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Dynamic Batch Scheduling for Fabrication and Assembly of Common and Multiple Unique Components in a Four Machine Flow Shop

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Abstract. *This research has developed a batch scheduling for fabrication and assembly scheduling in a dynamic flow shop with 4-machine processing multiple items with multiple due dates to minimize the total actual flow time. Each item comprises one unit of a common component and a number of multiple unique-components each of which consists of one unit. A common component is a similar component for all items and a unique component is a specific component for each item. The fabrication process of both components is conducted on the first three machines and the assembly process is conducted on the fourth machine. The common components and the unique components are fabricated in batches for the same unique component, and the assembly process is also performed in batches for the same items. The dynamic condition in this model means that new orders may arrive at any time over the planning horizon. The new order arrivals are accommodated by totally rescheduling the initial schedule. The proposed algorithm consists of two algorithms: (1) the static algorithm determining the number of batches, batch sizes and the schedule, and (2) the dynamic algorithm dealing with arrivals of the new jobs. Numerical experiments show that the proposed algorithm is appropriate to solve such problems.*

Keywords: *batch scheduling, common component, multi unique-component, multi-due date, dynamic, actual flow time.*

1. INTRODUCTION

One of the objectives of the so called just in time production system is to produce the right product at the right times in the right quantities. In achieving the objective, the production system integrates inventory and scheduling problems, i.e., simultaneously minimizing inventory and delivering the order at the due date. Batch scheduling models that accommodate the just in time concept have been studied by Halim and Ohta (1993, 1994) and Halim *et al*. (1994a, 1994b). The studies have proposed scheduling algorithms determining the number of batches, batch sizes and the schedule of processing the resulting batches of jobs required at due date. The models are to minimize the total actual flow time assuming that the jobs arrive at the shop floor when needed and the completed jobs are to be delivered to the consumers at their due date. Meanwhile, Halim and Barnali (1998) have studied a batch scheduling model for a dynamic flow shop processing multiple items.

The above models deal only with fabrication processes, but in reality there are assembly processes involved in a production activity. A model for scheduling fabrication and assembly of components in a two machine flow shop processing multiple items has been studied by Cheng and Wang (1999). In the model, each part consists of one unit of a common component and one unit of a unique component. A common component is a similar component for all items and a unique component is a specific component for each item. The fabrication of both common and unique components is conducted on the first machine. The common components are processed in batches with integer batch sizes, while the unique components are processed individually. The assembly is conducted on the second machine and could be performed if common and unique components have already been completed. The objective of the model is to minimize makespan.

Halim and Saleh (2004) have developed the model discussed in Cheng and Wang (1999) to accommodate the just in time concept by adopting the total actual flow time as the objective. Saleh and Zaini (2005) have modified the model in Halim and Saleh (2004) by adopting the objective of minimizing the maximum lateness instead of the total actual flow time, while Zaini and Saleh (2005) have replaced the objective of minimizing the total actual flow time by minimizing the number of tardy jobs. An extension to accommodate the case where a flow shop comprises 4 machines has been proposed by Saleh and Halim (2005). In the model, the first 3 machines are to perform fabrication of the common and unique components and the forth machine is to perform assembly. This model follows the model discussed in Chan dan Bedworth (1990) showing that a flexible manufacturing cell usually consists of 4 machines.

Furthermore, Halim and Yuniartha (2008) have extended the model in Halim and Saleh (2004) to be a model for a four machine flow shop processing multiple items with a common due date, where each item requires one common component and more than one unique components. Fabrication for the common components and the unique components, and the assemblies for the same item are performed in batches. However, this model has not accommodated a dynamic condition in the shop floor where jobs arrive in shop floor over times and must be delivered to the consumers at their different due dates.

Models discussing the dynamic condition have been studied in Halim and Barnali (1998) and Halim and Ras (2002). The model in Halim and Barnali (1998) deals only with fabrication processes and the rescheduling problem is solved by totally changing the initial schedule, and Halim dan Ras (2002) proposed the method of changing the initial schedule by adopting the insertion technique.

Accordingly, this paper deals with a problem for a four machine flow shop processing multiple items that must be delivered to the customers at their respective multiple due dates, and the customers' orders may arrive at any times over the planning horizon. Each item requires one unit of common component and more than one unique components, each of which consists of one unit. Fabrication is performed on the first three machines, and assembly is performed on the forth machine. The common components are fabricated in batches, the unique components are fabricated in batches for the same item, and the assemblies for the same item are also performed in batches.

2. FORMULATION

The following notation will be used in this paper

p : an index for item

P : the number of items

d : due date

G_p : the number of unique components of item p

$s_{c,k}$: the setup time for fabricating a batch consisting of common components on Machine k

$t_{c,k}$: the processing time for fabricating a unit of common components on Machine k

$s_{ugp,k}$: the setup time for fabricating a batch consisting of unique components of Item p on Machine k

$t_{ugp,k}$: the processing time for fabricating a unit of unique components of Item p on Machine k

s_{ap} : the setup time before assembling a batch of Item p

t_{ap} : the processing time of assembling a unit of Item p

H_h : time interval of two consecutive due dates with interval H_h (started from the due date backwardly)

N_{aph} : the number of batches of item p in Interval H_h

$Q_{aph,[i]}$: the size of batch of unique Component g of Item p sequenced in position i that processed in Interval H_h

N_{ch} : The number of batches of common components processed in Interval H_h

$Q_{ch[i]}$: the batch size of common components sequenced at Position i that processed in the Interval H_h

N_{ugph} : the number of batches of unique Component g of item p processed in Interval H_h

$Q_{ugph[i]}$: the size of batch of unique component g of item p sequenced at Position i that processed in Interval H_h

N_{aph} : the number of batches of items p processed in Interval H_h

n_{aph} : the number of items p processed in Interval H_h

n_{ch} : the number of common components processed Interval H_h

n_{ugph} : the number of unique Components g of Item p processed in Interval H_h

$B_{ch[i],k}$: the starting time of fabrication of a batch of common components sequenced in Position i on Machine k that processed in Interval H_h

$B_{ugph[i],k}$: the starting time of fabrication of a batch of unique Component g of Item p sequenced at Position i on Machine k that processed in Interval H_h

$B_{aph[i]}$: the starting time of assembly of a batch of Item p sequenced at Position i that processed in Interval H_h

Y_{ph} : 1 if in Interval H_h Item p is processed, or 0 if no Item p is processed in Interval H_h Item p

Supposed there is a company receives orders of n_{ap1},

$n_{ap2}, \ldots, n_{apr}$ different items that must be delivered at due date $d_1, d_2, \ldots, d_r$ respectively. Each item consists of 1 unit of common component (c) and a number (denoted by G_p) of unique components each of which consists of 1 unit. The item should be processed in a four machine flow shop where the first three machines perform fabrication of both components and the forth machine performs assembly after both components have been available. The processing time of a common component on Machine k is t_{ck} and setup time on Machine k before processing a batch consisting of common components is s_{ck}(k = 1, 2, 3). The processing time of unique Component g for Item p on Machine k and the setup times for a batch consisting of the unique components are t_{ugpk} and s_{ugpk}.

The decisions that should be made are: (1) how the distribution of items with their components to the processing period of H_h in so that each order in each duedate can be fulfilled, (2) how to batch the resulting distributions; i.e., how many batches with respective batch sizes for assemblies of complete items (N_{aph} with $Q_{aph[i]}$), for fabrication of common components (N_{ch} with $Q_{ch[i]}$) and unique components (N_{ugph} with $Q_{ugph[i]}$), and (3) how the schedules of the resulting batches in each of period H_h. The MIDS model to minimize total actual flow time can be formulated as follows.

Minimize

$$TF = \sum_{h=1}^{r}\sum_{i=1}^{N_{ch}}\left(d_h - B_{ch[i],1}\right)Q_{ch[i]} + \sum_{h=1}^{r}\sum_{p=1}^{P_h}\sum_{g=1}^{G_p}\sum_{i=1}^{N_{ugph}}\left(d_h - B_{ugph[i],1}\right)Q_{ugph[i]} + \sum_{a=1}^{r-1}\left\{\sum_{h=a+1}^{r}\left(W_{ch} - n_{ch}\right)\right\}\left(d_a - d_{a+1}\right) + \sum_{p=1}^{P}\sum_{g=1}^{G_p}\left[\sum_{a=1}^{r-1}\left\{\sum_{h=a+1}^{r}\left(W_{ugph} - n_{ugph}\right)\right\}\left(d_a - d_{a+1}\right)\right], \quad (1)$$

Subject to

$$\sum_{i=1}^{N_{ap\bullet}} Q_{ap\bullet[i]} Y_{p\bullet} = n_{ap\bullet}, \quad p = 1,2,3\ldots,P,$$

$$N_a = \sum_{p=1}^{P}\sum_{i=1}^{N_{ap\bullet}} Q_{ap\bullet[i]}, \quad (2)$$

$$\sum_{i=1}^{N_{c\bullet}} Q_{c\bullet[i]} = n_{c\bullet}, \quad (3)$$

$$n_{c\bullet} = \sum_{p=1}^{P_c} n_{ap\bullet}, \quad (4)$$

$$\sum_{i=1}^{N_{ugp\bullet}} Q_{ugp\bullet[i]} Y_{p\bullet} = n_{ugp\bullet}, \; g = 1,2,3\ldots,G_p, \quad p = 1,2,3\ldots,P, \quad (5)$$

$$\left(d_h - B_{ch[N_{ch}],1}\right) \le H_h, \quad h = 1,2,\ldots,r, \quad (6)$$

$$\sum_{h=a+1}^{r}\left(W_{ch} - n_{ch}\right) \ge 0, \; \sum_{h=a+1}^{r}\left(W_{ugph} - n_{ugph}\right) \ge 0, \quad a = 1,\ldots,r-1, \quad (7)$$

$$\sum_{h=1}^{r}\left(W_{ch} - n_{ch}\right) = 0, \; \sum_{h=1}^{r}\left(W_{ugph} - n_{ugph}\right) = 0, \quad (8)$$

$$B_{azh[1]} + t_{azh}Q_{azh[1]} = d_h, \quad z \in \{1,2,\ldots,P\}, \quad (9)$$

$$B_{az'h[1]} = B_{az''h[N_{z''h}]} - t_{az'h}Q_{az'h[1]} - s_{az''}, \quad z \ne z' \ne z'', \quad z, z', z'' \in \{1,2,\ldots,P\}, \quad (10)$$

$$B_{aph[i]} = B_{aph[i=1]} - t_{ap}Q_{aph[i]} - s_{ap}, \quad p \ne z \ne z'', \quad p, z, z', z'' \in \{1,2,\ldots,P\}, \; i = 1,2,\ldots,N_{aph}, \quad (11)$$

$$B_{ugph[1],3} = B_{aph[n_{ap}]} - t_{ugp,3}Q_{ugph[1]}, \quad p \in \{1,2,\ldots,P\}, \quad g \in \{1,2,\ldots,G_p\}, \quad (12)$$

$$B_{ugph[1],(3-k)} = B_{ugph[1],(3-(k-1))} - t_{ugp,(3-k)}Q_{ugph[1]}, \quad k = 1,2, \quad p \in \{1,2,\ldots,P\}, \quad g \in \{1,2,\ldots,G_p\}, \quad (13)$$

$$B_{ugph[i],3} = \min\left\{\left(B_{aph[x]} - t_{ugp,3}Q_{ugph[i]}\right), \left(B_{ch[j],3} - s_{c,3} - t_{ugp[i],3}Q_{ugph[i]}\right)\right\}, \quad g \in \{1,2,\ldots,G_p\}, p \in \{1,2,\ldots,P\}, \; i \in \{1,2,\ldots,N_{ugph}\}, \; j \in \{1,2,\ldots,N_{ch}\}, \; x \in \{1,2,\ldots,N_{aph}\}, \quad (14)$$

$$B_{ugph[i],(3-k)} = \min\left\{\left(B_{ugph[i],(3-(k-1))} - t_{ugp,(3-k)}Q_{ugph[i]}\right), \left(B_{ch[j],(3-k)} - s_{c,(3-k)} - t_{ugp[i],(3-k)}Q_{ugph,[i]}\right)\right\}, \quad k = 1,2, \; g \in \{1,2,\ldots,G_p\}, p \in \{1,2,\ldots,P\}, \; i \in \{1,2,\ldots,N_{ugph}\}, j \in \{1,2,\ldots,N_{ch}\}, \quad (15)$$

$$B_{uzph[i],3} = \min\left\{\left(B_{aph[x]} - t_{uzp,3}Q_{uzph[i]}\right), \left(B_{uz'ph[j],3} - s_{uz'p,3} - t_{uzp[i],3}Q_{uzph[i]}\right)\right\}, \quad p \in \{1,2,\ldots,P\} z, z' \in \{1,2,\ldots,G_p\} \; i \in \{1,2,\ldots,N_{uzph}\} \; j \in \{1,2,\ldots,N_{uz'ph}\} x \in \{1,,2,\ldots,N_{aph}\} \quad (16)$$

$$B_{uzph[i],(3-k)} = \min\left\{\left(B_{uzph[i],(3-(k-1))} - t_{uzp,(3-k)}Q_{uzph[i]}\right), \right.$$

$$\left. B_{uzph[i],(3-k)} = \left(B_{uz'ph[j],(3-k)} - s_{uz'p,(3-k)} - t_{uzp[i],(3-k)}Q_{uzph[i]}\right)\right\}, \quad k = 1,2, \; p \in \{1,2,\ldots,P\}, z, z' \in \{1,2,\ldots,G_p\}, \; i \in \{1,2,\ldots,N_{uzph}\}, j \in \{1,2,\ldots,N_{uz'ph}\}, \quad (17)$$

$$B_{ch[i],3} = B_{ugph[n_i],3} - s_{ugp,3} - t_{c,3}Q_{ch,[i]},$$

$$p \in \{1,2,...,P\}, g \in \{1,2,...,G_p\}, i \in \{1,2,...,N_{ch}\}, \quad (18)$$

$$B_{ch[i],(3-k)} = \min\{(B_{ch[i],(3-(k-1))} - t_{c,(3-k)}Q_{ch[i]}),$$
$$(B_{ugph[n_i],(3-k)} - s_{ugp,(3-k)} - t_{c,(3-k)}Q_{ch[i]})\},$$
$$k = 1,2,\ i \in \{1,2,...,N_{ch}\},$$
$$p \in \{1,2,...,P\},\ g \in \{1,2,...,G_p\}, \quad (19)$$

$$B_{cr[N_c],1} \geq 0, \quad (20)$$

$$Q_{ch[i]}, Q_{ugph[j]}, Q_{aph[x]} \geq 0 \text{ and integer,}$$
$$N_{ch}, N_{ugph}, N_{aph} \geq 1, Y_{ph} \in \{0,1\} \quad (21)$$

Equation 1 is the objective function of minimizing the total actual flow time, i.e. the summation of the total actual flow time of common components and the total actual flow time of unique components. The constrains showing a material balance are Constrains 2 to 5. Constrain 2 shows that the summation of the numbers of units of item p in all batches should be equal to the total number of units of Item p demanded. Constraint 3 shows that the summation of the numbers of units of common components in all bathes should equal the total number of units of common components required. Constraint 4 shows that the total number of units of common components should equal the summation of the numbers of units of all items processed in the shop. Constraint 5 shows that the summation of the numbers of units of unique Component g of Item p in all batches should be equal to the total number of units of unique Component g of Item p. Constraint (6) shows that the time required to produce components distributed to Interval H_h. Constraint (7) shows that the number of units of components processed in Interval of H_r to H_h must be greather or equal than the number of units of components demanded on these intervals. Constraint (8) shows that the number of units of items produced on the period must be equal to the number of units of demanded items on that period, or in other words there is no inventory at the end of the period. Constraint (9) to constraint (21) are used to schedule the resulting batches in each of Interval H_h. Constraints (9) shows that the completion time of the batch assembled last (backwardly sequenced first) should coincide with the common due date. Constraint (10) shows the starting times of batches of the items assembled last (but before assembling the last processed batch (nearest to the due date). Constraint (11) shows that the starting times of assembling batches of item p sequenced at position 2 to N_{aph}. Constraint (12) and constraint (13) show that the starting times of fabricating batches of unique Component g of Item p, backwardly sequenced first. Constraints (14) and (15) show that the starting times of fabricating batches of unique Component g of Item p backwardly sequenced after the common components processed on Machines 3, 2, and 1. Constraints (16) and (17) show that the starting times of fabricating batches of unique component of Item p backwardly sequenced after batches of another unique component. Constraints (18) and (19) show that the starting times of fabricating batches of common components backwardly sequenced after the unique components processed on Machines 3, 2, and 1. Constraint (20) shows feasibility of the schedule, i.e., the starting time of the batch of common components fabricated first (backwardly sequenced last) must be at or after time zero (the present time). Constraint (21) shows that the batch sizes should be positive and integer, and that the number of batches should be equal to or greater than one. Y_{ph} is equal to 1 if in the interval of H_h produced item p, or 0 on the contrary.

3. SOLUTION METHOD

The proposed model is an NP hard problem that is very difficult to be solved using the analytical method. Accordingly, the model is firstly relaxed by converting the variables of process sequences and the number of batches to parameters. The next step is to propose algorithm to solve the problem.

The proposed algorithm to solve the model is divided into 2 algorithms, i.e., Static Algorithm and Dynamic Algorithm. The Static Algorithm is a heuristic to solve the mathematic formula of MIDS using the algorithm developed in Halim and Yuniartha (2008) and Halim and Barnali (1998). The Dynamic Algorithm is to define the arrivals of new orders using the algorithm developed in Halim and Barnali (1998). The Static Algorithm is shown as follows.

[Static Algorithm]

Step 1. Sequence the due dates according to increasing due dates. Set the greatest due date as h = 1. Go to Step 2.

Step 2. Determine H_h, i.e. the interval between two consecutives duedates using

$$H_h = \begin{cases} d_h - d_{h+1} & h = 1,...,r-1 \\ d_r & h = r \end{cases}$$

Go to Step 3.

Step 3. Set h = 1. Go to Step 4.

Step 4. Schedule all the items that should be processed in Interval H_h using the algorithm discussed in Halim and Yuniartha (2008). Go to Step 5.

Step 5. For each item that should be processed in interval H_h, compute the number of batches of items that can be completed, and set as W_{aph} for p = 1, 2,…,P. Go to Step 6.

Step 6. Reschedule the batches of items that can be completely processed in Interval H_h (W_{aph}) using the algorithm discussed in Halim and Yuniartha (2008). Go to

Step 7.

Step 7. Compute the number of batches of items that can not be processed in Interval H_h, and set as γ_{aph} using $\gamma_{aph} = N_{aph} - W_{aph}$ for p = 1, 2,…,P. Go to Step 8.

Step 8. If h = r then go to Step 11, otherwise set h = h + 1 go to Step 9.

Step 9. If $h \le r$ then go to Step 10, otherwise go to Step 12.

Step 10. Compute the number of units of items that should be processed in Interval of H_h, and set as N_{aph} using $N_{aph} = N_{aph} + \gamma_{ap(h-1)}$ for p = 1, 2,…,P. Go to Step 4.

Step 11. If γ_{aph} = 0 then go to Step 13, otherwise the schedule is not feasible because the time to process all batches of all items is greater than the time available.

Step 12. Schedule the resulting batches as the final schedule and determine the total actual flow time using equation (1). Stop.

There are 2 things concerning the Dynamic Algorithm, i.e., the status of machine at the arrival time of a new order, and the order that should be processed as a consequence of the arrival of the new order. The proposed model assumes that in the dynamic condition, the batch processing can not be interrupted. As the consequence, the components on the batch that are processing at the time of the new order arrival must be continued processing until all the components in the batch are finished completely. The proposed algorithm should also check at the time of the new order arrival whether the machines are busy or not. This assumption have resulted in change of the number of units of components that should be processed to fulfill orders at their due dates. As the consequence, the number of units of components to be processed in Interval H_h, the finished batches and the processing batches should be identified in order to determine the batches that have not be processed yet. The Dynamic Algorithm is shown as follows.

[Dynamic Algorithm]

Step 1. Set the arrival time of a new order as A. If there is a batch processed at t = A go to Step 2, otherwise go to Step 5.

Step 2. Put an asterisk for batch processed at t = A, and check the batch of item where its common components are in one batch with the asterisk batch. Go to Step 3.

Step 3. Forwardly schedule all batches of items that its common components are in one batch with the asterisk batch until its assembly process finishes. Go to Step 4.

Step 4. Update A as the completion time of all batches of items in Step 3 for each machine. Go to Step 5.

Step 5. Schedule the remaining batches of items that have not been scheduled yet in Step 3, including the new order using [Static Algorithm]. Go to Step 6.

Step 6. If $B_{cr[N_c],1}\left(TF^{a}_{N_{ar}[N_{cr}]}*\right) \ge A$ the new order is rejected without changing the initial schedule (the schedule before the new order arrives). Otherwise set the resulting schedule as a new schedule, meaning that the new order can be approved. Stop.

4. NUMERICAL EXPERIENCE

The proposed algorithm has been tested on 3 steps. The first test is to observe whether the proposed model works. The second test is to compare the numerical experience for the proposed model and the model developed in Saleh and Halim (2004). The third test is to observe the behavior of the proposed model if the demand and or due date changes.

The first test uses a set of data consist of 10 orders, each of which has different types of item with the respective numbers of units of item demanded, the arrival times, and due dates. For the 10 orders, there are 4 types of items demanded. Numerical experience for the first test shows that the proposed algorithm can solve problem of scheduling for fabrication and assembly in a dynamic flow shop with 4-machines processing multiple items with multiple due date to minimize the total actual flow time. Each of the items comprises one unit of a common component and multiple unique components each of which consists of one unit.

The numerical experience of the second test shows that the proposed algorithm has the same sequence as that obtainer by Saleh and Halim (2004). This means that the proposed model is more general than the model in Saleh and Halim (2004). Even the proposed model and the model in Saleh and Halim (2004) have the same jobs sequence but they have different value of total actual flow time. This is because the applied programming to implemented the model Saleh and Halim (2004) has limitation, i..e.,. the applied programming cannot accommodate the equal value of item in jobs sequencing process. If the applied programming find the equal value of two items so it will sequence the item arbitrary. The equal value of items in job sequencing process produce more than one jobs sequenced and there will be more than one alternative solutions. The applied programming should give the best solution among the alternative solutions.

In the third test, the proposed algorithm has been tested using set of data used in the first test with variation in the demand, i.e. the number of items demanded by each order (Set 1) and the due dates of each order by using 8 variation of due dates (Set 2). For Set 1, demand of each order varies by adding or subtracting 5, 10, 15, 20, and 25. For Set 2, the variation of due dates has been determined by shifting the arrival time and the due date of each order but without changing the interval between the arrival time and the due date of each order. This variation is to accommodate the tight due date.. The tight due date has been solved by shifting the arrival time of an order to the due date of the previous order.

Tighter the due date, longer the interval between the arrival time of an order and the due date of the previous order. The variations of the interval between the arrival time of an order and the due date of previous order used to test are 200, 400, 600, 800, 1000, 1200, and 1400. The third test shows that the proposed algorithm has been able to obtain the change of demands and due dates.

5. CONCLUDING REMAKS

A batch scheduling model for fabrication and assembly in a dynamic flow shop with 4 machines processing multiple items with multiple due dates to minimize the total actual flow time has been studied. In the model, fabrication for both components is conducted on the first three machines and assembly is conducted on the forth machine. The dynamic condition in this model means that the new orders arrive at any time over the planning horizon. The arrival of new order is accommodated by totally rescheduling, that is, to change the initial schedule entirely.

The proposed algorithm has been able to obtain good solutions Furthermore, the proposed model could be extended to accommodate the condition where the flow shop has parallel machines or with simultaneous resources.

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