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# A multiple criteria decision-making model for justifying the acceptance of rush orders

M. C. WU and S. Y. CHEN

**Keywords** rush order, multiple objective programming, e-constraints

**Abstract.** Rush orders are immediate customer demands that exceed the expectation of a currently effective MPS (master production schedule). Decision-makers are often hesitant in the decision of accepting such orders. This paper presents a multiple criteria decision-making model for justifying the acceptance of rush orders for an assembly-to-order production system. Four criteria or production objectives are simultaneously considered and a multiple objective programming technique, the e-constraints approach, is adopted to solve the decision-making problem. This model could give the cost estimation for producing a rush order under various combinations of production objectives. The computed cost value could serve as a valuable reference for justifying the economics of accepting the rush order, and help to determine its pricing strategy.

## 1. Introduction

This paper investigates the decision-making problem presented by rush orders. Rush orders are immediate

customer demands that cannot be effectively supplied by performing the current master production schedule (MPS). In a dynamic market, rush orders are frequently faced by manufacturing companies, especially by those doing OEM business (making products for other Firms' brands) in developing countries. The decision for accepting or rejecting a rush order often puzzles decision-makers. Marketing department tends to accept it for increasing sales and the number of future customers; conversely, the production department tends to reject it to avoid the frequent change of MPS and the increase of production cost. To resolve the trade-off issue, an analytic model for justifying the acceptance of rush orders is required.

Since rush orders are immediate demands, if they are accepted, their production time should be scheduled in the first few periods of the new MPS. However, such a decision is forbidden in a 'freezing scheduling' environment. The concept of 'freezing scheduling' advocates that

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the MPS should be replanned periodically to respond to the updated demand data, while the first few periods of the MPS should be frozen in each planning cycle to accommodate the committed production resources. This concept is widely adopted in industry and much relevant literature has been published (Chung and Krajewski 1986, Lin and Krajewski 1992, Sridharan and Berry 1990). Such studies unquestionably would suggest the rejection of rush orders.

An alternative attempt to justify the acceptance of rush orders is by applying previous studies in aggregate production planning (APP) to replan the MPS and compute the increased production cost. However, at the concerned decision point, some production resources or purchasing activities associated with the original MPS have been committed. And the cost of such commitments has seldom been discussed in previous APP studies (Deckro and Herbert 1984, Masud and Hwang 1980, Nam and Logendran 1992, Rakes *et al.* 1984, Vercellis 1991). Therefore, the decision-making problem presented by rush orders cannot be directly solved by existing APP approaches.

This paper proposes a multiple objective programming model for justifying the acceptance of rush orders, in which the cost caused by commitments of the original MPS has been considered. Four production objectives for the decision-making are concerned, which involve (1) minimizing the extra spending for producing the rush order, (2) minimizing the shipping delay of crucial orders, (3) minimizing the demand of cash or quick assets, and (4) minimizing the inventory level. Of the existing multiple objective programming techniques (Steuer 1986), this research adopts the e-constraints approach. That is, one of the four objectives is considered as the main objective which is to be minimized if possible and the other three are taken as constraints by giving their upper bounds.

The proposed model can be used to compute the cost for producing a rush order under various combinations of production objectives. This cost value would provide good reference for justifying the acceptance of the rush order and help determine its pricing strategy. Moreover, the new MPS suggested by the model is optimal in the criteria of the main objective.

## 2. Assumptions of production systems

The production system concerned in this research is an assembly-to-order factory where products are assembled from various types of components upon request of customer orders (Krajewski and Ritzman 1987). Also, the system is assumed to be a single-stage system; that is, all the components or materials are purchased from out-

$$[M_{ik}] = \begin{bmatrix} 1 & 2 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 2 & 0 & 1 & 2 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 2 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \end{bmatrix}$$

Figure 1. An example of product-material relationship matrix (PMR), which represents the relationships between 5 products and 10 components.

side vendors. Some other assumptions concerning the product structures as well as relevant production planning activities are given below.

- (1) *Product structures*: multiple products are produced and they share the use of some common materials. The usage of common materials can be described by a product-material relationship (PMR) matrix as shown in Figure 1. The PMR matrix consists of  $n$  rows and  $m$  columns, which represent, respectively, the numbers of product types and material types. An element  $M_{ik}$  in the matrix denotes the quantities of materials  $k$  required for producing one unit of product  $i$ .
- (2) *Workforce size*: the workforce size has been pre-planned and cannot be changed at the decision point.
- (3) *Materials purchasing activities*:
  - No order cancellation: all issued orders of components cannot be cancelled.
  - Normal lead time: the normal lead time for each type of component is a constant.
  - Urgent purchasing: urgent delivery service of components is available. However, the price for any urgent purchasing is dependent upon the lead time. That is, urgently needed materials which require shorter lead time cost more.
  - Punctual delivery: all the purchasing materials are delivered punctually.
  - Beginning inventory: at the decision point the beginning inventory levels of all components are assumed to be zero.
- (4) *Production setup*: switching the production from one type of product to any other type demands a setup. At the end of each period, a maintenance or setup procedure is required in the factory. The setup time and cost for maintenance or production switching are constants.
- (5) *Backorders of products*: the company allows the occurrence of backorders. Each order is given an

upper bound of tolerable delay periods. In order to keep good relationship with customers, no order should be delayed beyond its tolerable delay period. That is, if the acceptance of a rush order would cause intolerable delay, the rush order would not be accepted.

- (6) *Rush order and capacity*: if the unassigned capacity left in the currently effective MPS is larger than the required production time of the rush order, then we come to a decision to justify acceptance of the rush order; otherwise, it is rejected. This means that the rush order together with the orders left in the original MPS should be completely produced in the new MPS.

### 3. Notation

Indices, parameters, constants, and decision variables used in the proposed model are introduced below.

#### 3.1. Indices, parameters and constants

$i$	an index denoting the type of product
$j$	an index denoting the identification of orders
$k$	an index denoting the type of components
$t$	an index denoting the time period in the planning horizon of the MPS; the rush order, if accepted, is to be produced at the first period $t = 0$
$m$	total number of component types
$n$	total number of product types
$J$	total number of orders planned in the original MPS
$T$	the last time period in the original MPS; that is, the total time periods left in the original MPS is $T + 1$ , starting from $t = 0$ to $t = T$ (period)
$W(t)$	the workforce size at period $t$ (men)
$L(k)$	normal lead time for the requisition of component $k$
$R_i$	the demanded quantity of product $i$ in the rush order
$CP_k$	the unit cost of purchasing component $k$ under normal lead time requirement
$r_k(t)$	the percentage of extra charge in purchasing component $k$ which is urgently needed and its demanded lead time is $t$ .
$W_r$	labour rate, regular time (\$/man-hour)
$W_o$	labour rate, overtime (\$/man-hour)
$C_s$	cost per setup (\$/setup)
$T_s$	required time per setup (hours/setup)
$K_i$	the conversion factor of product $i$ (man-hours/unit)

$PV_i$	the unit manufacturing cost of product $i$ (\$/unit)
$int$	the interest rate per period
$U(t)$	labour undertime at period $t$ planned in the original MPS (man-hours)
$O(t)$	labour overtime at period $t$ planned in the original MPS (man-hours)
$P_{ij}(t)$	for order $j$ , the quantity of product $i$ planned to be produced at period $t$ in the original MPS
$D_{ij}$	the demanded quantity of product $i$ for order $j$
$d_j$	the due date of order $j$
$n_j$	the time periods of tolerable delay for order $j$
$B_{ij}$	for order $j$ , the backorder quantity of product $i$ at its due date
$S(t)$	the number of setups at period $t$ in the original MPS
$UB$	the upper bound of overtime for each period (man-hours)
$M_{ik}$	the required quantity of component $k$ for producing a unit of product $i$
$M$	a positive constant of extremely large value.

#### 3.2. Decision variables

$NP_{ij}(t)$	for order $j$ , the quantity planned in the new MPS for producing product $i$ at period $t$ .
$PO_k(t)$	the purchasing quantity of component $k$ at period $t$ in the new MPS
$PI_k(t)$	the ending inventory of component $k$ at period $t$ in the new MPS
$NU(t)$	the undertime at period $t$ in the new MPS
$NO(t)$	the overtime at period $t$ in the new MPS
$NS(t)$	the number of setups at period $t$ in the new MPS
$y_i(t)$	a binary variable, equal to 1 if the production of product $i$ at period $t$ is planned and therefore requires a setup; equal to 0 otherwise.

### 4. Objective functions and constraints

In justifying the acceptance of a rush order, four objectives are considered in this research. They are: (1) minimizing the extra spending due to production of the rush order; (2) minimizing the shipping delay of crucial orders; (3) minimizing the demand of cash or quick assets; and (4) minimizing the inventory level. In dealing with the multiple criteria decision-making problem, the e-constraints approach is adopted. That is, one of the four objectives is taken as the main objective and the other three are taken as constraints by giving them upper bounds.

#### 4.1. Objective functions

##### 4.1.1. First objective: minimizing extra spending for producing the rush order

$$\begin{aligned} \text{Min } Z_1 = & \sum_{k=1}^m \sum_{i=0}^{L(k)-1} PO_k(t) CP_k \times r_k(t) + \sum_{k=1}^m \sum_{i=0}^T PI_k(t) \\ & \times (CP_k \text{int}) + \sum_{j=1}^J \sum_{i=0}^{d_j-1} \sum_{t=0}^n (d_j - t)(NP_{ij}(t) \\ & - P_{ij}(t)) PV_i \times \text{int} + \sum_{i=0}^T C_s(NS(t) - S(t)) \\ & + \sum_{i=0}^T W_0(NO(t) - O(t)) \\ & + \sum_{i=0}^T W_r(NU(t) - U(t)) \end{aligned} \quad (1)$$

The first objective  $Z_1$ , which denotes the extra spending due to production of the rush order, is composed of six terms as shown in equation (1). The first term models the extra spending for the urgent purchasing of components. In the new MPS, for production of the rush order, some components may be supplied from other existing orders due to common usage of materials; some may be missing and have to be urgently purchased; such purchasing surely costs more.

The second term models the carrying cost of component inventories. Due to production of the rush order, some planned production in the original MPS has to be delayed. This would result in an increase of component inventory. Note that in the original MPS, the beginning inventory is assumed to be zero and no safety stock is kept, therefore the ending component inventory at each period in the original MPS is also zero.

Due to change of the MPS, some orders may be partially completed at their due dates. This would result in an increase of product inventories, which is modelled in the third term. The fourth term models the increase of setup cost. The fifth term models the increase of overtime. The sixth term models the potential gain due to the decrease of undertime.

##### 4.1.2. Second objective: minimizing delay of crucial orders

The second objective is to minimize the delay of some crucial orders.

$$\text{Min } Z_2 = B_{ij}; \text{ for some crucial orders } j \quad (2)$$

Due to production of the rush order, some orders may be delayed in their shipping, within their tolerable bounds.

However, in some cases, principal customers may request that a particular part of an order should be *strictly punctual* and the other part can be delayed within tolerable bounds. That is, some products in the order should be supplied punctually with a lower bound quantity. Such an order is known as a crucial order and the delay of the strictly punctual portion should be minimized as much as possible.

##### 4.1.3. Third objective: minimizing increase of liquid assets

$$\text{Min } Z_3 = \sum_{k=1}^m \sum_{i=0}^{L(k)-1} PO_k(t) CP_k (1 + r_k(t)) \quad (3)$$

In order to produce the rush order, some components have to be urgently purchased. This would cause an increase of the *accounts payable*, that is, the demand for cash or *liquid assets* should be increased to balance the cash flow. If a company is usually short of cash or liquid assets, keeping a balanced cash flow should be a very important objective. In such cases, decision makers would expect the increase of liquid assets to be minimized as much as possible.

##### 4.1.4. Fourth objective: minimizing inventory levels

$$\begin{aligned} \text{Min } Z_4 = & 1/(T + 1) \left\{ \sum_{k=1}^m \sum_{i=0}^T PI_k(t) CP_k + \sum_{j=1}^J \sum_{i=0}^{d_j-1} \right. \\ & \left. \times \sum_{t=0}^n (d_j - t)(NP_{ij}(t) - P_{ij}(t)) PV_i \right\} \end{aligned} \quad (4)$$

The fourth objective models the average increase of inventory in each period. This objective involves two terms, the first one models the increase of component inventories, and the second term models the increase of product inventory. Both terms are divided by the total planning periods  $T + 1$  to compute the average increase in inventory at each period. If the company intends to perform a 'just-in-time' or 'zero-inventory' production policy, the decision makers would expect the inventory level to be minimized as much as possible.

#### 4.2. Constraints

This model involves two types of constraints: five balance equations and some upper or lower bounds on decision variables.

4.2.1. Balance equations

(1) Balance between component purchasing, component ending inventory and production of products:

$$PO_k(0) - PI_k(0) = \sum_{i \downarrow} R_i M_{ik} + \sum_{j \downarrow} \sum_{i \downarrow} (NP_{ij}(0) - P_{ij}(0)) M_{ik} \quad \text{for } k = 1, \dots, m \quad (5)$$

$$PO_k(t) - PI_k(t) = \sum_{j \downarrow} \sum_{i \downarrow} (NP_{ij}(t) - P_{ij}(t)) \times M_{ik} - PI_k(t-1) \quad \text{for } k = 1, \dots, m; t = 1, \dots, (L-1) \quad (6)$$

(2) Balance between production and labour time:

$$NO(0) - NU(0) = O(0) - U(0) + \sum_{i \downarrow} R_i K_i + \sum_{j \downarrow} \sum_{i \downarrow} (NP_{ij}(0) - P_{ij}(0)) K_i + (NS(0) - S(0)) T_s \quad (7)$$

$$NO(t) - NU(t) = O(t) - U(t) + \sum_{j \downarrow} \sum_{i \downarrow} (NP_{ij}(t) - P_{ij}(t)) K_i + (NS(t) - S(t)) T_s \quad \text{for } t = 1, \dots, T \quad (8)$$

(3) Balance between production and customer demand:

$$\sum_{i \downarrow}^{min\{d_j+n_j, T\}} NP_{ij}(t) = D_{ij}; \quad \text{for } i = 1, \dots, n; j = 1, \dots, J \quad (9)$$

In equation (9), the term in the left-hand side models the quantity of products to be produced in the new MPS, where two assumptions are implicitly made. First, all the orders planned in the original MPS should be completely produced in the new MPS. Second, any order, if its shipping is delayed, should be under a tolerable bound. The term is further illustrated below. For a particular order, say  $j$ , its due date is  $d_j$  and its tolerable delay period is  $n_j$ ; that is, the order should be shipped at least before the time period  $d_j + n_j$ . If the planning horizon  $T$  for the new MPS is less than  $d_j + n_j$ , then according to the policy of accepting rush orders, the order  $j$  should be completely produced before period  $T$ . Conversely, if the planning horizon  $T$  is greater than  $d_j + n_j$ , then the order should be produced before the period  $d_j + n_j$  to satisfy the requirement of tolerable delay.

(4) Balance between production and setup:

$$NS(t) = \sum_{i \downarrow}^n y_i(t); \quad \text{for } t = 0, \dots, T \quad (10)$$

$$\sum_{j \downarrow} NP_{ij}(0) + R_i \leq M y_i(0); \quad \text{for } i = 1, \dots, n \quad (11)$$

$$\sum_{j \downarrow} NP_{ij}(t) \leq M y_i(t); \quad \text{for } i = 1, \dots, n; t = 1, \dots, T \quad (12)$$

Equation (10) models the total number of setups in the new MPS. Equation (11) models the number of setups at the period  $t = 0$ , while equation (12) models the number of setups at the other periods. These two equations denote that if a particular product, say  $i$ , is produced at period  $t$ , then it requires a setup ( $y_i(t) = 1$ ); otherwise it requires no setup for this product ( $y_i(t) = 0$ ).

(5) Balance between backorders and production:

$$B_{ij} = D_{ij} - \sum_{t=0}^{d_j} NP_{ij}(t); \quad \text{for } i = 1, \dots, n \quad (13)$$

Equation (13) models the status of backorders at their due dates. That is, for product  $i$  in order  $j$ ,  $B_{ij}$  denotes the backorder quantity,  $D_{ij}$  denotes the prescribed demand quantity, and

$$\sum_{t=0}^{d_j} NP_{ij}(t)$$

describes the quantity to be produced before the due date, planned in the new MPS.

4.2.2. Upper and lower bounds

(1) All decision variables are real numbers, which are greater than or equal to zero. (14)

(2) Upper bound of overtime

$$NO(t) \leq UB \times W(t); \quad \text{for } t = 0, \dots, T \quad (15)$$

Equation (15) denotes that the overtime at each period should be at most a certain percentage ( $UB\%$ ) higher than the regular working time.

5. Numerical example

A numerical example is used to explain the proposed model. The hypothetical company, an assembly-to-order system, produces five types of products using 10 types of components; the product-material relationship matrix is as shown in Figure 1. Table 1 shows the conversion factor

Table 1. Conversion factors for the production of various products and relevant cost data.

Product type	Conversion factors ( $\kappa_i$ )	Manufacturing cost per unit ( $P V_i$ ) (\$)
Product 1	1.00	1000
Product 2	0.90	600
Product 3	1.10	1500
Product 4	0.60	500
Product 5	0.90	600

$W_r = \$ 60/\text{man-hour}$   
 $W_o = \$ 90/\text{man-hour}$   
 $C_s = \$ 6000/\text{setup}$   
 $T_s = 1 \text{ hour}/\text{setup}$   
 $int = 0.002/\text{period}$   
 $UW = 40.0 \text{ hours}/\text{man-period}$   
 $UB = 0.10 UW$

Table 2. Cost data, normal lead time of components and percentages of extra charge for their urgent purchasing.

Component type	Unit cost $CP_k$ (\$)	Normal lead time; $L(k)$ (periods)	Percentage of extra charge for urgent purchasing; $r_k(t)$ (%)
1	150	2	20, 10
2	100	2	15, 10
3	80	3	25, 15, 5
4	120	3	25, 15, 5
5	90	3	30, 15, 5
6	100	4	40, 35, 20, 15
7	150	3	40, 30, 20
8	120	4	40, 35, 20, 15
9	75	5	50, 40, 30, 20, 10
10	90	5	45, 40, 35, 15, 10

for producing various products, the hourly labour cost at regular time, the hourly labour cost at overtime, and some other cost terms. Table 2 shows the unit cost, normal lead time of each component, and the extra charge of urgent purchasing under various lead time requirements. For example, in the first row, the unit cost of component 1 is \$150, its normal lead time is 2 periods, and the extra charge for urgent purchasing is 20% for 0 period lead time, and 10% for 1 period lead time. Here, the 0 period lead time implies that the component should arrive in the current period.

Table 3 shows the relevant data for 12 customer orders. For example, in order 1, three types of products are ordered; their due date is at period 1; its tolerable periods for delayed shipping is 2 periods. The production of these orders has been planned in a current effective MPS (Table 4), where a portion of the plan has been executed and the time left is 13 periods (from  $t = 0$  to  $t = 12$ ). Note that order 4 is to be regarded as a crucial order.

Table 3. Relevant data of customer orders.

Order ID ( $j$ )	Product types ordered ( $i$ )	Quantities ordered ( $D_{ij}$ )	Due date of the order ( $d_j$ ) (periods)	Tolerable periods for delayed shipping ( $n_j$ ) (periods)
1	1	2500	1	2
	2	2000		
	5	1500		
2	1	1500	1	2
	2	1500		
	3	500		
	5	1000		
	5	1000		
3	1	2500	2	3
	3	1000		
	4	2000		
4	1	2000	4	1
	2	5500		
	3	1000		
	5	2000		
	5	2000		
5	1	2000	7	2
	2	1500		
	5	2500		
6	1	2500	7	2
	3	2000		
	5	1500		
7	1	1500	7	2
	2	2000		
8	1	1500	8	1
	2	1500		
	5	2000		
9	2	3000	9	1
	4	4000		
10	1	1500	12	3
	2	3000		
	5	1500		
11	1	2000	12	3
	3	1000		
	4	1000		
12	1	1000	12	3
	2	1000		
	5	4000		

At this point, a rush order arrives which demands 2000 pieces of product 1 (i.e.  $R_1 = 2000$ ) and 1500 pieces of product 2 (i.e.  $R_2 = 1500$ ). The decision maker wants to know the extra spend involved in producing the rush order under various combinations of production strategies. Here, a production strategy implies a set of upper bounds to be imposed on the last three objectives. That is, the last three objectives are modelled as constraints and the first objective is the main objective. The proposed model then becomes a mixed integer linear programming model.

The computation was performed on a PC486 machine through the use of software package LINDO 87. Four illustrated alternatives for justifying the acceptance of

Table 4. The original MPS together with undertime and overtime at each period, where the workforce size is a constant, that is,  $w(t) = 60$ .

$t$	$P_{1j}(t)$	$P_{2j}(t)$	$P_{3j}(t)$	$P_{4j}(t)$	$P_{5h}(t)$	$U(t)$	$O(t)$
0	$P_{11} = 2500$ $P_{12} = 1500$	$P_{21} = 200$	$P_{32} = 500$			32	0
1		$P_{21} = 1800$ $P_{22} = 1500$			$P_{51} = 1500$ $P_{52} = 1000$	0	212
2	$P_{13} = 2500$		$P_{33} = 1000$	$P_{43} = 2000$		0	3
3	$P_{14} = 2000$		$P_{34} = 1000$		$P_{54} = 2000$	0	53
4		$P_{24} = 5500$				0	76
5	$P_{15} = 2000$ $P_{16} = 2500$ $P_{17} = 3000$					0	1
6	$P_{17} = 1200$	$P_{25} = 100$			$P_{55} = 2500$ $P_{56} = 1500$	0	48
7		$P_{25} = 1400$ $P_{27} = 2000$	$P_{36} = 2000$			0	237
8	$P_{18} = 1500$	$P_{28} = 1500$			$P_{58} = 2000$	72	0
9		$P_{29} = 3000$		$P_{49} = 4000$		0	152
10	$P_{1,10} = 1500$ $P_{1,11} = 2000$ $P_{1,12} = 1000$			$P_{4,11} = 1000$		0	152
11		$P_{2,10} = 3000$ $P_{2,12} = 1000$	$P_{3,11} = 1000$			48	0
12					$P_{4,10} = 1500$ $P_{5,12} = 4000$	0	76

Table 5. Justification results for accepting the rush order under various production policies (main objective is  $z_1$ ).

Upper bounds of other objectives	$Z_1$ (\$)	$Z_2$ (pieces)	$Z_3$ (\$)	$Z_4$ (\$)
A1 *	125 846	$B_{14} = 2000$ $B_{24} = 222$ $B_{34} = 0$ $B_{54} = 0$	119 694	197 354
A2 $B_{14} \leq 0$ $B_{24} \leq 0$ $B_{34} \leq 0$ $B_{54} \leq 0$	136 706	$B_{14} = 0$ $B_{24} = 0$ $B_{34} = 0$ $B_{54} = 0$	171 612	101 940
A3 $B_{14} \leq 0$ $B_{24} \leq 0$ $B_{34} \leq 0$ $B_{54} \leq 0$ $Z_3 \leq 100\ 000$	152 645	$B_{14} = 0$ $B_{24} = 0$ $B_{34} = 0$ $B_{54} = 0$	100 000	131 324
A4 $B_{14} \leq 0$ $B_{24} \leq 0$ $B_{34} \leq 0$ $B_{54} \leq 0$ $Z_4 \leq (1\ 250\ 000/12)$	142 540	$B_{14} = 0$ $B_{24} = 0$ $B_{34} = 0$ $B_{54} = 0$	168 084	104 147

rush orders were evaluated and the results are shown in Table 5.

In alternative 1, there is no constraint imposed on the last three objectives. The proposed model suggests a new optimum MPS together with the following outcomes. The extra spend due to the production of the rush

order ( $z_1$ ) is \$125 846. The second objective ( $z_2$ ), back-order of the crucial order (order 4), is 2 000 pieces for product 1 and 222 pieces for product 2. The demand for liquid assets ( $z_3$ ) is increased by \$119 694. The inventory ( $z_4$ ) is increased by \$197 354.

Suppose the decision maker requests that the due date



Table 6. The new MPS proposed in alternative 4.

$t$	$NP_{1j}(t)$	$NP_{2j}(t)$	$NP_{3j}(t)$	$NP_{4j}(t)$	$NP_{5h}(t)$
0	$R_1 = 2000$ $NP_{12} = 894$	$R_2 = 1500$	$NP_{32} = 500$		
1		$NP_{21} = 2000$ $NP_{22} = 1500$			$NP_{51} = 1300$ $NP_{52} = 1000$
2	$NP_{11} = 2212$ $NP_{12} = 606$ $NP_{13} = 66$		$NP_{33} = 1000$	$NP_{43} = 2000$	
3	$NP_{11} = 288$ $NP_{14} = 2000$		$NP_{34} = 915$		$NP_{51} = 200$ $NP_{54} = 2000$
4		$NP_{24} = 5500$	$NP_{34} = 85$		
5	$NP_{13} = 2434$ $NP_{15} = 2000$ $NP_{16} = 844$				
6		$NP_{29} = 2273$	$NP_{36} = 2000$	$NP_{49} = 1713$	
7		$NP_{25} = 1500$ $NP_{27} = 2000$ $NP_{29} = 727$			$NP_{55} = 136$
8					$NP_{55} = 2364$ $NP_{56} = 1500$ $NP_{58} = 2000$
9	$NP_{16} = 1656$ $NP_{17} = 1500$ $NP_{18} = 1500$ $NP_{1,11} = 622$				
10	$NP_{1,10} = 1500$ $NP_{1,11} = 1378$ $NP_{1,12} = 1000$			$NP_{49} = 2287$ $NP_{4,11} = 43$	
11		$NP_{2,10} = 3000$ $NP_{2,12} = 1000$	$NP_{3,11} = 1000$	$NP_{4,11} = 957$	
12					$NP_{5,10} = 1500$ $NP_{5,12} = 4000$

of the whole crucial order be strictly met. Then, in alternative 2, he/she places a constraint on the second objective; that is, the shipping of the crucial order should not be delayed. We can see that now  $z_1$  increases to \$136 706,  $z_3$  increases to \$171 612, and  $z_4$  decreases to \$101 940. Note that we can also request that only a part of the crucial order, rather than the whole order, should be strictly punctual.

By evaluating the results of alternative 2, the decision maker is still not satisfied and wants to impose more control on the outflow of cash. Therefore, in alternative 3, he/she further constrains that the increase of cash demand ( $z_3$ ) should be less than \$100 000. We see that now the extra spending for producing the rush order becomes \$152 645 (21% higher than that in alternative 1).

Suppose the decision maker pays more attention to the inventory level than to the cash flow demand. Therefore, in alternative 4, he/she sets up an upper bound on the inventory level and also requests that the crucial order be

punctually shipped. We see that now  $z_2$  increases to \$168 084 (68% higher than that in alternative 3), while  $z_1$  decreases to \$142 540 (6% lower than that in alternative 3). The new MPS of this alternative is shown in Table 6.

Other alternatives can be evaluated by placing various constraints on the last three objectives, or on any three objectives by appropriately choosing the main objective. The computed value of  $z_1$  can be a reference for justifying the acceptance of the rush order and can help determine the pricing strategy for accepting the rush order.

## 6. Concluding remarks

This paper presents a multiple criteria decision-making model for justifying the acceptance of rush orders. In justifying the acceptance of rush orders, the MPS has to be replanned by placing the rush order in the immediate production period ( $t = 0$ ). Of the four objectives con-

cerned, one is taken as the main objective and the other three are described as constraints; the proposed model then becomes a mixed integer programming model for deriving the new optimum MPS.

In planning the new MPS, some notable characteristics are discussed below. First, the main objective ( $Z_1$ ) is modelled on a *differential or incremental cost basis*. That is, we have proposed a method for modelling the extra spend incurred by the new MPS for producing the rush order. In previous literature, replanning of an MPS has generally been performed on a *partial total cost basis*. That is, such an approach aims to minimize the total cost for producing a new set of orders; however, it generally ignores some cost terms associated with the original MPS. For example, some components which have been committed for production in the original MPS may become idle for some period in the new MPS. The cost of such idleness is generally ignored in the replanning of an MPS because it can only be computed on a differential basis.

Some extension to this research may be considered. First, the measurement of production objectives may be subjective; in such cases fuzzy mathematics may be included to enhance the model. Second, the assumptions about the production system can further be relaxed or elaborated to accommodate various situations in the real world.

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