Determining Items to be Inventoried in a Manufacturing Process

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Abstract: In most manufacturing systems, all customers are expected to take deliveries from inventory. However, in some situations, management may keep inventory only for some customers and not keep inventory for the others. The reason is that they would like to make as much benefit as possible from the first group of customers and this may help sell these customers on further products. This paper attempts to determine the cutoff between the group of customers who are given products immediately when their orders come and other customers who will be served but have to wait for the production of their products. The optimum set of customers to be served immediately and the optimum set of customers who have to wait for the production are found using linear programming to optimize perceived manufacturer benefits measured as the product of the benefit factor and the corresponding profit per customer. The results indicate that it is not necessarily wise to keep inventory for all customers.

Keywords: Inventory, Manufacturing Process, Linear Programming, Deterministic Demand, Make-To-Order Policy, Make-To-Stock Policy

1. INTRODUCTION

Inventory management plays a significant role in most business. Reasons to have the inventory can be classified into four groups. The first is to minimize the cost of manufacturing. The second is to balance demand and material supply. The third is to smooth production. The last is to compensate for uncertain demand. "When the inventories are wrong, they affect directly and immediately the production control" [17]. However, keeping inventories increases the cost of the product and this type of cost, called inventory cost, is an extremely component of the manufacturing cost. Inventory costs can be categorized into three categories which are the cost of carrying items, the cost of replenishment, and the cost of insufficient capacity or of being out of stock [10]. Therefore, management has the responsibility of controlling the proper amount of the raw material, work-in-process (WIP), finished products, spare parts, production/manufacturing supporting materials, etc. used in the production/manufacturing systems in the inventory. High value of inventory can cause the failure of the business while inadequate raw material and components used for production can stop the production and business as well. Hence, the good inventory policy is to accomplish two conflicting objectives simultaneously. That is to control the inventories at the lowest cost while maintaining adequate service to the customer.

In most manufacturing systems, all customers are expected to take deliveries from inventory. However, in some situations, management may keep inventory only for some customers and not keep inventory for the others. The reason is that they would like to make as much benefit as possible from the first group of customers and this may help sell these customers on further products. This paper attempts to determine the cutoff between the group of customers who are given products immediately when their orders come and other customers who will be served but have to wait for the production of their products. An assumption here is a limitation on inventory area.

2. LITERATURE REVIEW

In literature, many researchers have studied inventories for a long time. Various topics related to inventory have been investigated including both deterministic demand and probabilistic demand. Quantities to replenish can be determined using heuristics [8, 12-13, 15], mathematical model [1, 3-4, 5-7, 9, 11, 14, 16], and simulation [2].

No mater what type of the demand is, most researchers tend to concentrate on keeping inventory for all customers. Replenishment quantities are then calculated for all customers. From the literature, no methods currently exist that address the cutoff between the group of customers who will be served immediately and those who have to wait so comparisons with existing methods are not performed.

3. PROPOSED METHODOLOGY

To determine which customers we will keep the inventory for, all customers are given a priority, which is an index related to the perceived benefit to the company. This paper uses a customer's total demand for each product across the planning cycle to assign a priority to each customer of that product. The highest priority goes to the customer with largest total demand. Similarly, a benefit factor is assigned to each customer based on the customers' total demand for products across the planning cycle. Thus, the first-priority customer will also be the customer who has been assigned the highest benefit factor while the lowest-priority customer will be the customer who has been assigned the lowest benefit factor.

Because of the attempts to send all ordered products to the customers in the first group immediately when they order, all orders for these customers in a given period must be finished and kept in the inventory since the previous period. Hence, inventory-carrying costs will grow as the number of customers in the first group is increased. The optimum set of customers to be served immediately and the optimum set of customers who have to wait for the production are found using linear programming to optimize perceived manufacturer benefits measured as the product of the benefit factor and the corresponding profit per customer. An assumption here is a limitation on inventory area so management cannot keep inventory for all customers.

Using the notation from Table 1, the customers for product j can be categorized into three groups. The first group includes the customers who are members of the set N_j. The second group takes account of the customers who are members of the set K_j but not for the set N_j. The last group holds the customers outside the set K_j.

Table 1 Notations

Problem Parameters		
P	=	is the number of product categories (product)
Per	=	is number of periods in one cycle (period)
C_j	=	is the set of potential customers of product j
Rev_j	=	is the selling price of one unit of product j ($/unit)
Reg_{max}	=	is the maximum regular hours per period (hour/period)
OT_{max}	=	is the maximum overtime hours per period (hour/period)
$HR_{req,j}$	=	is the hours required to complete one unit of product j (hour/unit)
Reg_j	=	is the costs of producing one unit of product j in the regular hours ($/unit)
OT_j	=	is the costs of producing one unit of product j in the overtime hours ($/unit)
Inv_j	=	is the costs of keeping one unit of product j for one period ($/unit/period)
Sh_j	=	is shortage costs when management cannot send the entire order of product j ($/unit/period)
I_{max}	=	is the maximum inventory area (area unit)
$I_{req,j}$	=	is the inventory area required to keep one unit of product j (area unit/product)
$Bf_{i,j}$	=	is the benefit factor associated with product j and customer i
$D_{i,j,t}$	=	is demand of product j from customer i during period t
$I_{i,j,t}$	=	is the number of units of product j kept in the inventory for customer i during period t (unit)
$B_{i,j,t}$	=	is the number of backordering units of product j ordered by customer i during period t (unit)
Decision Variables		
N_j	=	is the set of customers for whom management will keep inventory of product j
K_j	=	is the set of customers from whom management decides to accept orders of product j
$P_{i,j,t}$	=	is the number of units of product j produced in regular hours for customer i during period t (unit)
$O_{i,j,t}$	=	is the number of units of product j produced in overtime hours for customer i during period t (unit)

To obtain the optimum sets of N_j and K_j while C_j is given, the linear programming model must be developed. The objective function is to maximize the total perceived manufacturer benefits from all customers. The perceived manufacturer benefits here are measured as the product of the benefit factor and the corresponding profit per customer. The costs associated is the costs of producing and keeping products for customer in the first group and the second group and can be written as in Eqs (1) ~ (2), respectively.

$$\min_{P_{i,j,t},O_{i,j,t}} \left\{ \sum_{j=1}^{P} \left(\begin{array}{l} Reg_j \sum_{i\in N_j} \sum_{t=1}^{Per} P_{i,j,t} \\ +OT_j \sum_{i\in N_j} \sum_{t=1}^{Per} O_{i,j,t} \\ +Inv_j \sum_{i\in N_j} \sum_{t=1}^{Per} I_{i,j,t} \end{array} \right) \right\} \tag{1}$$

$$\min_{P_{i,j,t},O_{i,j,t}} \left\{ \sum_{j=1}^{P} \left(\begin{array}{l} Reg_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} P_{i,j,t} \\ +OT_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} O_{i,j,t} \\ +Inv_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} I_{i,j,t} \\ +Sh_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per-1} Ba_{i,j,t} \end{array} \right) \right\} \tag{2}$$

The complete objective function for the linear program can be written as

$$\max_{N_j,K_j} \left[\begin{array}{l} \sum_{j=1}^{P} \left\{ \begin{array}{l} Rev_j * \left(\sum_{i\in N_j} \sum_{t=1}^{Per} D_{i,j,t} \right) \\ - \min_{P_{i,j,t},O_{i,j,t}} \left\{ \sum_{j=1}^{P} \left(\begin{array}{l} Reg_j \sum_{i\in N_j} \sum_{t=1}^{Per} P_{i,j,t} \\ +OT_j \sum_{i\in N_j} \sum_{t=1}^{Per} O_{i,j,t} \\ +Inv_j \sum_{i\in N_j} \sum_{t=1}^{Per} I_{i,j,t} \end{array} \right) \right\} \end{array} \right\} * BF_{i,j} \\ + \left\{ \begin{array}{l} Rev_j * \left(\sum_{i\in K_j-N_j} \sum_{t=1}^{Per} D_{i,j,t} \right) \\ - \min_{P_{i,j,t},O_{i,j,t}} \left\{ \sum_{j=1}^{P} \left(\begin{array}{l} Reg_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} P_{i,j,t} \\ +OT_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} O_{i,j,t} \\ +Inv_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per} I_{i,j,t} \\ +Sh_j \sum_{i\in K_j-N_j} \sum_{t=1}^{Per-1} Ba_{i,j,t} \end{array} \right) \right\} \end{array} \right\} \end{array} \right] \tag{3}$$

Several requirements are needed to complete the model.

- Total regular hours used each period must not be over than the maximum regular hours. Likewise, total overtime hours used each period must not be over than the maximum overtime hours.

$$\sum_{i\in K_j} \sum_{j=1}^{P} HR_{req,j} P_{i,j,t} \le Reg_{max} \quad \forall t \tag{4}$$

$$\sum_{i \in K_j} \sum_{j=1}^{P} HR_{req,j} O_{i,j,t} \leq OT_{max} \quad \forall t \tag{5}$$

- For any product, total numbers of units produced during regular hours and overtime hours must be at least total demand ordered by the customers.

$$\sum_{t=1}^{Per} \sum_{i \in K_j} \left(P_{i,j,t} + O_{i,j,t}\right) \geq \sum_{t=1}^{Per} \sum_{i \in K_j} D_{i,j,t} \quad \forall j \tag{6}$$

- Total area required in each period to keep the inventory for the customers in the first group should not be over than the maximum inventory area (I_{max})

$$\sum_{i \in N_j} \sum_{j=1}^{P} I_{req,j} D_{i,j,t} \leq I_{max} \quad \forall t \tag{7}$$

- The relationship between the level of the inventory during the existing period and the level of the inventory during the previous period can be written as

$$\begin{aligned} I_{i,j,t} - Ba_{i,j,t} = \; & I_{i,j,t-1} - D_{i,j,t-1} \\ & + P_{i,j,t} + O_{i,j,t} - Ba_{i,j,t-1} \quad \forall i, j, t \end{aligned} \tag{8}$$

- In order to keep the inventory for the customers in the first group, the number of units of product j kept in the inventory for customer i during period t must be at least the demand of product j ordered by customer i during period t + 1.

$$I_{i,j,t} \geq D_{i,j,t+1} \quad \forall i \in N_j, j, t \tag{9}$$

4. NUMERICAL ILLUSTRATION

Management produces 2 kinds of products called product A and B, respectively. The number of potential customers for all products is six. The demand is assumed to be known and the demand pattern has three periods which continue from year to year; thus the annual demand will be the same in every year and one period is equal to 4 months. That is, the demand during the period 4 is as same as the demand during period 1. Table 2 shows the demands of products A and B across a 3-period horizon for each of these customers. Table 3 exhibits all data needed to solve for the best N_j when j = {A, B}.

Table 2 Demand of Products A and B

Customer	Demand for Product A			Demand for Product B		
	Period			Period		
	1	2	3	1	2	3
1	268	122	9	113	50	101
2	225	49	151	182	210	366
3	176	364	35	102	220	268
4	348	128	44	30	221	314
5	211	98	366	391	356	358
6	240	378	213	316	210	126

Table 3 Other Necessary Parameters

Parameter	Value	
P	2	Products
Per	3	Periods
C_1	6	Customers
C_2	6	Customers
Rev_1	1000	Dolars/Unit
Rev_2	1500	Dolars/Unit
Reg_{max}	3000	Hours/Period
OT_{max}	1000	Hours/Period
$HR_{req,1}$	2	Hours/Unit
$HR_{req,2}$	3	Hours/Unit
Reg_1	250	Dollars/Unit
Reg_2	350	Dollars/Unit
OT_1	350	Dollars/Unit
OT_2	500	Dollars/Unit
Inv_1	10	Dollars/Unit/Period
Inv_2	5	Dollars/Unit/Period
Sh_1	100	Dollars/Unit/Period
Sh_2	150	Dollars/Unit/Period
I_{max}	70,000	Cm^2
$I_{req,\,1}$	50	Cm^2
$I_{req,\,2}$	25	Cm^2

For each product, assuming that the benefit factor for the customer with the lowest priority is 1.00, the benefit factors are shown in Table 4.

The linear program for this numerical illustration can be modeled according to Eqs. (1) ~ (9). Using the local search algorithm, the results can be shown in Tables 5 and 6. In Tables 5 and 6, according to the limited capacity, orders of product A from customers 1 to 5 as well as orders of product B from customers 1 and 4 are rejected; thus, only orders of product A from customer 6 plus orders of product B from customers 2, 3, 5, and 6 will be included in the production plan. Table 5 also shows that production plan for orders of product B from customers 2, 5, and 6 is make-to-stock while production plan for the rest is make-to-order. Table 6 displays the results when the production plan for all orders is make-to-order. Although, the profit obtained when using the make-to-order policy for the entire orders are a little higher but the perceived benefits are much lower.

Table 4 Benefit Factors

Customer	Product A	Product B
1	1.00	1.00
2	1.07	2.87
3	1.44	2.23
4	1.30	2.14
5	1.69	4.19
6	2.08	2.47

Table 5 Results when Applying Both Make-to-Stock and Make-to-Order Policies

	Product A	Product B
N_j	{-}	{2, 5, 6}
K_j	{6}	{2, 3, 5, 6}
Objective Value	10,876,373	
Actual Profit	4,095,150	

Table 6 Results when Applying Only Make-to-Order Policy

	Product A	Product B
N_j K_j	{-} {6}	{-} {2, 3, 5, 6}
Objective Value	4,942,650	
Actual Profit	4,942,650	

5. CONCLUSION

In this paper, the cutoff between the group of customers who are given products immediately when their orders come and other customers who will be served but have to wait for the production of their products is determined. The optimum set of customers to be served immediately and the optimum set of customers who have to wait for the production are found using linear programming to optimize perceived manufacturer benefits measured as the product of the benefit factor and the corresponding profit per customer. The results indicate that it is not necessarily wise to keep inventory for all customers. However, only whole shipments are considered in this paper. A topic for future research is the possibility for partial shipments. Management may use an assessment of desired service level to help make the partial shipment decision. Using partial shipments, management may be able to send orders to more customers as compared to the case of whole order shipment. This means that they will benefit from satisfying more customers although the benefit from each customer is not as much. Management should carefully consider the tradeoff between full benefits from fewer customers and partial benefits from more customers.

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