A and C are machines and B is basket to translocate the part. Every machine has setup time and processing time to process the part. And there is an additional time to fill the basket and to translocate the part to next machine. After the basket is moved to next machine, the operator must bring it back to early machine.
(2) Modification to Static Batch Job Shop Scheduling Algorithm
Scheduling model Herlina (2010) assume that company has heterogeneous machines. While company of this research uses parallel machines. Parallel machines affects the rule of machine selection becomes easier because the machine can be selected randomly. "Static Batch Job Shop Scheduling Algorithm" can also accommodate the parallel machines. Therefore, it is no need to modify the algorithm.

(3) Modification to Dynamic Batch Job Shop (BJS) Scheduling Algorithm
Customer has fixed number type of part order. While scheduling model in Herlina (2010) assume that customer can make order changes with addition new type of part. This research assume that order changes only consists of change of due date or change of order number.

The company starts their production activity two days before due date. Here is the proposal of production schedule

<table>
<thead>
<tr>
<th>Table 1 Proposal of Production Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Due Date</td>
</tr>
<tr>
<td>Monday</td>
</tr>
<tr>
<td>Wednesday</td>
</tr>
<tr>
<td>Friday</td>
</tr>
</tbody>
</table>

This proposal is not accommodated on "Static Batch Job Shop (BJS) Scheduling" and "Dynamic Batch Job Shop (BJS) Scheduling" Algorithms. Consequently, the rule to decide status of order changes is not clear. Status of order changes consists of order changes accepted or order changes rejected.

We then develop the following procedures to decide the status of order changes.

(1) Do production activity.
(2) Is there any order changes?
   If yes, go to Step 3.
   If no, go to Step 7.
(3) Is order for one due date ahead?
   If yes, reject order changes and go to Step 7.
   If no, go to Step 4.
(4) Check production capacity on two days before due date. Is the capacity is sufficient?
   If yes, accept order changes and go to Step 7.
   If no, go to Step 5.
(5) Check production capacity on previous day. Is the capacity is sufficient?
   If yes, accept order changes and go to Step 7.
   If no, go to Step 6.
(6) Do overtime and check financial condition. Is there any profit?
   If yes, accept order changes and go to Step 7.
   If no, reject order changes and go to Step 7.
(7) Finish

For example, customer make order changes on Monday for due date on Friday. Based on the proposed algorithm, we must first check the production capacity on Wednesday and Thursday. If the capacity is not sufficient, we then check the capacity on Wednesday. Overtime is possible to be done if the capacity on Wednesday is still not sufficient and if company still has more profit considering the overtime cost. The company uses many machines so it is possible for machine breakdown event during the production period. Below is procedure to deal with machine breakdown.

(1) Check machine availability. Is all of the machines in use?
   If no, move batch operation part to available machine and go to Step 5.
   If yes, go to Step 2.
(2) Move batch operation of part to next due date.
(3) Use Dynamic Batch Job Shop Scheduling Algorithm.
(4) Negotiate with customer.
(5) Finish.

Data Collection
In this research, there are five types of data to collect, namely:

(1) Type of part
(2) Demand and due date for every part
(3) Process and machine routing for every part
(4) Processing time and setup time
(5) Number of machines on production floor

Table 2 until Table 7 show the five types of data respectively.

<table>
<thead>
<tr>
<th>Table 2 Demand and Due Date for Each Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
Table 2 describes customer order on July 2012. The table only captures three of thirteen due dates and five of thirty-six parts.

Table 3 Processing Time

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Time (Second)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Spring seat STP</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>R brake hose bracket comp</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Damper cap 101</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Bump stopper comp (RR SMUV)</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Bump stopper comp CRV 10</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 4 Setup Time

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Time (Second)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Spring seat STP</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>R brake hose bracket comp</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>Damper cap 101</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>Bump stopper comp (RR SMUV)</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>Bump stopper comp CRV 10</td>
<td>600</td>
</tr>
</tbody>
</table>

Table 5 Process Routing

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Process Routing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spring seat STP</td>
<td>Blanking + Drawing, Restrike, Trimming + Piercing</td>
</tr>
<tr>
<td>2</td>
<td>R brake hose bracket comp</td>
<td>Blanking + Piercing, Bending</td>
</tr>
<tr>
<td>3</td>
<td>Damper cap 101</td>
<td>Forming 1, Forming II</td>
</tr>
<tr>
<td>4</td>
<td>Bump stopper comp (RR SMUV)</td>
<td>Blanking + Drawing, Drawing 2, Forming + Restrike, Piercing</td>
</tr>
<tr>
<td>5</td>
<td>Bump stopper comp CRV 10</td>
<td>Blanking + Drawing, Drawing 2, Forming + Restrike, Piercing</td>
</tr>
</tbody>
</table>

Table 6 Machine Routing

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Machine Routing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Spring seat STP</td>
<td>M5</td>
</tr>
<tr>
<td>2</td>
<td>R brake hose bracket comp</td>
<td>M3</td>
</tr>
<tr>
<td>3</td>
<td>Damper cap 101</td>
<td>M3</td>
</tr>
<tr>
<td>4</td>
<td>Bump stopper comp (RR SMUV)</td>
<td>M5</td>
</tr>
<tr>
<td>5</td>
<td>Bump stopper comp CRV 10</td>
<td>M5</td>
</tr>
</tbody>
</table>

Each part has different processing time, setup time, process routing and machine routing.

Table 7 Number of Machines

<table>
<thead>
<tr>
<th>Machine</th>
<th>Number of Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>7</td>
</tr>
<tr>
<td>M3</td>
<td>8</td>
</tr>
<tr>
<td>M5</td>
<td>8</td>
</tr>
<tr>
<td>M6</td>
<td>1</td>
</tr>
<tr>
<td>M7</td>
<td>2</td>
</tr>
<tr>
<td>M8</td>
<td>6</td>
</tr>
<tr>
<td>M9</td>
<td>2</td>
</tr>
<tr>
<td>M13</td>
<td>2</td>
</tr>
</tbody>
</table>

III Solution

Software with Visual Basic Application language on Microsoft Excel has been made in order to easier the scheduling process. The function of this software is to make month scheduling for initial order and to make rescheduling when order changes occur. Table 8 shows the total actual flow time for every due date.

Table 8 Total Actual Flow Time Every Due Date

<table>
<thead>
<tr>
<th>Due Date</th>
<th>(seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Jul-12</td>
<td>194,613,461</td>
</tr>
<tr>
<td>4-Jul-12</td>
<td>184,625,624</td>
</tr>
<tr>
<td>6-Jul-12</td>
<td>203,514,621</td>
</tr>
<tr>
<td>9-Jul-12</td>
<td>225,416,614</td>
</tr>
<tr>
<td>11-Jul-12</td>
<td>214,462,752</td>
</tr>
<tr>
<td>13-Jul-12</td>
<td>194,652,672</td>
</tr>
<tr>
<td>16-Jul-12</td>
<td>184,641,367</td>
</tr>
<tr>
<td>18-Jul-12</td>
<td>204,626,257</td>
</tr>
<tr>
<td>20-Jul-12</td>
<td>194,615,641</td>
</tr>
<tr>
<td>23-Jul-12</td>
<td>201,543,627</td>
</tr>
<tr>
<td>25-Jul-12</td>
<td>212,645,636</td>
</tr>
<tr>
<td>27-Jul-12</td>
<td>184,546,256</td>
</tr>
<tr>
<td>30-Jul-12</td>
<td>231,421,102</td>
</tr>
</tbody>
</table>

The result shows that all due date are fulfilled. Moreover, two days before the due date are enough to satisfy the target of part order on every due date. Model's purpose is to minimize total actual flow time as the performance criteria so that can minimize both work in process and finish goods on a production floor.

Dynamic Batch Job Shop (BJS) Scheduling Algorithm and Procedure to "Decide Status of Order Changes" are used when order changes occurs. Table 9 shows the six scenarios that are generated to test the dynamism of this algorithm.
Table 9 Six Scenarios of Order Changes

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Order Changes Received</th>
<th>Due Date</th>
<th>Initial Number of Order</th>
<th>New Number of Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R brake hose bracket</td>
<td>2-Jul</td>
<td>4-Jul</td>
<td>300 unit</td>
<td>600 unit</td>
</tr>
<tr>
<td>2</td>
<td>Bump stopper comp RR</td>
<td>2-Jul</td>
<td>6-Jul</td>
<td>120 unit</td>
<td>240 unit</td>
</tr>
<tr>
<td>3</td>
<td>Bump stopper comp RR</td>
<td>2-Jul</td>
<td>6-Jul</td>
<td>120 unit</td>
<td>800 unit</td>
</tr>
<tr>
<td>4</td>
<td>Bump stopper comp LRV</td>
<td>3-Jul</td>
<td>6-Jul</td>
<td>60 unit</td>
<td>360 unit</td>
</tr>
<tr>
<td>5</td>
<td>Spring seat STP</td>
<td>3-Jul</td>
<td>6-Jul</td>
<td>90 unit</td>
<td>180 unit</td>
</tr>
<tr>
<td>6</td>
<td>Damper cap 101</td>
<td>7-Jul</td>
<td>13-Jul</td>
<td>270 unit</td>
<td>360 unit</td>
</tr>
</tbody>
</table>

(1) Scenario 1
Customer makes change of order number for one due date ahead. This change is received on Monday for due date on Wednesday on the same week.

(2) Scenario 2
Customer makes change of order number for two due dates ahead. This change is received on Monday for due date on Friday on the same week.

(3) Scenario 3
Customer makes change of order number for two due dates ahead. This change is received on Monday for due date on Friday on the same week.

(4) Scenario 4
Customer makes change of order number for two due dates ahead. This change is received on Monday for due date on Friday on the same week.

(5) Scenario 5
Customer makes change of order number twice for same part and same due date. First, company receives this order changes on Monday for due date on Friday. Second, company receives order changes on Tuesday for due date on Friday.

(6) Scenario 6
Customer makes change of order number for three due dates ahead. This order changes are received on Saturday for due date on Friday next week.

The second until fourth scenario seem similar but they have some differences. The differences lay on number of part order and type of part order. Those scenarios give different result. Table 10 shows result of "Dynamic Batch Job Shop (BJJ) Scheduling Algorithm and Procedure to Decide Status of Order Changes" for every scenario.

Here are some brief explanations for decision of every scenario.

Scenario 1
Company must reject order changes from customer because the change of production schedule can make on going production process becomes untidy.

Scenario 2
Company can accept order changes from customer because the change of production schedule is still possible and all of part order on Friday can be done on Wednesday and Thursday.

Table 10 Decision for Every Scenario

<table>
<thead>
<tr>
<th>No</th>
<th>Result</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Order changes rejected</td>
<td>Order changes are rejected because the production activity is on.</td>
</tr>
<tr>
<td>2</td>
<td>Order changes accepted</td>
<td>Order changes are accepted and can be done on two days, namely Wednesday and Thursday.</td>
</tr>
<tr>
<td>3</td>
<td>Order changes accepted</td>
<td>Order changes are accepted although its cannot be done on two days. Half of production process can be moved on previous day, namely Tuesday.</td>
</tr>
<tr>
<td>4</td>
<td>Production capacity is full, need overtime.</td>
<td>Order processing cannot be done on two days. Half of production process cannot be moved to previous day.</td>
</tr>
<tr>
<td>5</td>
<td>Order changes accepted</td>
<td>Order changes are accepted and can be done on two days, Wednesday and Thursday.</td>
</tr>
<tr>
<td>6</td>
<td>Order changes accepted</td>
<td>Order changes are accepted and can be done on two days, Wednesday and Thursday.</td>
</tr>
</tbody>
</table>

Table 11 Production schedule on machine no.5 on Thursday

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Quantity</th>
<th>Start Time</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>120</td>
<td>5.63</td>
<td>5.28</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>180</td>
<td>5.13</td>
<td>6.06</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>280</td>
<td>6.47</td>
<td>7.16</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>220</td>
<td>7.92</td>
<td>8.45</td>
</tr>
</tbody>
</table>

Table 11 above informs production schedule on machine no.5 on Thursday. The starting time and finishing time are stated with actual time, where company start to produce at 7.00 and finish at 16.00. Part A and Part B need extra time because the production time on that day is not enough. Therefore, the production schedule on previous day must be checked.

Table 12 Production Schedule on Machine 5 on Wednesday

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Quantity</th>
<th>Start Time</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>144</td>
<td>11.78</td>
<td>12.47</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>40</td>
<td>12.86</td>
<td>13.17</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>244</td>
<td>13.36</td>
<td>14.34</td>
</tr>
</tbody>
</table>

Table 12 informs the production schedule on machine 5 on Wednesday. Based on that schedule, machine 5 is used until 14.34. So, it still have time until 16.00 and some production process (Part A and Part B) on Thursday can be translocated to this day.

Scenario 4
There is another condition on production schedule. Table 13 informs the production schedule on machine no.3 on Thursday. Part A and Part B need extra time because production time on that day is not enough. So production schedule on previous day must be checked.
Table 13 Production schedule on machine no.3 on Thursday

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Quantity</th>
<th>Start Time</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>156</td>
<td>4.32</td>
<td>5.55</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>78</td>
<td>6.98</td>
<td>7.32</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>96</td>
<td>7.56</td>
<td>8.02</td>
</tr>
<tr>
<td>4</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table 14 Production Schedule on Machine 3 on Wednesday

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Quantity</th>
<th>Start Time</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>150</td>
<td>14.06</td>
<td>14.64</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>142</td>
<td>14.8</td>
<td>15.44</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>142</td>
<td>15.44</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 14 above informs production schedule on machine 3 on Wednesday. Based on that schedule, machine 3 is used until 16:00. So, it’s has not extra time and some production process (Part A and Part B) on Thursday can’t be transferred to this day.

Scenario 5
Company can accept order changes from customer because the change of production schedule is still possible and all of part order on Friday can be done on Wednesday and Thursday.

Scenario 6
Company can accept order changes from customer because the change of production schedule is still possible and all of part order on Friday can be done on Wednesday and Thursday.

The above scenarios are to examine dinamism of the algorithm. It is interesting to know the relationship between replenishment order and replenishment number of batch. The following table shows that relationship.

Table 15 Relationship between replenishment order and replenishment number of batch

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Number of Order</th>
<th>Number of Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>240</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>260</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>270</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>280</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>290</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>150</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>160</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>170</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>190</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>210</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 15 shows the replenishment order for two parts, namely part A and part B. Part A has three batches with order number 240 until 290. For order number 240, the algorithm results on three batches with each size of batch is 140, 80, and 20. For number of order 250, the algorithm results on three batches with each size of batch is 144, 83, and 23.

On the other hand, Part B has two batches with order number 120 until 200. For number of order 120, the algorithm results on two batches with each size of batch is 90 and 30. For order number 130, the algorithm results on two batches with each size of batch is 95 and 35.

From this experiment, we conclude that replenishment order will be divided evenly to every batch until some number of order. When the algorithm will not be divided evenly again, then it will make new batch.

IV Analysis

The output of this scheduling model is to determine number of batch and size of batch first in order to minimize total actual flow time. Normally, batch size is produced with decline size. For example, 100 unit parts can be divided into four batches, respectively 40 units, 30 units, 20 units, and 10 units.

The operator on a production division uses basket as tools of material handling. Scheduling model of Herlina (2010) has been modified so that size of batch will not exceed the tools capacity.

In order to approach real condition, scheduling model must consider transportation time between machines. Therefore, this proposed model has three types of time, namely setup time, processing time, and transportation time.

A very small size of batch can make the operator work improperly. In most cases, operator will combine that batch with another batch for the same part. This action can make the total actual flow time on floor becomes different from the total actual flow time on the scheduled model.

In this case, the supervisor shall do the routine inspection to ensure that the production matches with the number of batch and size of batch optimal.

The more number of batch that is produced impacts on the more setup machine. Setup machine is the activity to set dies that are suitable for production process. In order to setup machine in a proper way, the operator must locate dies neatly.

Production division can provide a particular cabinets to store dies. On that cabinets, dies is stored and classified by its function so that the operator can take it easier. For example, dies for cutting and dies for trimming is located separately. The proposed scheduling model sets the total actual flow time as the performance criteria. Three important parameters that influence the value of total actual flow time are:
(1) Number of order part
The more number of order part to be processed on the production floor will increase the total actual flow time.

(2) Number of part process
Part with more number of processes is likely to have a higher total actual flow time than part with less number of process.

(3) Total processing time of one part
Part with longer total processing time has a higher total actual flow time than part with shorter total processing time.

V Conclusion

The conclusions for our research are:

(1) Scheduling model concept of Herlina (2010) is adopted to minimize the tardiness and earliness on a job shop production system, with batch production, parallel machine, multi due date, multi part, and dynamic order.

(2) The model is based on a heuristic approach and consists of three algorithms, namely a) determination number of batch and size of batch algorithm, b) static batch job shop scheduling algorithm, and c) dynamic batch job shop scheduling algorithm.

(3) This research observes a company with deterministic of due date. The company has to send the order three times a week while work day of that company is six days a week and eight hours a day. The proposal of scheduling improvement is to start production activity two days before due date.

(4) The model is modified in order to accommodate the limited capacity of material handling, using parallel machines, and no new type part of order changes. Moreover, there are two addition or modified procedures, namely procedure to decide status of order changes and procedure to deal with breakdown machine.

(5) From the scenario, we conclude that rescheduling has to consider the starting time, machine availability, and due date in order to know the acceptance/rejection decision of the order changes.

References


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