CHAPTER 6

DEVELOPMENT OF FINITE CAPACITY MATERIAL REQUIREMENT PLANNING SYSTEM (FCMRP) WITHOUT OVERTIME ON WORK CENTERS

In the last chapter, the development of FCMRP system with overtime on work centers (NFCMRP) was explained. In this chapter, the development of FCMRP system without overtime on work centers is discussed and analyzed. There are two types of the FCMRP systems which the overtime is not allowed. The first one called conventional FCMRP system (CFCMRP). It consists of Forward (F) and Forward-Backward (FB) scheduling systems. The F and FB scheduling systems are developed based on non-optimization approach, which is the same as the NFCMRP system. The second one is developed based on optimization approach (OFCMRP) using a weighted goal programming model (WGP) in order to minimize the sum of penalty points incurred by exceeding the goals of performance measures (tardiness, earliness, and flow-time).

This chapter is organized as follows:

1. The algorithm of the OFCMRP system is described and presented in section 6.1.
2. The algorithm of the CFCMRP system is described and presented in section 6.2.
3. Experiments are conducted to analyze the effects on scheduling performance of options available in the OFCMRP and CFCMRP systems are presented in section 6.3.
4. Results and discussions are presented in section 6.4.
5. Conclusion is presented in section 6.5.

6.1 The algorithm of OFCMRP system.

The FCMRP systems in this chapter have five main steps. The first three steps are the same as that of the NFCMRP system as explained in the last chapter. Fourth, the sequence of orders in all work centers is determined by applying simple dispatching rules. An objective of applying the dispatching rules is to generate different sequences of orders that may affect the performance measures. Finally, the start and due times of all operations are calculated using a linear goal programming model. An objective of this step is to minimize the sum of penalty points incurred by exceeding the goals of performance measures (tardiness, earliness, and flow-time). The characteristic and structure of the manufacturing process of the OFCMRP system are the same as those of the NFCMRP system explained in the last chapter. However, the limitation of the OFCMRP system is that the lot sizing rule is lot-for-lot.

The parameters and decision variables in the WGP model are defined as follows:

Parameters

j	index of customer order starting from 1 to N
i	index of work center starting from 1 to W
$p_{i,j}$	processing time of order j on work center i
d_j	due date of order j
c_j	completion time of order j
f_j	flow-time of order j
e_j	earliness of order j
t_j	tardiness of order j
C_t	penalty weight of exceeding the goal of total tardiness
C_e	penalty weight of exceeding the goal of total earliness
C_f	penalty weight of exceeding the goal of average flow-time
X	goal of total tardiness
Y	goal of total earliness
Z	goal of average flow-time
T^+, T^-	deviation of the total tardiness from the goal X
E^+, E^-	deviation of the total earliness from the goal Y
AF^+, AF^-	deviation of the average flow-time from the goal Z

Decision variables

$x_{i,j}$ start time of order j on work center i

A block diagram of the OFCMRP system is shown in figure 6.1. The system is described step-by-step and illustrated by an example as follows.

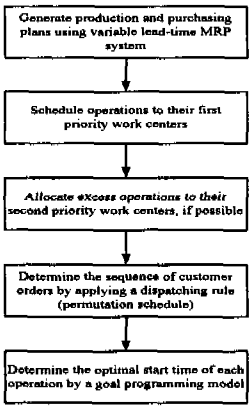


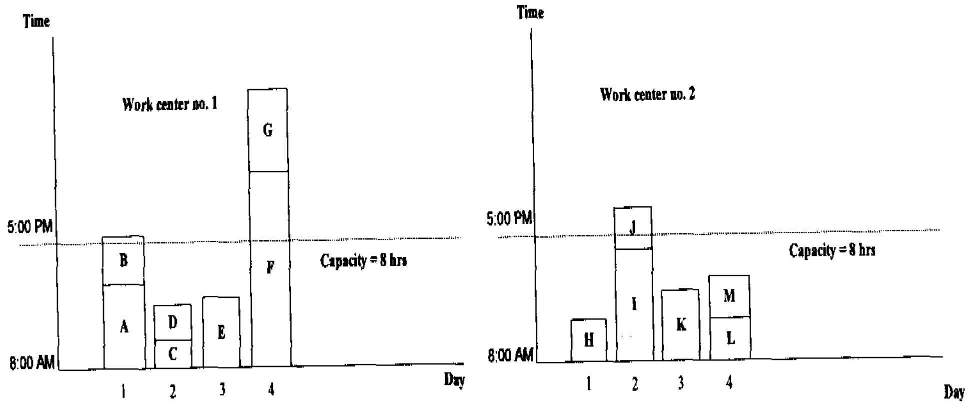
Figure 6.1. Block diagram of the OFCMRP system

1. Generate production and purchasing plans using variable lead-time MRP system

This step is the same as that of the NFCMRP system explained in the last chapter.

2. Schedule operations to the first priority work centers

In the last chapter, there are two rules for scheduling the operations of each order (j) to the first priority work centers (i), namely, SR and SD. The result shows that the SD outperforms SR rule for all performance measures. Therefore, only the SD rule is applied to this step. Figure 6.2 shows an example of load profiles of work centers 1 and 2. The X-axis shows the day and the Y-axis shows the time of day based on the SD rule.

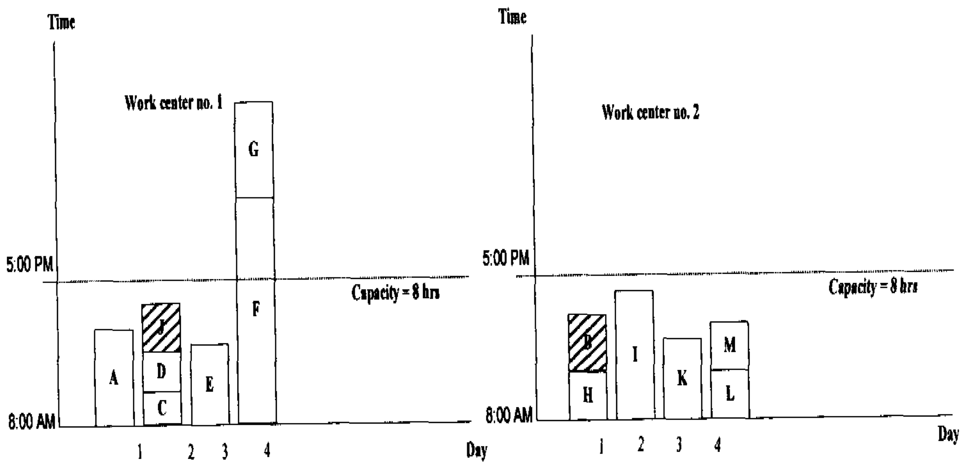


(a) (b)

Figure 6.2 Load profile on the first priority work centers

3. <u>Allocate the excess operations to the second priority work centers</u>

In the NFCMRP algorithm (chapter 5), the rearranging rule was applied in order to determine the excess operations in each day. They are ERT and EDT rules. The result shows that there is no significant effect between the ERT and EDT rules. Therefore, any rule can be applied. After that, the excess operations are moved to the second priority work centers by using the same method as explained in the NFCMRP system. From figure 6.2(a), the excess operation B on work center 1 in day 1 can be moved to work center 2 (see figure 6.3(b)). Similarly, from figure 6.2(b), the excess operation J on work center 2 in day 2 can be moved to work center 1 (see figure 6.3(a)). However, the excess operation G on work center 1 on day 4 cannot be moved to work center 2 since the slack capacity of work center 2 is not enough to accept the operation G.



(a) (b)

Figure 6.3 Load profile on work centers after allocating excess operations to the second priority work centers

4. <u>Determine the sequence of customer orders by applying dispatching rules</u>

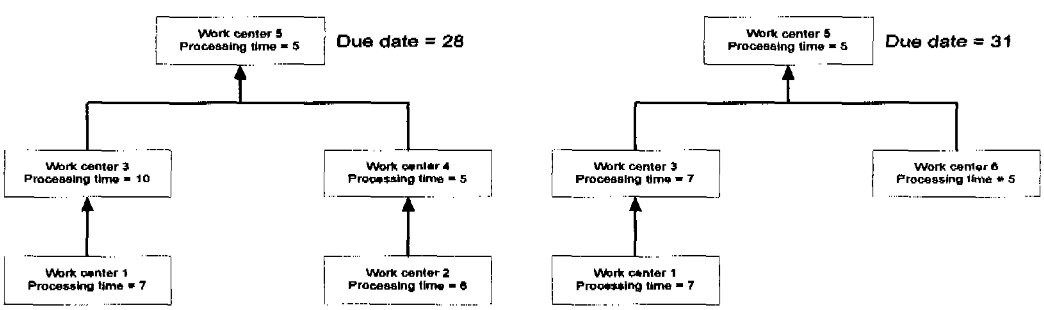
From the last step, all operations are assigned to the work centers considering finite capacity. However, the sequence of each operation on the work center is unknown. This step tried to determine the sequence of orders *(j)* based on the priority of customer orders by applying some dispatching rules. The objectives of this step are to generate different sequences and to study how dispatching rules affect the performance measures. There are three dispatching rules as follows:

4.1 Earliest due date (EDD) rule. This rule tries to produce the order which has the earliest due date first and produce the order with relatively late due date later.
4.2 Shortest total processing time on the longest path (SPT). This rule tries to produce the order, which has the shortest total processing time on the longest path first and produce the order with relatively long total processing time on the longest path later.
4.3 Minimum slack time (MST). This rule tries to produce the order, which has the minimum slack time first and produce the order with relatively long slack time later. The slack time is defined in Formula 1.

Slack time = due date – current date – total processing time along the longest path (1)

Figure 6.4 shows an example for illustrating the dispatching rules. Order A requires work centers 1, 2, 3, 4, and 5 while order B requires work centers 1, 3, 5, and 6. Due dates of orders A and B are 28 and 31, respectively. When the EDD rule is applied, the production sequence is to produce order A and then B. The total processing time on the longest path of order A is 22 days (sum of processing times of work centers 1, 3, and 5) while that of order B is 19 days (sum of processing times of work centers 1, 3, and 5). Therefore, if the SPT rule is applied, the production sequence is to produce order B and then A. Suppose the current date is 1. The slack time of order A is 5 (28-1-22) while that of order B is 12 (31-1-19). According to the MST rule, the production sequence is to produce order A and then B.

To reduce the complication of the scheduling algorithm, the sequence of all operations on each work center is assumed the same as the sequence of orders. For instance, after applying MST rule, a sequence of orders is A and then B. Therefore, the operation of order A must be performed before the operation of order B on any required work center. This is a concept of permutation schedule, which is well known in flow shop scheduling.



(a) Order A (b) Order B

Figure 6.4 An example for illustrating the dispatching rules

5. Determining the optimal start time of each operation by a weighted goal programming model (WGP)

The objectives of all previous steps are to assign operations to work centers in a manner that reduces the capacity problem on work centers and to determine the sequence of all operations (j) on each work center. However, the start and due times of each operation obtained from the first step have not been optimized. This section presents a linear goal programming approach to determine the optimal start time ($x_{i,j}$) and due time of each operation. The three performance measures considered as objectives (goals) are total tardiness (t_j), total earliness (e_j), and average flow-time (f_j). Other common performance criteria could also be of interest to the decision maker, including the number of early orders and tardy orders. They are not included as they do not alter the essential model characteristics. It is, however, possible and fairly easy to incorporate them as two additional goals. The model presented is a so-called weighted goal program (WGP) in that it considers all goals simultaneously as they are embodied in a composite objective function. From a modeling point of view there are several alternatives, see e.g. Romero (1991), Tamiz et al (1998). In lexicographic goal programming (LPG), for example, goals are classified into different levels of priority and highest priority goals are satisfied first and only then are lower priority goals considered. The selection of the best modeling alternative should be based on the practical problem under consideration; the decision maker's preferences are the most important. LPG may be preferred over WGP, for example, in the case that the company considers trying to meet due dates of customer demand immeasurably more important than inventory levels, in which case total earliness and average flow-time would be goals in a lower class of priority than total tardiness. In addition, the decision maker may wish to include the number of tardy orders as an additional goal in the highest priority class.

Objective

The objective of the model is to minimize the sum of penalty points incurred by exceeding the goals of total tardiness, total earliness, and average flow-time as shown in formula 2.

$$\text{Minimize} \quad C_t \cdot T^+ + C_e \cdot E^+ + C_f \cdot AF^+ \tag{2}$$

The penalty weights C_t, C_e, and C_f can be adjusted to obtain desirable performance measures. For example, if C_t is relatively high but C_e and C_f are relatively low, the total tardiness tends to be low but total earliness and average flow-time tend to be high.

Constraints

1. The sequence of orders on each work center must follow the one obtained by the dispatching rule in step 4.

   Note that the orders are renumbered based on the sequence of orders in a way that the first order in the sequence has $j = 1$ and the second order has $j = 2$. Constraint 3 ensures that on any work center, the first order in the sequence must start no later than the second order in the sequence, and so on.

$$x_{i,j} \leq x_{i,j+1} \qquad j = 1, 2, \ldots, N\text{-}1;\; i = 1, 2, \ldots, W \tag{3}$$

2. The work center cannot simultaneously produce more than one order.

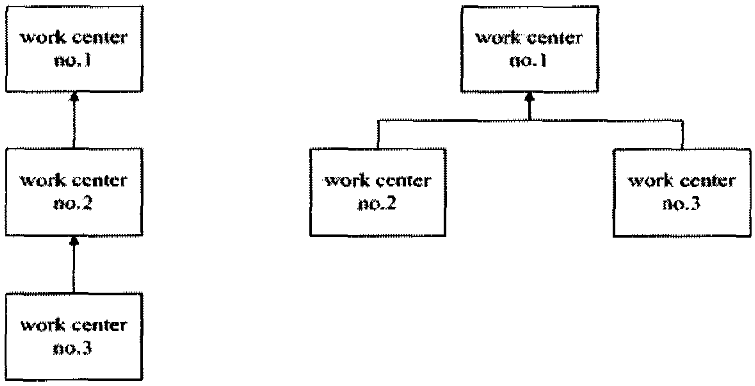
   Constraint 4 ensures that the next order on the same work center cannot be started unless the earlier one has finished.

$$x_{i,j+1} \geq x_{i,j}+p_{i,j} \qquad j = 1, 2, \ldots, N\text{-}1;\ i = 1, 2, \ldots, W \qquad (4)$$

Note that constraints (4) in fact make constraints (3) redundant.

3. The precedence relationship between work centers must be maintained.

Each product may have different production routes and requires different set of work centers. Based on the production route, there are some precedence relationships between work centers, which can be classified into two basic types, namely, sequential and convergent relationships (see figure 5). Complicated precedence relationships can be constructed from the basic sequential and convergent relationships.



(a) Sequential relationship (b) Convergent relationship

Figure 6.5 Precedence relationship between work centers

For sequential relationship:

$$x_{1,j} \geq x_{2,j} + p_{2,j} \qquad j = 1, 2, \ldots, N \qquad (5)$$
$$x_{2,j} \geq x_{3,j} + p_{3,j} \qquad j = 1, 2, \ldots, N \qquad (6)$$

For convergent relationship:

$$x_{1,j} \geq x_{2,j} + p_{2,j} \qquad j = 1, 2, \ldots, N \qquad (7)$$
$$x_{1,j} \geq x_{3,j} + p_{3,j} \qquad j = 1, 2, \ldots, N \qquad (8)$$

Note that the constraints 5 to 8 can be modified in order to allow the overlapping of production batches. For example, if the downstream work center is allowed to start after 10% of work has been finished on the upstream work center, the constraints can be modified as shown in Formulas 5' to 8'

For sequential relationship:

$$x_{1,j} \geq x_{2,j} + 0.1\, p_{2,j} \qquad j = 1, 2, \ldots, N \qquad (5')$$
$$x_{2,j} \geq x_{3,j} + 0.1\, p_{3,j} \qquad j = 1, 2, \ldots, N \qquad (6')$$

For convergent relationship:

$$x_{1,j} \geq x_{2,j} + 0.1\, p_{2,j} \qquad j = 1, 2, \ldots, N \qquad (7')$$
$$x_{1,j} \geq x_{3,j} + 0.1\, p_{3,j} \qquad j = 1, 2, \ldots, N \qquad (8')$$

4. Calculation of the completion time, tardiness, earliness, and flow-time.
   Based on the data in figure 5, the completion time of finished products, tardiness, earliness, and flow-time of each order can be formulated as follows:

$$c_j = x_{1,j} + p_{1,j} \qquad j = 1, 2, \ldots, N \qquad (9)$$
$$t_j = \max(c_j - d_j, 0) \qquad j = 1, 2, \ldots, N \qquad (10)$$
$$e_j = \max(d_j - c_j, 0) \qquad j = 1, 2, \ldots, N \qquad (11)$$

Of course, constraints (10) and (11) may be better written as one constraint:

$$d_j - c_j = e_j - t_j \qquad j = 1, 2, \ldots, N.$$

For sequential structures:

$$f_j = c_j - x_{3,j} \qquad j = 1, 2, \ldots, N \qquad (12)$$

For convergent structures:

$$f_j = \max\,(c_j - x_{3,j}\,,\, c_j - x_{2,j}) \qquad j = 1, 2, \ldots, N \qquad (13)$$

The constraint 13 may be specified as

$$f_j \geq c_j - x_{3,j} \qquad j = 1, 2, \ldots, N$$
$$f_j \geq c_j - x_{2,j} \qquad j = 1, 2, \ldots, N$$

5. The deviation of the total tardiness from its goal is defined by constraint 14.

$$\sum_{j=1}^{N} t_j + T^- - T^+ = X \qquad (14)$$

6. The deviation of the total tardiness from its goal is defined by constraint 15.

$$\sum_{j=1}^{N} e_j + E^- - E^+ = Y \qquad (15)$$

7. The deviation of the average flow-time from its goal is defined by constraint 16.

$$(1/N)\sum_{j=1}^{N} f_j + AF^- - AF^+ = Z \qquad (16)$$

8. Non-negativity condition
   All parameters and decision variables are non-negative.

It is quite essential for the model, in particular because of the precedence relationship constraints, that all work centers are operational and only operational during the same hours of a day, for example, x hours a day. This can be easily handled by defining a day as only consisting of x hours (as if the non-working hours of the day are not existent). The flow-time, earliness and tardiness measures are all relative to this new definition of time.

Note that the goals X, Y, and Z must be set before solving the goal programming model. In this paper, the best possible values of the total tardiness, total earliness, and average flow-time are set as the goals X, Y, and Z, respectively. A new objective function 17 and constraints 3 to 13 are used to determine the best possible values of the total tardiness, total earliness, and average flow-time.

$$\text{Minimize } C_t \cdot \sum_{j=1}^{N} t_j + C_e \cdot \sum_{j=1}^{N} e_j + C_f \cdot \left(\frac{1}{N} \sum_{j=1}^{N} f_j\right) \qquad (17)$$

The best possible values of the total tardiness, total earliness, and average flow-time are determined by setting $(C_t, C_e, C_f) = (1, 0, 0)$, $(0, 1, 0)$, and $(0, 0, 1)$, respectively. In this way, the goal of total tardiness (X) is equal to the minimum total tardiness obtained by minimizing the total tardiness without considering the total earliness and average flow-time, subjected to all constraints. As a result, the deviation T^+ is positive but the deviation T^- is always zero. The effects on the goals Y and Z are similar to that of the Goal X. The goal program obtained in this way has an underlying "optimizing philosophy" similar to distance metric optimization and therefore the solutions obtained will be Pareto optimal (see Tamiz et al, 1998). Alternatively, the decision maker may wish to set a value for X, Y, or Z lower than the highest possible achievable value which then reflects a "satisficing philosophy". In that case, it is best to check if the obtained solution is dominated and if so, to restore Pareto optimality (as in Tamiz and Jones, 1996). Finally, when including the number of early jobs and the number of late jobs as objectives, it is recommended to use a normalization technique in order to reduce any unintentional bias towards the objectives with a larger magnitude (see Tamiz et al, 1998).

6.2 Conventional FCMRP Systems (CFCMRP)

The CFCMRP systems used in industries are a combination of MRP and finite capacity scheduling systems, which are non-optimization approaches. The MRP system generates production orders assuming infinite capacity of work centers. The production orders indicate part ID, quantity to produce, and recommended start and due times. Then, the production orders will be loaded into the finite capacity scheduling system, where the start and completion times of each order will be calculated considering finite capacity of work centers. There are three conventional FCMRP systems, namely, forward (F), backward (B), and forward-backward (FB) scheduling systems. These systems have significant effect on system performances since they use different scheduling concepts.

This section explains the concept of the CFCMRP systems, namely, Forward (F) and Forward-Backward (FB) scheduling systems. The algorithm of the F scheduling system is presented in figure 6.6. The first four blocks of the algorithm are the same as those of the OFCMRP system. The remaining blocks of the algorithm try to schedule the operations based on the priority of customer orders (obtained from the dispatching rules). The operations of the order with index 1 will be produced first and the operations of the order with larger index will be produced later. These operations will be scheduled as soon as possible to the available time on the work centers considering precedence relationships of operations. By this method, some orders may be completed before their due dates. This results in increasing inventory holding cost. The FB scheduling system tries to alleviate this drawback by delaying the early-completed orders as much as possible without making the orders completed late. The algorithm of the FB scheduling system is presented in figure 6.7. Note that the characteristic and structure of the manufacturing process of CFCMRP system are the same as NFCMRP system explained in the last chapter.

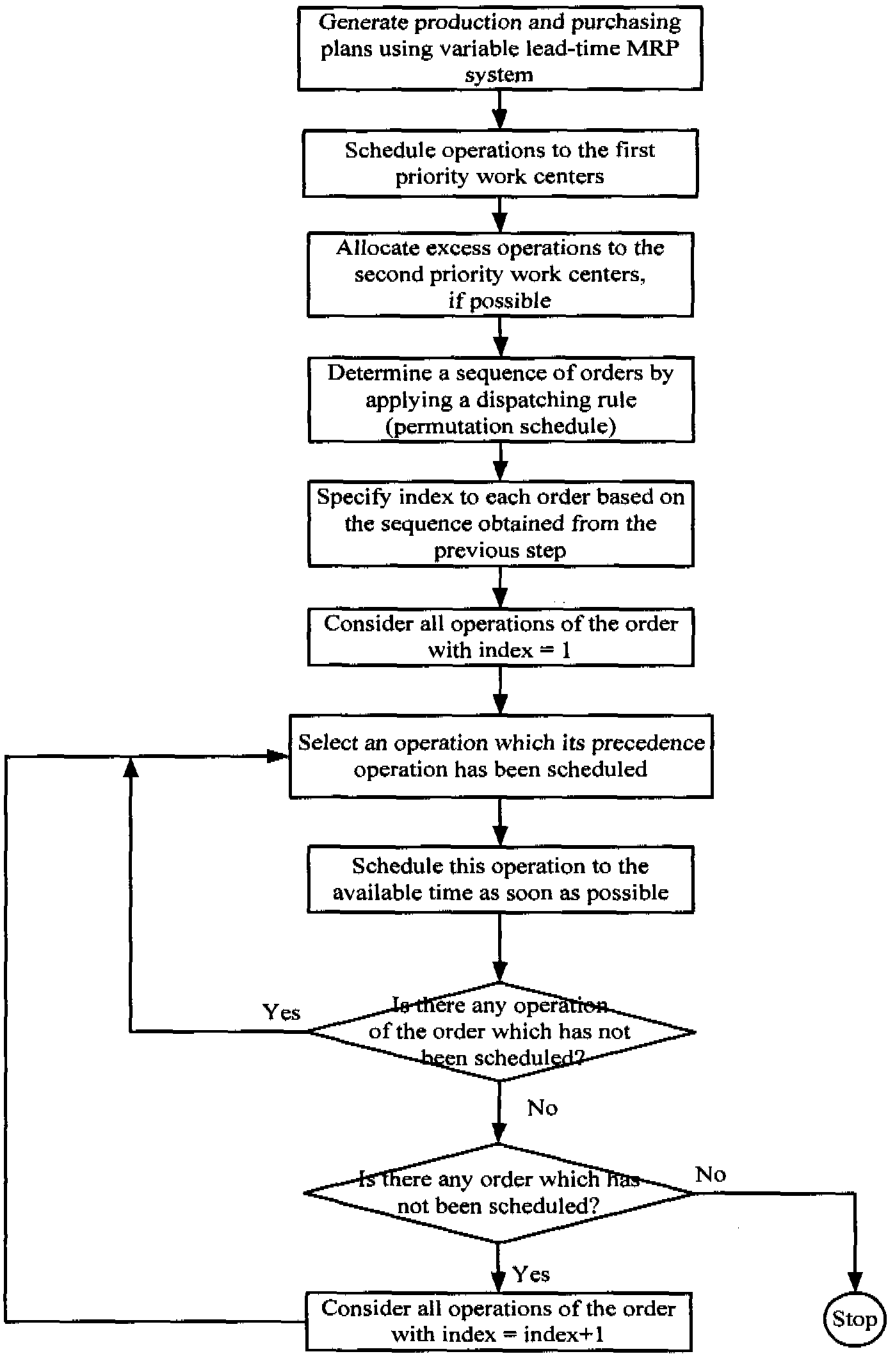


Figure 6.6 Algorithm of F scheduling system

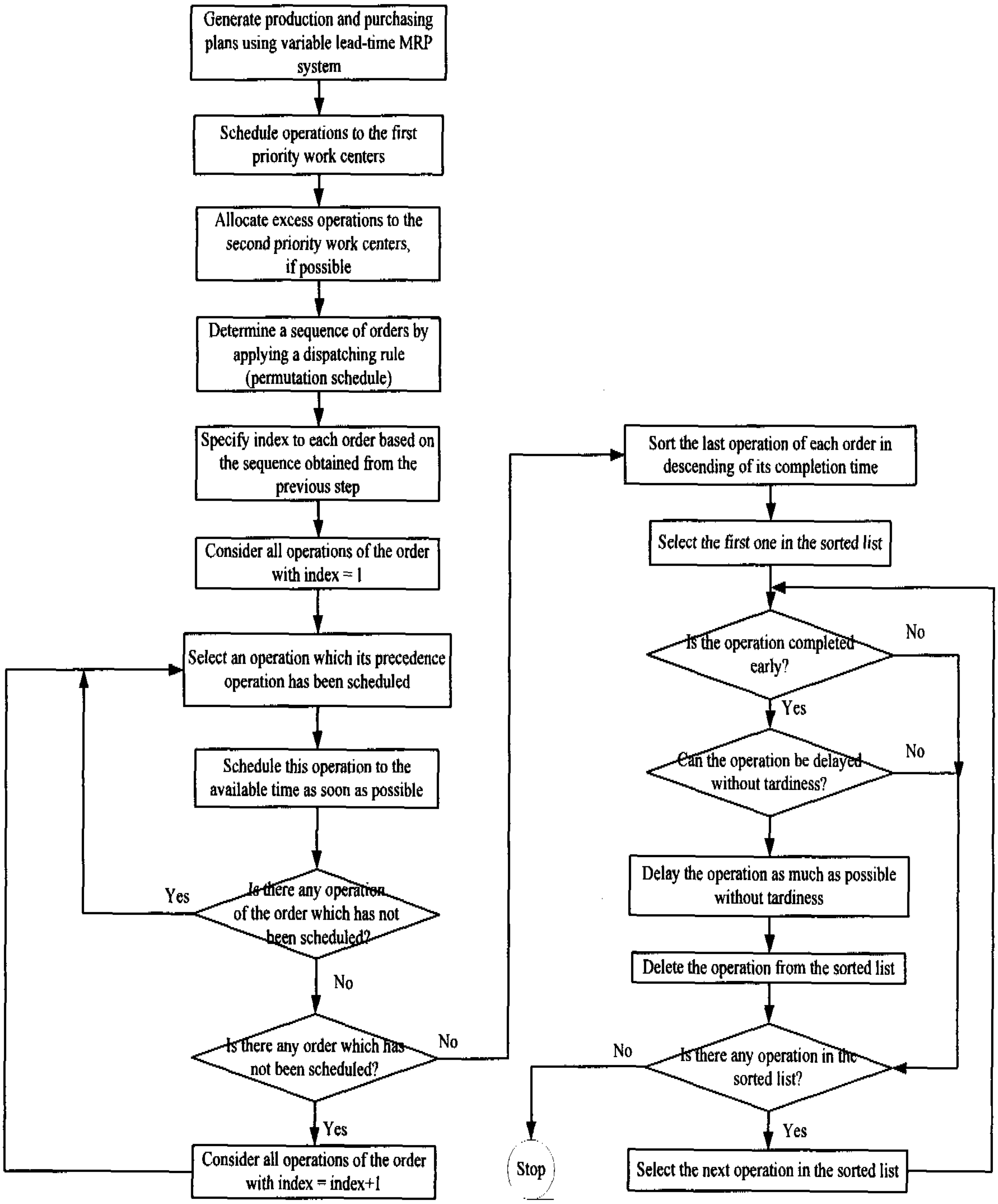


Figure 6.7 Algorithm of FB scheduling system

6.3 Design of Experiments.

There are two experiments in this chapter. The first experiment is to analyze the effect of the penalty weights (C_t, C_e, and C_f) on the performance measures. The second experiment is to analyze the effect of different FCMRP systems (OFCMRP, F, and FB) and dispatching rules on performance measures. Results of the analysis will indicate how the penalty weights and dispatching rules are selected to obtain the desirable performance. Both experiments use the same experimental case and dependent variables but different independent variables. The independent variables, dependent variables, and the experimental case are explained as follows.

Independent variables

1. Experiment to analyze the effect of penalty weights in the proposed OFCMRP system

The independent variable of this experiment is the set of penalty weight settings in the proposed OFCMRP system. There are four sets of penalty weights as follows:

1. Set $C_t = 0.80$, $C_e = 0.1$, $C_f = 0.1$ denoted by OFCMRP 1.
2. Set $C_t = 0.1$, $C_e = 0.80$, $C_f = 0.1$ denoted by OFCMRP 2.
3. Set $C_t = 0.1$, $C_e = 0.1$, $C_f = 0.80$ denoted by OFCMRP 3.
4. Set $C_t = 0.33$, $C_e = 0.33$, $C_f = 0.33$ denoted by OFCMRP 4.

Note that the dispatching rule in this experiment is EDD.

2. Experiment to analyze the effect of different FCMRP systems (OFCMRP, F, and FB) and dispatching rules

In this experiment, the penalty weights are set based on the opinion of the planner of this company. The planner feels that one day of total earliness is as important as one day of average flow-time while one day of total tardiness is five times as important as one day of total earliness. Thus, the penalty weights of total tardiness (C_t), total earliness (C_e), and average flow-time (C_f) are 0.72, 0.14, and 0.14, respectively. The objective of this experiment is to analyze the effect of different FCMRP systems (FCMRP, F, and FB) and dispatching rules on the performance measures. There are two independent variables as follows:

2.1 FCMRP systems

There are three FCMRP systems, namely, OFCMRP, F, and FB systems.

2.2 Dispatching rules

There are three dispatching rules: EDD, SPT, and MST.

Dependent variable

The dependent variable is the set of performance measures of the schedule generated by the FCMRP systems. There are five performance measures: number of early orders, total earliness (in days), number of tardy orders, total tardiness (in days), and average flow time of all products (in days). Note that the total tardiness and earliness are calculated only from the operations for producing finished products. The flow time of a product is the elapsed time, from the earliest time among the start times of all parts, to the finish time of the finished product.

Experimental case

The experiment is performed based on a real situation of a selected manufacturing company producing automobile steering wheels and gearshift knobs. The situation under consideration is briefly explained as follows:

1. The company is a shop with sequential and convergent precedence relationships and has 25 items of finished goods.
2. Bill of materials (BOM) has 3 to 10 levels depending on the products.
3. There are 20 work centers and two of them, work centers 13 and 15, are bottlenecks.
4. Some operations can be produced on more than one work center.
5. The first and second priority work centers are specified by the planner.
6. All work centers are operated 8 hours a day and overtime is not allowed.
7. Overlapping of production batches is not allowed.
8. The lot-sizing technique being used is lot-for-lot since it results in a low inventory level and it is the most popularly used by MRP users (Haddock and Hubicki, 1989).
9. The customer demand is assumed to follow a uniform distribution, where the maximum and minimum demands are ± 15% of the mean demand.
10. The actual demand of each product in a month is collected and used as the mean demand.

The experiment is conducted in 30 replications using 30 sets of randomly generated demands. The replication number of 30 is sufficient to obtain accurate mean values of performance measures since the 95% confidence interval of the population mean of each performance measure is within ± 2% of the mean value. A one-way ANOVA is used to statistically analyze the first experiment while two-way ANOVA is used for the second experiment.

6.4 Results and Discussions.

The results and discussions are divided into two sections. The first one is the analysis on the effect of penalty weights in the proposed OFCMRP system. The second one is the analysis on the effects of different FCMRP systems and dispatching rules.

6.4.1 Analysis on the effect of the penalty weights in the proposed OFCMRP system

Based on the method explained at the end of Section 2, the goals of the total tardiness (X), total earliness (Y), and average flow-time (Z) are set at 154.47, 15.06, and 12.52 days, respectively. The average value of the performance measures and the ranking of the performance measures obtained from the Duncan's multiple mean comparison method are shown in table 6.1. The ranks are presented in parentheses. The lower rank has a better performance than the higher rank. The performance measures with the same rank are not significantly different.

Table 6.1 clearly shows that the penalty weights have a significant effect on all performance measures, the number of early orders, total earliness, the number of tardy orders, total tardiness, and average flow-time. The total tardiness is the lowest when OFCMRP 1 is applied. This occurs since the penalty weight of exceeding the goal of total tardiness (C_t) is set to 0.80, which is greater than those of total earliness (C_e) and average flow-time (C_f). If the planners want to minimize the earliness and average flow-time, OFCMRP 2 and OFCMRP 3 should be applied, respectively. In contrast, if they want to compromise all performance measures, all penalty weights should be set equally (OFCMRP 4).

Table 6.1 Effects of penalty weights in objective function on performance measures

Factors	penalty weights			Total tardiness (days)	No. of tardy orders	Total earliness (days)	No. of early orders	Average flow-time (days)
	C_t	C_e	C_f					
OFCMRP 1	0.8	0.1	0.1	159.15(1)	119.58(1)	29.77(3)	24.52(3)	15.63(3)
OFCMRP 2	0.1	0.8	0.1	169.64(5)	130.56(4)	22.33(1)	16.33(1)	15.11(3)
OFCMRP 3	0.1	0.1	0.8	166.43(4)	126.72(3)	24.92(2)	18.84(2)	13.78(1)
OFCMRP 4	0.33	0.33	0.33	164.33(3)	125.37(2)	25.06(2)	19.33(2)	14.48(2)

Dispatching rule = EDD
Total number of customer orders = 252 orders

6.4.2 Analysis on the effects of different FCMRP systems and dispatching rules

The ANOVA results of the experiment used to analyze the effects of the different FCMRP systems and dispatching rules are shown in table 6.2. It reveals that different FCMRP systems and dispatching rules have significant effect on all performance measures. The interaction effect between the FCMRP systems and dispatching rules is only significant on total earliness and number of early orders but insignificant on other performance measures. The average values and ranking of performance measures are shown in table 6.3.

Table 6.2 Analysis of variance results

Factors	Total tardiness (days)	No. of tardy orders	Total earliness (days)	No. of early orders	Average flow-time (days)
FCMRP systems (FCMRP)	0.000*	0.000*	0.000*	0.000*	0.000*
Dispatching rules (D)	0.000*	0.000*	0.000*	0.000*	0.000*
FCMRP x D	0.658	0.487	0.000*	0.000*	0.554

* the effect is significant at significant level of 0.05

Table 6.3 Average values and ranking of performance measures

Factors	Total tardiness (days)	Number of tardy orders	Total earlines s (days)	Number of early orders	Average flow-time (days)	Overall performance index
FCMRP systems (FCMRP)						
OFCMRP	162.89(2)	120.97(2)	30.87(1)	25.13(1)	15.56(1)	209.32(1)
F	156.36(1)	115.06(1)	43.79(3)	39.08(3)	16.22(2)	216.37(3)
FB	156.36(1)	115.06(1)	38.80(2)	33.04(2)	16.49(2)	211.77(2)
Dispatching rules (D)						
EDD	156.69(1)	116.23(1)	36.37(2)	32.04(2)	16.60(2)	209.66(1)
SPT	159.94(3)	117.81(2)	35.74(1)	30.66(1)	16.04(1)	211.73(2)
MST	159.09(2)	116.96(1)	41.35(3)	32.54(2)	16.62(2)	217.07(3)

Based on table 6.3, the proposed OFCMRP system significantly outperforms F and FB systems for all performance measures. This evidence shows that the linear goal programming model presented in step 5 of the proposed OFCMRP algorithm is effective to determine the optimal start time of each operation. The FB system significantly outperforms F system for total earliness and number of early orders, but both systems are not significantly different in terms of total tardiness, number of tardy orders, and average flow-time. This indicates that the algorithm of FB system, which tries to delay too early-completed orders, is effective for reducing the earliness without significantly deteriorating other performance measures.

An overall performance index can be determined using a weighted average of some performance measures calculated based on the opinion of the planner (see Section 4). The weights of total earliness (C_e), total tardiness (C_t), and average flow-time (C_f) are 0.14, 0.72, and 0.14, respectively. The reason why the tardiness is the highest is the same as explained in chapter 5. The overall performance indices are presented in table 3. It indicates that the proposed OFCMRP system results in the best overall performance index when compared to the F and FB systems. The OFCMRP system can offer the best overall performance index since it has an ability to trade-off between conflicting performance measures.

However, when the trade-off is not required, such as to minimize only the tardiness (C_t =1), the OFCMRP system results in total tardiness, the total earliness, and average flow-time of 156.35, 43.77, and 16.22 days, respectively. These performance measures are the same as those of F system since the proposed OFCMRP tries to minimize only the tardiness which is similar to the algorithm of F system that tries to start and finish all operations as soon as possible.

Comparing the dispatching rules presented in table 6.3, the EDD rule turns out to be the best for total tardiness and number of tardy orders (it has rank 1 for these performance measures). The SPT rule is the best for total earliness, number of early orders, and average flow-time. The MST rule is not the best for any performance measure. The EDD rule is more appropriate than the SPT rule when the planner feels that the tardiness is more important than the earliness, and vice versa. Although the scheduling algorithm and environment in this experiment are much more complicated than those of the basic single-work center scheduling theory, the results are complying. Based on the single-work center scheduling theory, the SPT rule minimizes the average flow-time and the EDD rule minimizes the maximum tardiness. Moore (1968) developed an algorithm based on EDD, which minimizes the number of tardy orders.

The interaction effect between the different FCMRP systems and dispatching rules is significant only on total earliness and number of early orders. The graphs showing the interaction effect are presented in figures 6.8 and 6.9. They show that the effect of dispatching rules on total earliness and number of early orders of F system is greater than that of FB and the proposed OFCMRP system.

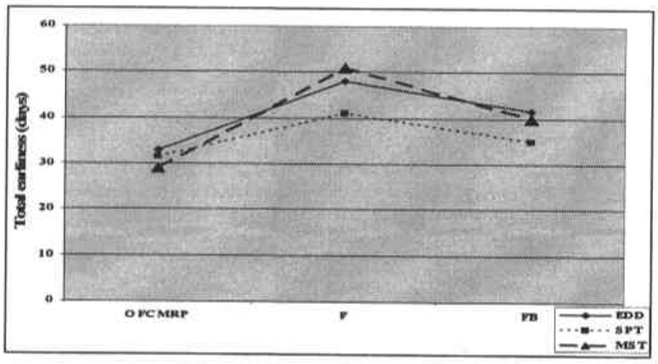


Figure 6.8. Interaction between FCMRP systems and dispatching rules on total earliness

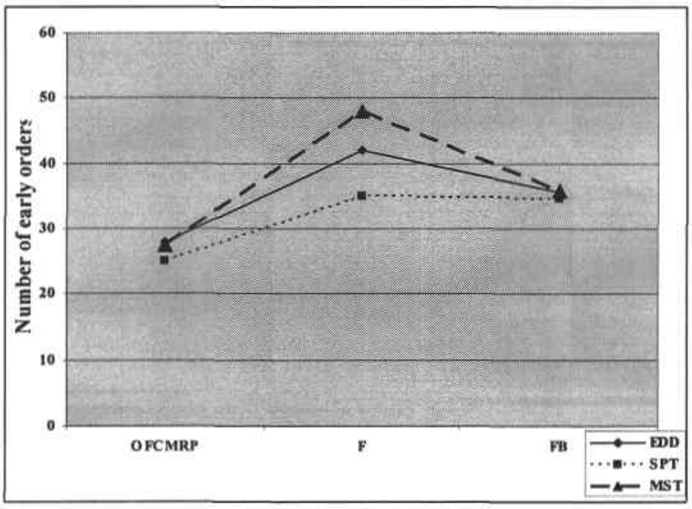


Figure 6.9. Interaction between FCMRP systems and dispatching rules on number of early orders

6.5 Conclusions

A new FCMRP system, which has optimization ability and is applicable for real industrial problems, was developed. It uses a linear goal programming model to determine the optimal start time of each operation to minimize the sum of penalty points incurred by exceeding the goals of total earliness, total tardiness, and average flow-time considering finite capacity of all work centers and precedence of operations. Based on the experimental results, the proposed OFCMRP system outperforms the CFCMRP systems (F and FB scheduling systems) for all performance measures.

The performances of the proposed OFCMRP system can be controlled by selecting appropriate dispatching rules and penalty weights. The effects of the dispatching rules and penalty weights on the performance measures are statistically analyzed based on the real data of an auto-part factory.

The penalty weights should be set based on relative importance of each performance measure. For example, when the planner feels that the tardiness is the most important, followed by the earliness and flow-time, the weight of tardiness should be the highest, followed by those of the earliness and flow-time. In this way, the resulting schedule will have relatively low tardiness.

Three dispatching rules, namely, SPT, EDD, and MST, are considered in the proposed FCMRP system. The EDD rule results in low tardiness. The SPT rule results in low earliness and flow-time. The MST rule is not the best for any performance measure.

The proposed OFCMRP system still has limitations. The lot-sizing policy under consideration is only lot-for-lot and the effect of different lot-sizing policies has not been studied. All work centers must be operated during an identical number of hours per day. This limitation can be relaxed by introducing some binary variables to the model. However, the model with binary variables is more difficult to solve. The dispatching rules under consideration are only simple rules. More complicated and effective dispatching rules can be developed. Thus, further research is needed to analyze and develop the FCMRP system to improve these limitations.

Next chapter, a comparison between the IMFCMRP system which is an improvement of NFCMRP system and the OFCMRP system is discussed and analyzed.