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THE BATCH SCHEDULING MODEL FOR DYNAMIC MULTI-ITEM, MULTI-LEVEL PRODUCTION IN AN ASSEMBLY JOB SHOP WITH PARALLEL MACHINES

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ABSTRACT

Most classical scheduling approaches deal with single products, single machines, and static manufacturing environments. In real-world manufacturing systems, however, scheduling can be assigned for multi-item production on multimachines in a dynamic environment in which unexpected new orders may be received. This paper focuses on scheduling problems in an assembly job shop with parallel machines that produce multi-item multi-level products. Models were developed for due date fulfillment and due date assignment in static and dynamic conditions, with the objectives of minimizing total actual flow time, while considering the defect rate at each stage of the process. The insertion technique was used in the scheduling process; insertion can be performed in batch operations at all available positions on all machines. A hypothetical case of job shop scheduling problems associated with multi-item, multi-level production on parallel machines was studied, and the computational results demonstrated the validity of the proposed algorithms.

Keywords: Assembly job shop; Batch scheduling; Defect rate; Insertion technique; Total actual flow time

1. INTRODUCTION

Rapid industrial development has caused competition among manufacturers to become increasingly aggressive, where it involves all aspects in business, i.e., technical, commercial and management aspects (Saroso, 2012). From a management aspect, quality improvement in rapid response to customer demand has become extremely important. This condition has resulted in a shift from mass production to mass customization. Generally, inventory has been used to meet customer demands quickly. According to Baker (1974), Baker and Trietsch (2009), Dobson et al. (1987), and Halim and Ohta (1993), it is necessary to minimize inventory to minimize the length of a job on the shop floor (i.e., shop time).

Previous studies state that the accuracy of due date fulfillment is regarded as more important than minimizing shop time because compliance with the exact due date tends to be related to customer satisfaction. Just-In-Time (JIT) production systems can accommodate these conditions, aiming to fulfill the exact due date, while simultaneously trying to minimize inventory (Vollman et al., 2005).

Due dates in the scheduling process can be set either externally by the customer or internally by the scheduling system (Vinod & Sridharan, 2011). If the due date has been determined at the

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beginning, then the scheduling process is planned to comply with due date fulfillment. However, if the due date has not been determined and can be negotiated with the customer, the scheduling process will be undertaken as a due date assignment.

Due date assignment in scheduling has been studied by many researchers. Most classical scheduling approaches deal with single products, single machines, and a static manufacturing environment. In real-world manufacturing systems, scheduling of production for multi-item products can be produced on multimachines in a dynamic environment in which new orders are received. However, early research on batch scheduling based on the forward approach by Dobson et al. (1987) did not cite the due date as a limiting factor.

A timely scheduling model has been developed by Halim and Ohta (1993); it is based on actual flow time. Sotskov et al. (1999) developed heuristic algorithms for scheduling problems associated with the batch insertion technique utilized in a job shop environment with independent setup time. Job shop production systems allow the manufacturer to produce several different products or parts, and each part may have a different processing route. However, the conditions discussed in these studies pertained only to a single machine; furthermore, the Bill of Material (BOM) in the scheduling process was not considered.

The development of the insertion technique for static and dynamic conditions to solve resource-constrained project scheduling problems was carried out by Artigues et al. (2003); the authors also considered the minimum and maximum time lags (Artigues & Briand, 2009). The results showed that the insertion technique facilitates better scheduling in a dynamic condition. Thiagarajan and Rajendran (2005) developed a scheduling model for dynamic assembly job shops, where each item may have a different BOM, by combining the relative costs associated with holding and tardiness of jobs. The authors used a simulation to obtain the smallest total weight.

Wong et al. (2009) applied the Lot Streaming (LS) technique to a resource-constrained assembly job shop scheduling problem (RC_AJSSP). This technique involves splitting jobs into smaller sub-jobs so that successive operations overlap. Chan et al. (2008) also applied LS for scheduling problems in assembly job shops; a generic algorithm was used for breaking the job into smaller sub-jobs. In these studies, BOM has been considered, but the general focus was still on a single machine at each stage of the production process.

Cheng et al. (2007) studied the problem of scheduling deteriorating jobs on identical parallel machines, with the objective of minimizing the sum of due date, earliness, and tardiness penalties. Xia et al. (2008) developed an heuristic procedure to solve the problems of job sequence and due date assignment to minimize a linear combination of penalties (i.e., penalties for completing jobs before or after the due date, and penalties associated with long-term assignments).

Shabtay and Steiner (2008) studied due date assignment problems in various multi-machine scheduling environments to minimize a cost function, which includes earliness, tardiness, and due date assignment costs. Shabtay (2010) also developed a model for scheduling problems associated with batch delivery from a single machine, where due dates are controllable and objectives include minimizing earliness, tardiness, holding, due date assignments, and delivery costs. In the model, a Different Due Date Method (DIF) is used so that each job will have a different due date.

Due date assignment and scheduling in JIT for single machine and parallel machine problems involving jobs of equal size have been studied by Tuong and Soukhal (2010). The objective is to minimize total weighted earliness, tardiness, and due date costs based on the Common Due Date (CON) method, where all work is assigned the same due date.

Despite the potential benefits of previous studies, only a few studies have focused on scheduling models for assembly job shops with parallel machines that produce multi-item, multi-level products in static and dynamic conditions. This study attempts to fill this research gap. The aim of the study is to develop models, which were designed to minimize TF in a JIT assembly job shop, while considering the defect rate that occurs in each stage of the production process.

In this study, total actual flow time (TF) was used as the criterion for performance measurement. Finding solutions to problems were performed using insertion techniques. The models were developed based on defect rates that occurred at each stage of the production process. In this study, dynamics can be interpreted as inevitable and unpredictable real-time events that may cause changes in scheduled plans. Most manufacturing systems operate in dynamic environments (Ouelhadj & Petrovic, 2009). Hence, the model is relevant for the successful implementation of real-world scheduling systems.

2. METHODOLOGY

The structure of the methodology is initiated by a problem description and sub-sections, which explain the scheduling problem to be solved. In the following sub-sections, two types of models, i.e.: due date fulfillment and due date assignment are described. The last part of the methodology is solution algorithms for both models.

2.1. Problem Description

Model development begins with solving problems in static conditions, then proceeds to solving problems in dynamic conditions. A problem can be formulated with a condition; where r types of items are expressed by p_{i0} (i = 1,2,…,r). Each p_{i0} will be produced as many as n_{i0}, which must be completed on due date, d_{i0}.

Each item produced has e_{io} levels (l = 1,2,…,e_{i0}) and requires c_{io} component types, where each type of component is expressed by p_{ij} ($j = 1,2,\ldots,c_{i0}$). The number of p_{ij} items that will be produced is n_{ij}.

Each item and its components are processed on h_{ij} operations with the operation sequence expressed by k ($k = 1,2,\ldots,h_{ij}$) in a job shop production system having v kind of machines ($m = 1,2,\ldots,v$) and w identical machines ($n = 1,2,\ldots,w$).

Each machine has a setup time and a processing time of s_{ijkmn} and t_{ijkmn}, respectively, by which the operation time is the same for all n identical machines. Each operation identifies a defect rate for each item and its components as dr_{ijkmn}.

Notations used in this study are as follows:

I	Types of items ($i = 1,2,\ldots,r$)
r	Number of items that will be produced
p_{i0}	Item i to be produced ($i = 1,\ldots,r$)
J	Component of items i ($j = 1,2,\ldots,c_{i0}$)
p_{ij}	*j-th* component of item i
$z(p_{ij})$	Set of parent component j of item i
n_{ij}	Number of *j-th* components of item i
k	Sequence of h_{ij} process in making the *j-th* component of item i ($k = 1,2,\ldots,h_{ij}$)
H_{ij}	Number of *j-th* components required to make one unit of its parent in the BOM (or the number of components j required to make the component at the level above it)
L	Level of item i ($l = 1,2,\ldots$)

m	Machine ($m = 1,2,3,\ldots,v$).
v	Number of machine types available in the system
n	Identical machine at each stage of the process ($n = 1,2,\ldots,w$)
w	Number of identical machines available for each m-th machine
u	Batch for each component of p_{ij}
c_{i0}	Number of component types to make item i (not the number of levels)
h_{ij}	Number of processes in making the *j-th* component of the *i-th* item
e_{i0}	Number of levels of item i in the product structure
d_{i0}	Due date for item i (known from due date fulfillment problem).
O_{ijklmn}	Operation *k-th* for components p_{ij} at *l-th* level performed at the *n-th* machine
TF	Total actual flow time
$t_{ijkm\bullet}$	Processing time for operation $O_{ijklm\bullet}$ for each unit of p_{ij}
$s_{ijkm\bullet}$	Setup time for all m identical machines for operation $O_{ijklm\bullet}$.
$dr_{ijklm\bullet}$	Defect rate of operation k, level of l, components p_{ij} on all m machines
Q_{ij}	Variable to denote the p_{ij} components that will be produced
S_{ijklmn}	Variable to denote start time of operation O_{ijklmn}
C_{ijklmn}	Variable to denote the completion time of operation O_{ijklmn}
$Q_{ijkm[b]}$	Number of parts in batch $L_{ijkmn[b]}$ for the *b-th* sequence
$B_{ijklmn[N]}$	Starting time for batch N of the item p_{ij}, for the *l-th* level, *k-th* operation, on the *n-th* of the m machines

2.2. Due Date Fulfillment Model

The scheduling model for due date fulfillment can be formulated as follows:

Objective function:

Minimize

$$TF = \sum_{i=1}^{r}\left(d_{i0} - B_{i\bullet 1e\bullet\bullet[N]}\right) \tag{1}$$

Constraints:

$$n_{ij} = n_{i0} * H_{ij}\left(\prod_{p_{iq}\in Z(p_{ij})} H_{iq}\right), \quad \underset{p_{iq}\in Z(p_{ij})}{H_{iq}} \geq 1;\ \forall i, j \tag{2}$$

$$n_{ijk(produced)} \geq n_{ij(k+1)(produced)} * (1 + dr_{ijkm\bullet}) \tag{3}$$

$$\sum_{u=1}^{N} Q_{ij[u]} = n_{ij};\ \forall i, j \tag{4}$$

$$B_{ij1\bullet\bullet\bullet[N]} \geq 0;\ \forall i, j \tag{5}$$

$$C_{ijhl+1\bullet\bullet} - B_{ij1l\bullet\bullet} \leq 0;\ \forall i, j, k, l \tag{6}$$

$$C_{ij(k-1)l\bullet\bullet\bullet[u]} - B_{ijkl\bullet\bullet[u]} \leq 0;\ \forall i, j, k, l, u \tag{7}$$

$$B_{ijklm\bullet[u]} \leq B_{ijklm\bullet[u-1]} - \left(Q_{ijkl[u]} * t_{ijkm\bullet}\right) - s_{ijkm\bullet};\ \forall i, j, k, l, m, u \tag{8}$$

$$B_{i0he\bullet\bullet[1]} = d_{i0} - \left(Q_{i0h0[1]} * t_{i0h\bullet\bullet}\right);\ \forall i \tag{9}$$

$$C_{\bullet\bullet\bullet\bullet mn[w]} - C_{\bullet\bullet\bullet\bullet mn[y]} + \alpha\left(X_{wy}\right) \geq \left(Q_{\bullet\bullet\bullet\bullet[w]} * t_{\bullet\bullet\bullet\bullet mn}\right);\ \forall\ m, n \tag{10}$$

$$C_{\bullet\bullet\bullet\bullet mn[y]} - C_{\bullet\bullet\bullet\bullet mn[w]} + \alpha\left(1 - X_{wy}\right) \geq \left(Q_{\bullet\bullet\bullet\bullet[y]} * t_{\bullet\bullet\bullet\bullet mn}\right);\ \forall\ m, n \tag{11}$$

$$X_{\mathrm{wy}} \in \{0,1\},\ Q_{ijkl[u]} > 0, \text{ and } N_{ijk} \geq 1, \text{integer} \tag{12}$$

Equation (1) expresses the objective function (i.e., minimizing TF for all items), where $B_{i\bullet 1e\bullet\bullet[N]}$ identifies the start time of the first operation of the last batch and $B_{ijklmn[N]}$ indicates the start time of the *N-th* batch of item p_{ij}.

Equation (2) expresses the quantity relationship between the product item and its components. Equation (3) states the number of the *j-th* components of item *i* at the *k-th* operation that must be produced. Equation (4) states the material balance before and after breaking it into batches.

Equation (5) ensures that the start time for processing the first batch of a component p_{ij} is greater than or equal to zero, which means the job is feasible within the planning horizon. Equation (6) ensures that processing associated with the first operation ($k = 1$) for the first batch of component p_{ij} of *l-th* level can be initiated if the last operation ($k = h$) of the p_{ij} components has been completed for all machines.

Equation (7) states that processing of an operation of the u-th batch can be performed if the previous operation has been completed. Equation (8) states that processing of the *u-th* batch should be performed immediately if the batch of *u-1* has been completed.

Equation (9) states that the last operation ($k = h$) of the first batch should be completed exactly on the due date. Equation (10) shows the completion time of the batch at position w, where the batch from the earlier order will be processed first on the *n-th* of the *m* machines. If the processing sequence is reversed, then equation (11) will apply.

Equation (12) states that the value of X_{wy} is 1 if the *k-th* batch operation is at position *w* (i.e., $L_{[w]}$ precedes $L_{[k]}$); otherwise, it will be zero. Additionally, batch size must be positive and the batch number must be an integer value greater than or equal to one.

2.3. Due Date Assignment Model

In this model, the due date of each item is not known; presumably, it will be negotiated with the customer. Hence the constraint in equation (11) can be removed, while the other constraints still apply to this model. The objective function is obtained by modifying equation (1), so that it can be formulated as follows:

Minimize

$$TF = \sum_{i=1}^{r}\left(C_{i0\bullet 0\bullet\bullet} - B_{i\bullet 1e\bullet\bullet[N]}\right) \tag{13}$$

Equation (13) expresses minimization of TF for all items, where $B_{i\bullet 1e\bullet\bullet[N]}$ is the start time of the first operation of the first batch of components at level *e* of item *i* that is first scheduled on any machine. C_{i0} states the completion time for all operations of item *i* on all machines. C_{i0} can be interpreted as an item *i* whose completion time used as a basis for due date determination.

2.4. Solution Algorithm

Given the number of variables in the model, an heuristic approach was used to change some variables into parameters (i.e., number of batches and batch processes). Hence, before solving the mathematical formulation, it is necessary to determine the value of both parameters, for which numbers depend on the number and type of items, number of machines (multi-stage), and number of machines for each type.

In the dynamic model, it is possible to receive new orders in the planning period, which leads to the need for rescheduling. A new order can be accepted when if it will not cause delays in existing orders.

2.4.1. Due Date Fulfillment

The algorithm developed consists of the following stages. In the first stage, a determination is made regarding the number and sizes of batches while taking into account the defect rate. Then, a schedule is developed to meet existing orders (at t = 0) by means of the steps below.

(i) Sort items by due date in descending order.

(ii) Determine the number and sizes of batches for each item (starting with Ni = 2) to keep TF to a minimum.

(iii) For backward scheduling, start from the latest due date.

(iv) Sequence operations of the items according to machine type, and split the batch of each item (starting with the batch closes to the due date).

(v) Combine schedules for each type of machine using the insertion technique.

In the second stage, if there is a new order, then it is necessary to reschedule using the insertion technique to determine the feasibility of accepting new orders.

The proposed model consists of two algorithms: (i) a scheduling algorithm based on static conditions and insertion technique to combine the schedules of each machine type into a final schedule, and (ii) algorithm to determine the feasibility of new orders by using insertion technique (i.e., scheduling algorithm for dynamic condition), where new items received will be considered as a single item. Subsequently, the item is inserted into the schedule associated with the static condition. If the time machine available (Tav)mn is met, the new orders can be accepted; if (Tav)mn is not met, then the new orders must be rejected. The flow chart for the developed algorithm can be seen in Figure 1.

2.4.2. Due Date Assignment

The process of finding a solution for the due date assignment problem consists of the following stages: (i) sorting the items based on the total setup and processing time in ascending order, (ii) determining the number of and sizes of batches while taking into account the defect rate, (iii) performing forward scheduling, starting from t = 0, (iv) merging the schedules for each machine to obtain the final schedule, (v) determining the due date for each item. Rescheduling is used when there are new orders. The flow chart for the algorithm can be seen in Figure 2.

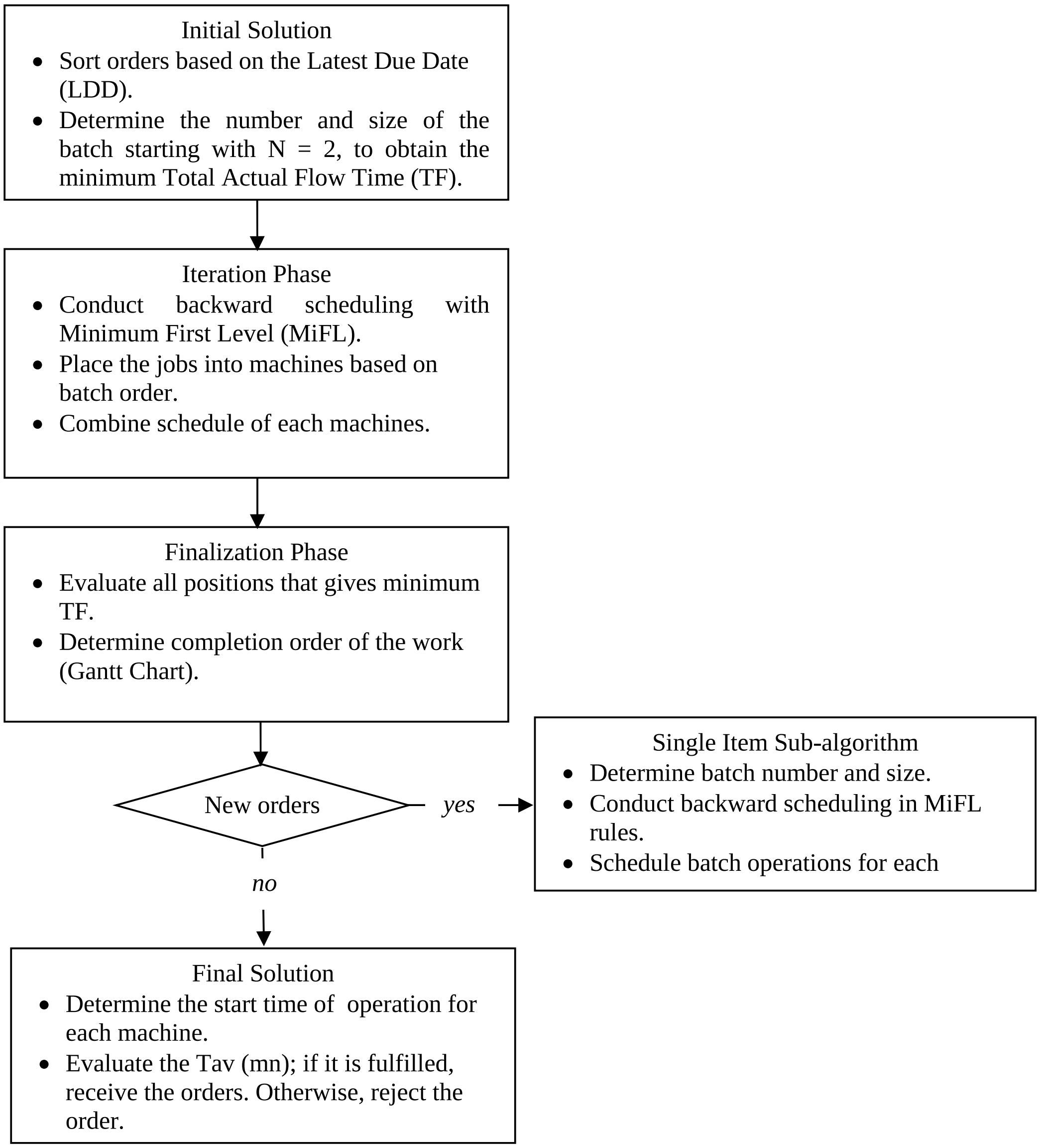

Figure 1 Flow chart of due date fulfillment

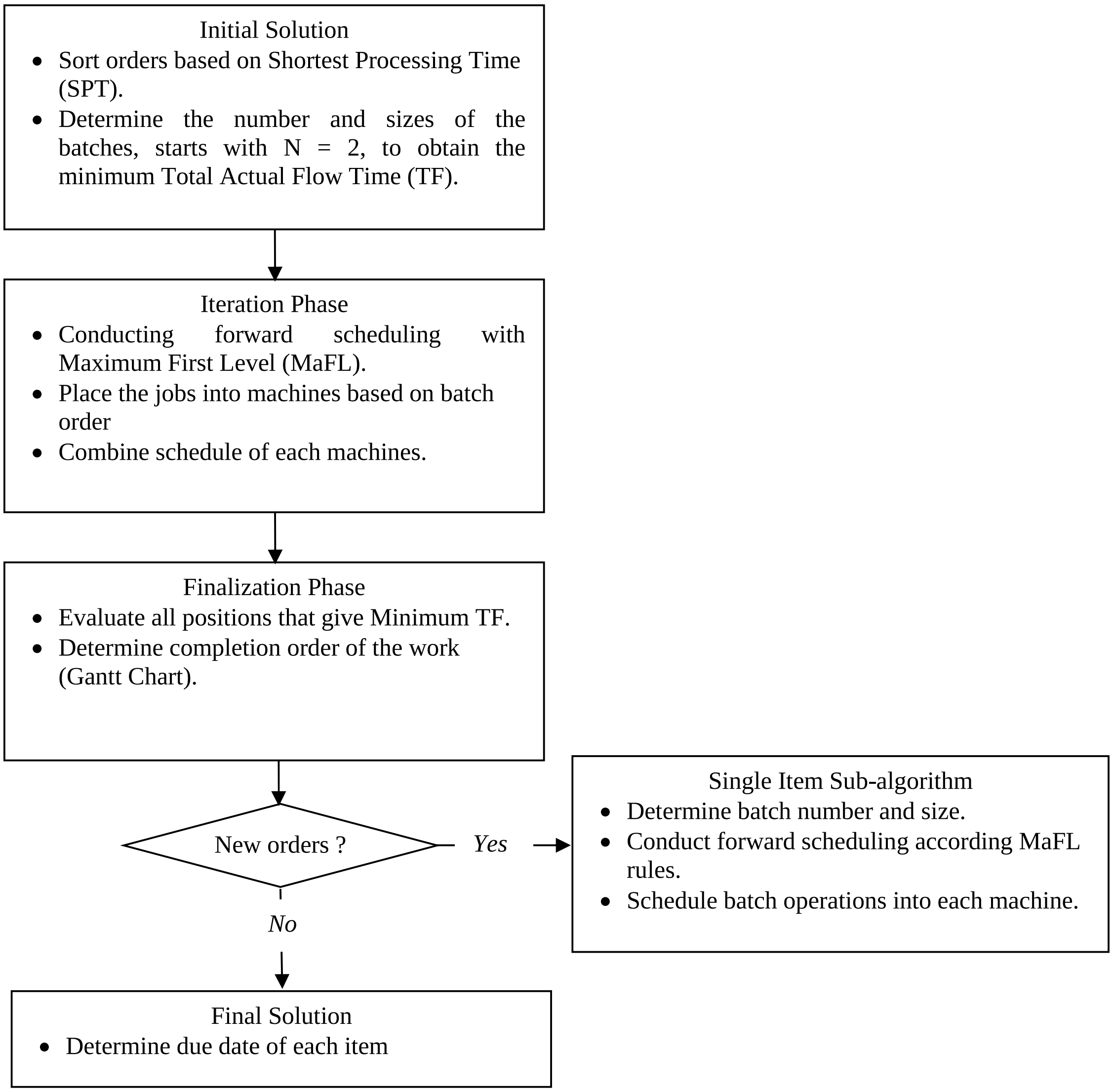

Figure 2 Flow chart based on due date assignment

3. RESULTS AND DISCUSSION

To demonstrate the performance of the proposed algorithm, a series of computational experiments was carried out. The algorithms were coded in Java language using Eclipse IDE, and the experiments were carried out on a computer with Intel^{R}Core^{TM}2Duo operating at 2.00 GHz with 20148 GB of memory. The process began with verification and validation of the model before testing the model using a larger data set.

3.1. Verification and Validation

Verification and validation were performed using hypothetical data for static (Tables 1 and 2) and dynamic conditions (Tables 4 and 5) with the arrival of order at T = 1100. Table 3 shows the number of each machine used in the production.

Table 1 Setup and processing times and defect rates

P_{ij}	Operation	Machine	Setup Time (minute)	Processing Time (minute)	Defect Rate (%)
10	1	3	30	10	4
20	1	1	40	15	5
30	1	2	15	5	8
11	1	4	10	5	6
	2	3	20	5	5
12	1	2	25	10	10
	2	1	45	15	4
21	1	3	15	5	8
	2	2	45	15	6
22	1	1	100	20	5
	2	4	50	15	7
31	1	3	25	5	8
32	1	1	30	10	6
33	1	3	35	5	5
	2	4	50	10	10
34	1	4	45	5	5
	2	2	60	15	8

Table 2 Item for static conditions

P_{i0}	Quantity (unit)	Due date (minute)
10	10	3400
20	15	3250
30	20	3300

Table 3 Machine data

No	Machine	Unit
1	1	3
2	2	1
3	3	3
4	4	2

Table 4 Item for dynamic conditions

P_{i0}	Quantity (unit)	Due-date (minute)
40	15	3875
50	25	3950

Table 5 Setup and processing times and defect rates for new orders

P_{ij}	Operation	Machine	Setup Time (minute)	Processing Time (minute)	Defect Rate (%)
40	1	3	25	10	6
50	1	2	15	5	4
41	1	4	10	1	6
	2	3	20	5	5
42	1	3	25	10	10
	2	1	15	15	4
51	1	4	20	5	8
52	1	1	15	1	6

Using the heuristic algorithm for static conditions, we found that p_{10} started at t = 2915, p_{20} at t = 2372, p_{30} at t = 1553.75; further, TF = 3,108.25 minutes. For the dynamic condition, p_{40} starting at t = 3060, p_{50} at t = 3535; TF = 4,194.05 minutes.

By using the same data set with the due date assignment algorithm (i.e., due date negotiated with customer), the TF obtained was 3,470 minutes, where p10 could be completed at t = 500, and p_{20} and p_{30} at t = 1080 and t = 2030, respectively. After the arrival of new orders at T = 1100, the new TF was 4,920 minutes, and the due date of new orders p_{40} and p_{50} could be completed at t = 1865 and t = 1825.

Based on the results, it can be seen that TF in the dynamic condition for the due date assignment problem was greater than that for due date fulfillment. This condition is likely due to differences in job priority rules for the two problems.

Based on the results, it can be seen that TF in the dynamic condition for the due date assignment problem is greater than that for due date fulfillment. This condition is likely due to differences in job priority rules for the two problems.

3.2. Discussion

The data set used in testing the model included 10 types of items, with variations in quantity and due date. Five machines were used to complete the job, and there were three identical machines for each type of machine. The product structure of the items included four levels with each level further subdivided into two levels of constituent components. The product structure can be seen in Figure 3.

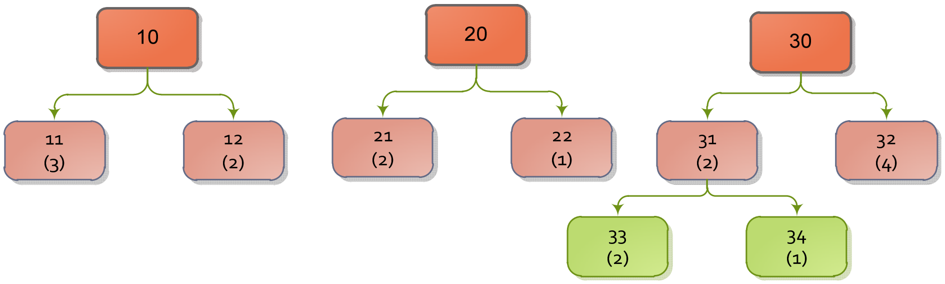

Figure 3 Product structure

Two different operations were performed for each component on two different machines. This hypothetical condition illustrated the existence of a multi-item, multi-level, multi-component multi-operation.

Each item and its components had different setup and processing times, as well as defect rates, based on the machine or stage of the process.

The experiment was carried out to obtain the number of alternative schedules and average CPU time for a variety of different combinations (i.e., variation in number of items, types of items, and levels), as shown in Figures 4 and 5.

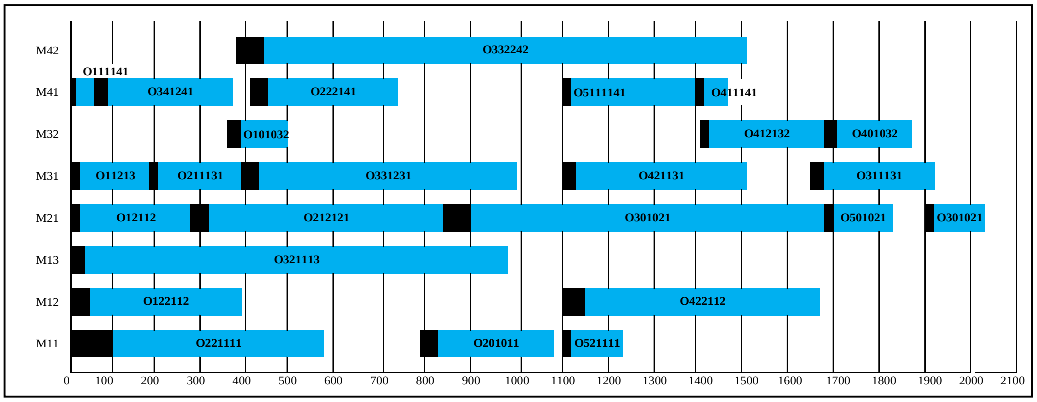

Figure 4 Gantt chart for due date fulfillment under dynamic conditions

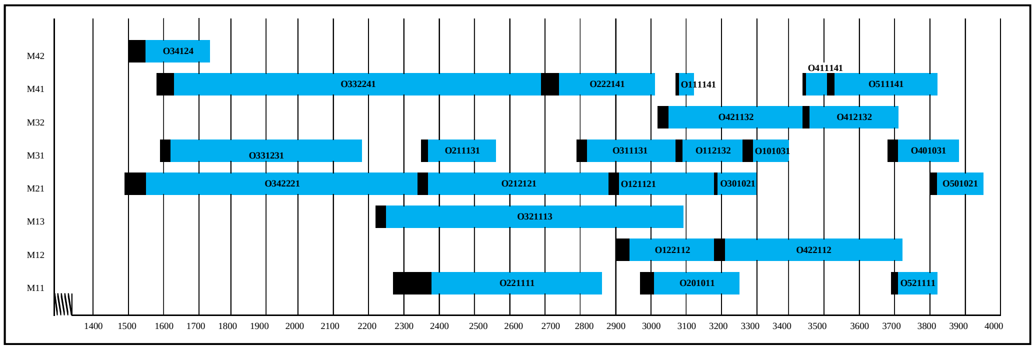

Figure 5 Gantt chart for due date assignment under dynamic conditions

Increasing the number of items for the same level will increase significantly the number of alternative schedules. This condition also occurs with an increase in the number of levels, which subsequently increases CPU time.

In this study, increasing the number of levels significantly affected the complexity of scheduling problems. The number of alternative schedules was more sensitive to an increase in the number of levels, rather than an increase in the number of item types. In addition, an increase in time devoted to problem resolutions for due date assignment was greater than that associated with due date fulfillment.

From Figure 4 and Figure 5, it is clear that CPU time for the due date assignment was larger than that for due date fulfillment. This condition was caused by the random selection in determining the initial process to be used for the due date assignment (i.e., any process without a predecessor at the beginning of the scheduling process). This caused a number of iterations and a shift in scheduling to obtain a schedule with the smallest total actual flow time. For due date fulfillment, the first operation scheduled was determined at the beginning of the scheduling process.

4. CONCLUSION

This study considers due date fulfillment and due date assignment problems under static and dynamic conditions for the objective of minimizing TF while taking into account the defect rate at each stage of operation. Unlike previous studies, multi-item, multi-level products were explicitly considered. Computational experiments were carried out as part of a hypothetical case, and the results verified the validity of the models and the proposed algorithm.

The effect of an increase in the number of product levels on the number of alternative schedules is greater than the effect of an increase in the number of product items. The same thing happened in the time required for completion of sequencing operations. This comparison shows that the complexity of the scheduling problems is affected mostly by an increase in the number of product levels.

In conditions with more than one level and more than two product items, due date assignment will produce more alternative schedules than that due date fulfillment, and vice versa for other conditions. CPU time required to solve the due date assignment problem was greater than that for due date fulfillment.

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