PRODUCTION PLANNING WITH FUZZY DUE WINDOWS

Yue Wu and K K Lai
Department of Management Sciences
City University of Hong Kong
HONG KONG

Abstract:- This paper is concerned with production loading planning problems for a multinational company in Hong Kong. Loading orders from different counties in a factory is a practical and important problem. According to the JIT (Just-In-Time) global supply chain strategy, we define an objective function based on some definition, such as fuzzy due date, satisfaction grade and membership function. An algorithm for loading production planning is provided with fuzzy due windows. A practical example provided by the company shows the effectiveness of the algorithm.

Keywords: - Global supply chain, production planning, fuzzy due window, Just-In-Time.

1. Introduction

Industrial corporations of the past several years have substantially increased the scope and magnitude of production and distribution systems. Most companies that have adopted global strategies have sought to improve their competitive position by utilizing the “best” mix of available worldwide resources. There is a wealth of literature that addresses global supply chains and related topics. Bhatnagar et al. [1] review the coordination of production planning among multiple plants in a vertically integrated firm. Geoffrion and Power [2] discuss the evolution of strategic distribution systems design over the last 20 years. Slats et al. [3] analyze and evaluate the role that operations research can play in logistic chain integration and business process re-engineering. Thomas and Griffin [4] review the literature addressing coordinated planning between two or more stages of the supply chain. Vidal and Goetschalckx [5] present an extensive literature review of strategic production-distribution systems models. Beamon [6] reviewed the available supply chain models and methods, and identified agenda for future research. Erengυc et al. [7] offered a focused review of the literature on effective management of operations by integrating production and distribution planning in supply chains.

Under the competitive environment, companies adopt Just-In-Time (JIT) supply chain strategies, where producing orders early, as well as late, is discouraged. In a JIT environment, customers may not accept early delivery of orders, even if they do they may not be willing to be billed for the orders until the original due date. In either case, the company incurs several costs when an order is produced early; for example, costs caused by the extra investment in its finished products inventory, costs involved in extra storage facilities and product spoilage cost. Recent developments have focused on extending models to a more practical application. However, some models often fail in applying to real-world problems because they treat data as precisely known. Information that expert receive about the system’s data is however often imprecise. As a result, a model may not perform well for practical problems. Fuzzy set theory has its uses in solving these problems during manufacturing processing. It provides a means for modeling parameter values, which are not given as crisp numbers but as imprecise data. Ishii, Tada and Masuda studied two machines open shop scheduling problems with a defined fuzzy due date [8]. Publications do exist that address inclusion of a fuzzy due date [9, 10]. In the company’s JIT global supply chain situation, human-centered factors are incorporated into the problems, it may thus be more appropriate to consider fuzzy due windows due to man-made factors that exist in production loading planning problems.

In this study we concentrate on a production loading planning problem in a multinational company in Hong Kong. The production loading planning process and model are described in Section 2. We outline the orders allocating process in the company, and formulate a production loading planning model with fuzzy due windows. A production loading planning algorithm is presented in Section 3. In Section 4 we discuss an example for the practical application of the proposed algorithm in the company.

2. Production Loading Planning

We are typically motivated by a problem faced with a multinational garment manufacturing company which has its headquarters in Hong Kong, its sales branches in North America and Europe, and its manufacturing factories (owned, incorporated or subcontracted) in mainland China, the Philippines and other South-east Asian countries. In a global market, each factory has its own production structure differing from other factories in terms of capacity and type of production facilities, amount and price of raw materials, technical capacity, labour costs, transportation patterns and customer response. The Hong Kong headquarters collects the orders through its American and European branch offices. It then allocates the production plan among its manufacturing factories. These purchasing orders often have special requirements. In particular, a preferred manufacturing location is associated with orders. The orders from North America and Europe are usually required to be finished in the mainland China factory, while orders from the UK or other countries can be made in the Philippines or Sri Lanka. For example, a kind of orders for silk needs to be processed in a special China factory, as good raw material, novel style, low product defect, and low cost. Loading of these special orders among these special factories according to customer requirements is continuous. Planners, in certain circumstances, may need to negotiate with the factory to ensure the actual manufacturing time of each order.

In many situations, the concept of due window does not formulate the customer preference well. Customers provide a fixed due window for manufacturing, and hope that their orders are manufactured during the window period. However, orders are often not processed due to insufficient factory capacity or the taking on of other commitments. We thus propose the concept of the fuzzy due window in replacement. Customer satisfaction can in this way be achieved with help in target of accuracy. Based on the concept of the fuzzy due window, we define the membership function of the fuzzy due window in such a way that it corresponds to a customer satisfaction grade which is related to manufacturing time. The company then loads its production plan among the factory in order to maximize the number of satisfied customers.

2.1 Problem Formulation

There are *N* orders to be processed in a factory. Order preemption and splitting are not permitted. The factory cannot process two or more orders simultaneously. Processing time p_j and satisfaction level r_j of order *j* is known. The satisfied due window of order *j* is $[d_j^b, d_j^e]$. We then define another two variables associated with the due window: the optimistic due date d_j^o and the pessimistic due date d_j^p, where $d_j^o \le d_j^b \le d_j^e \le d_j^p$. The actual beginning time and completion time of manufacturing order *j* is described by b_j and c_j. The membership function of order *j* is defined as follows:

$$m_j = \begin{cases} 0 & c_j \in (-\infty, d_j^o) \cup (d_j^p, +\infty) \\ 1 & c_j \in [d_j^b, d_j^e] \\ (c_j - d_j^o)/(d_j^e - d_j^b) & c_j \in (d_j^o, d_j^b) \\ (d_j^p - c_j)/(d_j^p - d_j^e) & c_j \in (d_j^p, d_j^e) \end{cases} \quad (1)$$

If order *j* is completed within its due window $[d_j^b, d_j^e]$, the customer is satisfied, and the membership function value is equal to 1. If order *j* is completed within $[d_j^o, d_j^b]$ or $[d_j^e, d_j^p]$, the customer satisfaction grade is lower and the membership function value of order *j* will be located between 0 and 1 ($0 < m_j < 1$). If the completion time of order *j* is among $(-\infty, d_J^o]$ or $[d_j^p, +\infty)$, the customer will not be satisfied and the membership function will be equal to 0.

We define a 0/1 variable as follows:

$$w_j = \begin{cases} 1 & m_j \geq r_j \\ 0 & m_j < r_j \end{cases} \qquad (2)$$

Where j=1,2,…,N.

Thus, we define the objective function as:

$$f = \sum_{j=1}^{N} w_j \qquad (3)$$

Our objective is to find the optimal production planning system for the company, so as to maximize the objective function. From our definition of the objective function, we know that the optimal production plan will result in the maximum number of satisfied customers.

3. Loading Planning

Obviously, there exists an optimal plan, which involves no order being early. As the membership function is lower than the customer satisfaction grade meaning that customers will not be satisfied with this completion time. It would also result in a fixed penalty. During loading planning process, the planner does not allocate manufacturing of this order before its delivery window because early production would result in higher inventory costs.

Let $[e_j^a, e_j^b]$ denote the satisfied time window, where the completion time of order j achieves a customer satisfaction grade. Another time window [s_j^a, s_j^b] correspondingly denotes the starting time interval of order j, i.e. $s_j^a = e_j^a - p_j$ and $s_j^b = e_j^b - p_j$. Let N denotes the set of all orders, and A denotes the set of satisfied orders. Let $k = \arg(\max_{j \in n} s_j^b)$ and $t = \max_{j \in n}\{s_j^b\}$. t is the latest starting time among all orders, which are the satisfied orders and k is the processing position.

At the beginning of the iterations, if k belongs to A, k is the first order in A. If two orders are processed during their satisfaction interval time, there is an overlapping time interval. We call these two orders as overlapping orders. Order i and order j are overlapping order, when case 1 or case 2 occurs, as shown in Figure 1 and Figure 2.

Case 1: $e_j^a \leq t \leq e_j^b$

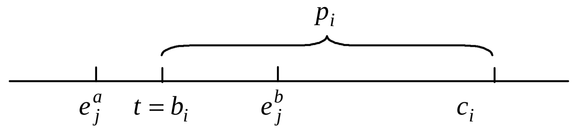

Figure 1. Overlapping Orders When $e_j^a \leq t \leq e_j^b$

In this case, we can reduce the satisfaction time interval, i.e. $s_j^b = t - p_j$; $e_j^b = t$. Thus, order j and order i become non-overlapping orders.

Case 2: $t < e_j^a$

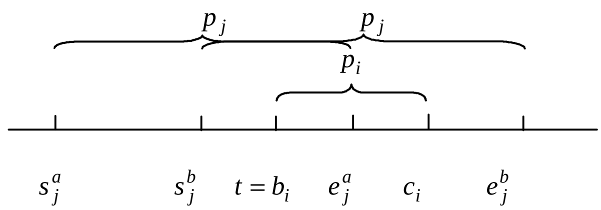

Figure 2. Overlapping Orders When $t < e_j^a$

If order i is excluded from the set A, in the meantime let order j belong to set A as a substitute. However, it is clear that all orders prior to order i cannot belong to set A by this replacement. Thus, set A cannot be expanded by this replacement. This case is shown in Figure 3.

In our algorithm, the first order to be selected is the last satisfied order to be processed. In each of the following iterations, an order is selected which has the largest e_k^b among the remaining orders. In each iteration, the iteration results of order k are described as follows:

- Order k belongs to set A , if $t \leq e_j^a$
- Order k belongs to set B, if $t > e_j^a$
- The satisfied window of order k is updated, if $e_j^a \leq t \leq e_j^b$.

The loading process is completed after all orders have been allocated. Our objective is to minimize the objective function. From our definition of the objective function, we know that maximization of the objective function will result in the maximum number of the satisfied customers. In our algorithm, we also consider the utilization ratio of the factory. We allocate non-satisfied orders to be processed during idle time between two satisfied orders or after all satisfied orders have been processed.

3.1 Algorithm Procedure

As above, we present a polynomial-time algorithm to allocate all orders in a factory. *A* is the set of satisfied orders; n_1 is the number of orders in *A*; *B* is the set of non-satisfied orders; n_2 is the number of orders in *B*; g_i is the idle time interval, after all the orders in *A* have been processed; *G* is the set of g_i, $i = 1,2,...,n_1 - 1$; g_i^{left} is the value of left end point of g_i; g_i^{right} is the value of right end point of g_i; g_i^{size} is the length of g_i. The algorithm steps are shown in Figure 3.

4. Illustrative Example

To illustrate the model, we use the data provided by company orders from North America and Europe. Silk orders must be processed in the Shenzhen factory, which is located next to Hong Kong. The orders received in the production season during June 1999 are shown in Table 1. A total of 10 orders from the company's North American and European markets are considered. Table 2 shows the results of the production loading plan as provided by our algorithm. The company may utilize the results to arrange the factory's production plan. Figure 4 shows the start and completion times of each order in the factory.

5 Conclusion

In this paper, we studied a production loading planning problem in a multinational garment manufacturing company located in Hong Kong with "remote" product markets and "remote" manufacturing bases. In this case, orders from North America and Europe are required to be processed in certain factories located in mainland China, the Philippines, and other South-east Asian counties. We define an objective function corresponding to a JIT supply chain system so as to satisfy customer delivery requirements. We provide a polynomial time algorithm to assign the production loading plan. An illustrated example shows the effectiveness of the algorithm. Our study can also be applied to other cases involving multinational production projects, although certain adjustments may be necessary. We are currently extending the problem to chain structures that have an impact on production planning over the multiple levels of a subcontracting network in order to achieve overall planning effectiveness.

6 References

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Step 0: N={all available orders}; n={number of all orders};

Initialize: $A = \Phi$; $B = \Phi$; $G = \Phi$; $n_1 = 0$; $n_2 = 0$; $j = 1$;

Input: p_j; r_j; d_j^o; d_j^b; d_j^e; d_j^p;

Step 1: $e_j^a = d_j^o + r_j(d_j^b - d_j^o)$; $e_j^b = d_j^p + r_j(d_j^p - d_j^e)$; $s_j^a = e_j^a - p_j$; $s_j^b = e_j^b - p_j$;

If ($j \le n$), go to Step 1; otherwise, go to Step 2;

Step 2: $k = \arg(\max_{j \in N} s_j^b)$; $t = \max_{j \in N}\{s_j^b\}$; $B = B \setminus \{k\}$;

If ($n_1 + n_2 \ne n$), $q_1 = s_k^a$; $q_2 = s_k^b$; $q_3 = e_k^a$; $q_4 = e_k^b$; $q_5 = p_j$;

$s_k^a = s_m^a$; $s_k^b = s_m^b$; $e_k^a = e_m^a$; $e_k^b = e_m^b$; $p_k = p_m$;

$s_m^a = q_1$; $s_m^b = q_2$; $e_m^a = q_3$; $e_m^b = q_4$; $p_m = q_5$;

$b_{n_1} = s_m^b$; $c_{n_1} = e_m^b$; $A = \{k\}$; $n_1 = n_1 + 1$; $n = n - 1$; i=1;

Step 3: If ($d_i^o \le t \le d_i^b$), $s_i^b = t - p_i$; $e_i^b = t$; go to Step 5;

otherwise, if ($t < d_i^o$); $B = B \cup \{i\}$; $n_2 = n_2 + 1$; N=N\{i}; h=j; go to Step 4;

otherwise, go to Step 5;

Step 4: If ($h < n$), $s_h^a = s_{h+1}^a$; $s_h^b = s_{h+1}^b$; $e_h^a = e_{h+1}^a$; $e_h^b = e_{h+1}^b$; $h = h + 1$; go to Step 4;

Step 5: $i = i + 1$; If ($i < n$), go to Step3;

Step 6: If ($N \ne \Phi$), $m = m - 1$; go to Step 2;

Step 7: Arrange the jobs of set B in ascending order of p_j;

Arrange the jobs of G in ascending order of g_i^{size}; i=1; j=1;

Step 8: If ($i \le n_1$) &($j \le n_2$), if ($delay_j \le g_i^{size}$), $b_j = g_i^{left}$; $c_j = s_j + p_j$; $B = B/\{j\}$; $g_i^{left} = g_i^{left} + delay_j$;

$g_i^{size} = g_i^{right} - g_i^{left}$; j=j+1; go to Step 8;

otherwise, i=i+1;

Step 9: For the orders in A: $c_j = d_j^b$, $b_j = c_j - p_j$, $j \in A$;

For the orders in B: b_1 = completion time of the first order in A, $c_1 = b_1 + p_1$,

$b_j = c_{j-1}$, $c_j = b_j + p_j$, $j \in B, j \ne 1$;

Figure 3. Algorithm Procedure

Order	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	Order 7	Order 8	Order 9	Order 10
p_j	12	6	16	7	6	8	10	4	4	2
r_j	0.8	0.3	0.2	0.6	0.9	0.7	0.5	0.6	0.8	0.9
d_j^p	14	15	29	31	35	35	36	51	31	37
d_j^b	18	18	35	36	41	40	40	56	38	38
d_j^e	20	25	40	39	49	49	50	60	45	38
d_j^p	24	30	50	42	51	52	58	70	56	40

Table 1. Orders Data from North American and European

Order	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	Order 7	Order 8	Order 9	Order 10
p_j	12	6	16	7	6	8	10	4	4	2
b_j	8	22	72	29	54	64	44	40	60	36
c_j	20	28	88	36	60	72	54	44	64	38
w_j	0	0	1	0	1	1	0	0	0	0

Table 2: The Results of the Production Loading Plan from Our Algorithm

Figure 4. Actual Manufacturing Time of Orders in the Shenzhen Factory