Optimization of Postponed Production Decision in Mass Customization

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Abstract

Whether to implement postponed production with higher production cost is puzzled by more manufacturers, and to solve this problem, we set the total cost model considering inventory cost and customer waiting cost in non-postponed production and postponed production respectively. Then, we apply the M/M/1 model in queuing theory to optimize the total cost, and by simulation and sensitivity analysis, we find out some important factors influencing whether to apply postponed production such as customer waiting cost, the product categories, and so on. Besides, if the postponed production is adopted, where is the best CODP (Customer order decoupling point) in the postponed production process, and these research results will provide theoretical support for the manufacturer to locate the CODP point correctly, and help the manufacturer to make decision on implementing postponed strategy.

Keywords: *Mass customization, Postponed production, Production cost, CODP*

1. Introduction

In the current market environment, with the changing speed of product categories accelerating, the market demands appeared more various. Postponed production can complete the customized order according to customer demand and finish the final delivery by delaying the customization work until the certain customer order is received, and thus the postponed production can decrease the delivery lead time, reduce the risk of outdated inventory, and meet the various customer demands (Su, 2005). Italian clothing company Benetton adopted the postponement strategy to delay the CODP in the production process until to the end production process, and thus to reduce the risk of uncertainty demand. There have been many theories and literatures on postponement strategy. The postponed production is applied by retailer to increase the profit, but the manufacture is ignored (Yang et al., 2009). The inventory managing strategy model is set in supply chain applying postponed strategy, but the total production cost was not considered (Shao, 2004 and Ji, 2009). Jin et al. (2011) proposed the method of “Kanban” to achieve customization, but they didn’t analyze whether the Kanban system can reduce the cost of manufacture in the quantitative way. Lee and Tang (1999) implemented the postponed production by restructure the product portfolio and set an simple model by combing the profit, cost and product strategy, and the model was an general postponed production model to achieve customization, but in their model, they thought the manufacture need different processes to obtain the customization after the CODP (Customer Order Decoupling Point). Hua (2007) optimized the flexible production system by queue theory. Van (1998), Krajewski (2005) and Rao (2007) research the postponed production in terms of simple customization and mass customization, but the key to their problem is whether the manufacture can reduce cost by customized postponement. Huang et al. (2008) compared the cost change before and after the CODP, but they ignored the payment of customer waiting cost to keep the customer purchasing the product. Dan (2009) set the cost optimization model for the two-stage supply chain made up of retailer and manufacture applying postponed production, and Li (2010) set the similar model and CODP orientation model, but both of them didn’t consider the cost change before and after the CODP only for the manufacture, i.e. they didn’t compare the cost change in different condition in applying postponed production or not applying the postponed strategy.

To perfect the postponed strategy, based on the research of Dan (2009) and Li (2010), this paper will focus on the manufacture and set the cost model when the manufacture in postponed production and without the postponed production (non-postponed production) respectively in the first place. And then we will adopt the extended M/M/1mode in queue theory to simulate the postponed production cost of manufacture to find out the condition when the manufacture can apply postponed production mode and the optimal CODP location in postponed production. Finally, the sensitive analysis of factors influencing the production cost of manufacture will be analyzed.

2. The model under the non-postponed production mode

2.1 Denotation

The manufacture will face the uncertain market demand and produce N kinds of customized products belonged to the same product family while keeping some safe inventory. Each kind of product need time T to be finished. The customer demand of the K th customized product is a random variable whose average value is λ_k , and the variant value is σ_k^2 . The average demand amount of total customized products is $D=\sum_{k=1}^{N}\lambda_k$, where λ_k is the unit demand reaching ratio of the K th product, μ_k is the expected demand of the K th product, m_k is the unit average production cost, v_k is the unit holding cost of K th product inventory, h_k is the average inventory cost and $E[I_k]$ is the expected inventory amount of the K th product.

2.2 Assumption

① The manufacture will produce some product and keep the inventory according to the forecast information of the market demand, and the produce intension will be bigger than the reaching ratio of customer demand, so there will be no shortage cost and customer waiting cost.

② Whether to implement the postponed production will not influence the transportation time, so we will not consider the transportation cost.

2.3 Model

Under non-postponed production mode, the manufacture should consider the total cost in a production period including manufacture cost, holding cost of processing product, the inventory cost, etc.

$$Z=\sum_{k=1}^{N}\lambda_k m_k+\frac{\lambda_k}{\mu_k}v_k+\sum_{k=1}^{N}h_k E[I_k] \qquad (1)$$

Formula (1) denote the total production cost under the non-postponed production mode, where the first three items denote the manufacture cost, holding cost of processing product and the inventory cost respectively.

For easy analysis, we will further assume the condition based on the general instance, as following: in the random time zone, the probability of customer demand for the certain customized product is dependent on the length of time zone, but it independent of the terminal of time zone, and if the time zone is small enough, the probability that the number of customer demand for the certain customized product is more than twice can be ignored. Besides, in each independent time zone, the demand of product is independent. All the customized products are belonged to the same product family K , and thus each customized products are similar and have the same production time, so we can assume that λ_k , μ_k , m_k , v_k and $E[I_k]$ can be equal λ , μ , m , v and $E[I]$ respectively.

We can adopt the M/M/1model to compute the production cost under non-postponed production.

The production intension is: $\rho=\dfrac{\lambda}{\mu}$

The expected inventory amount is:

$$E[I]=s-\rho(1-\rho^s)$$

The total production cost is:

$$Z=Dm+\frac{\lambda}{\mu}v+Nh[s-\rho(1-\rho^s)]$$

3. The model under postponed production mode

3.1 Denotation

The manufacture will face the uncertain market demand and produce N kinds of customized products belonged to the same product family by postponed production. The investment cost that the manufacture invest in the equipment so as to implement postponed production is $F(r)$. Each kind of product need time T to be finished. The production time can be divided into two parts: before CODP, the pushed production process needs time T_1 , and after CODP, the pulled production process needs time T_2 . The customer demand of the K th customized product is a random variable whose average value is $\lambda_{2,k}$, and the variant value is $\sigma_{2,k}^2$. The average demand amount of total customized products is $D=\sum_{k=1}^{N}\lambda_{2,k}$, where λ_1 is the unit reaching ratio of the standard semi-finished products, μ_1 is the expected demand of the standard semi-finished product, $m_1(r)$ is the unit average production cost of the standard semi-finished product, $v_1(r)$ is the unit holding cost of semi-finished inventory, $h_1(r)$ is the average inventory cost and $E[I_1](r)$ is the expected inventory amount of semi-finished inventory. After CODP, $\lambda_{2,k}$ is the unit demand reaching ratio of the K th customized product, $\mu_{2,k}$ is the expected demand of the K th product, $m_{2,k}(r)$ is the unit average production cost, $v_{2,k}(r)$ is the unit holding cost of K th product inventory, $E[T_{2,k}](r)$ is the expected production time of the K th product and $w_{2,k}$ is the unit customer waiting cost of the K th customized product.

3.2 Assumption

①Whether to implement the postponed production will not influence the transportation time, so we will not consider the transportation cost. The location of CODP can be denoted as the ratio of production time of standard product to the total production time, i.e. $r(0 \le r \le 1)$.
② The manufacture will start production according to customized customer order, and once the customer ordered, it can't be hauled off, and thus, it can't influence the profit of manufacture, so the shortage cost will be not considered.

3.3 Model

Under postponed production mode, the manufacture should consider the total cost in a production period including manufacture cost, holding cost of processing product, the inventory cost, customer waiting cost, etc. The model of production cost under postponed production is as following:

$$\min Z(r) = F(r) + \sum_{k=1}^{N} \lambda_{2,k} m_1(r) + \sum_{k=1}^{N} \lambda_{2,k} m_{2,k}(r) + h_1(r)E[I_1](r) + \sum_{k=1}^{N} \lambda_{2,k} w_{2,k} ET_{2,k}(r) \quad (2)$$

s.t.
$$0 \le r \le 1 \quad (3)$$

$$0 < \frac{\lambda_1(r)}{\mu_1(r)} < 1 \ , \ 0 < \frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)} < 1 \quad (4)$$

Formula (2) denote the total production cost under the postponed production mode, where the first three items denote the investment cost, manufacture cost respectively. The fourth and fifth item is the holding cost of processing product before and after CODP. The sixth item is the inventory cost at CODP. The seventh item is the customer waiting cost afforded by manufacture so as to keep customer to purchase. Constraint (3) denotes the location of CODP can be at random stage in the whole production process. Constraint (4) denotes the production intension of manufacture is bigger than the reaching ratio of customer demand, which indicate that the overstock condition will not be appeared.

3.4 The extended model of M/M/1

For easy analysis, we will further assume the condition based on the general instance, as following: in the random time zone, the probability of customer demand for the certain customized product is dependent on the length of time zone, but it independent of the terminal of time zone, and if the time zone is small enough, the probability that the number of customer demand for the certain customized product is more than twice can be ignored. Besides, in each independent time zone, the demand of product is independent. All the customized products are belonged to the same product family K , and thus each customized products are similar and have the same production time, so we can assume that $\lambda_{2,k}$, $\mu_{2,k}$, $m_{2,k}$, $v_{2,k}(r)$, $E[T_{2,k}](r)$ can be equal λ_2 , μ_2 , $m_2(r)$, $v_2(r)$ and $E[T_2](r)$ respectively. With the location of CODP moving to the end of production process, more process will be standard and modular, and the manufacture center finishing more standard semi-finished products need be more flexible, leading the increasing investment cost. We can assume $F(r)$ is the simple increasing function of r . The customized products of product family are not the high additional-value product, and the incremental process is a continuous and even process of production time, i.e. $m_1(r)$, $h_1(r)$ are the simple increasing functions of r , and $m_2(r)$ is the simple decreasing functions of r .

According to the assumption of extended model, the manufacture intension of standard semi-finished product is $\rho_1(r)$ before CODP, and the production intension of customized product is $\rho_2(r)$.

$$\rho_1 = \frac{\lambda_1}{\mu_1} = rDT \ , \rho_2 = \frac{\lambda_2}{\mu_2} = (1-r)DT$$

We can obtain the efficiency index before and after CODP according to the research of Buzacott and Shanthikumar (1993). The expected inventory amount of standard semi-finished products and the expected production time of customized products can be denoted as following:

$$E[I_1] = s_1 - \frac{\rho_1(1-\rho_1^{s_1})}{1-\rho_1} = s_1 - \frac{rDT-(rDT)^{s_1+1}}{1-rDT}$$

$$E[T_2] = \frac{1}{\mu_2 - \lambda_2} = \frac{NT(1-r)}{1-DT(1-r)}$$

In the formula, s_1 is the safety factor relative to the inventory before CODP, so the cost model of manufacture can be transformed as:

$$\min Z(r) = F(r) + Dm_1(r) + Dm_2(r) + rDTv_1(r) + N(1-r)DTv_2(r) + h_1(r)[s_1 - \frac{rDT-(rDT)^{s_1+1}}{1-rDT}] + \frac{DwN(1-r)T}{1-D(1-r)T} \quad (5)$$

$$\text{s.t.} \quad 0 \le r \le 1 \quad (6)$$

$$0 < DT < 1 \quad (7)$$

$$v_1(r) < h_1(r) < v_2(r) \quad (8)$$

$$\frac{\partial F(r)}{\partial r} > 0, \frac{\partial m_1(r)}{\partial r} > 0, \frac{\partial h_1(r)}{\partial r} > 0 \quad (9)$$

$$\frac{\partial m_2(r)}{\partial r} < 0 \quad (10)$$

$$s_1 \in Z^+ \quad (11)$$

Formula (5) denote the total production cost under the postponed production mode, where the first three items denote the investment cost, manufacture cost before and after CODP respectively. The fourth and fifth item is the holding cost of processing product before and after CODP. The sixth item is the inventory cost at CODP. The seventh item is the customer waiting cost afforded by manufacture so as to keep customer to purchase. Constraint (6) denotes the location of CODP can be at random stage in the whole production process. Constraint (7) denotes the production intension of manufacture is bigger than the reaching ratio of customer demand, which indicate that the overstock condition will not be appeared. Constraint (8) means the unit holding cost of processing product before CODP is smaller than the unit holding cost of standard semi-finished product after CODP, and thus it is smaller than the unit holding cost of processing product after CODP and unit inventory cost of standard semi-finished product at the same time. The three items of constraint (9) that the investment cost, value and inventory cost of standard semi-finished product before CODP is increasing with increasing r. Constraint (10) denote the production time of customization after CODP is shortening gradually and incremental value of customization after CODP is decreasing gradually at the same time. Constraint (11) indicates the safety stock is an integer.

4. Simulation and computation

For further research, we will apply MATLAB software to simulate the two models under postponed production mode and non-postponed production, so as to compare the cost in the two different production modes. By referring to the data in research of Rietze (2006), the parameter value of production cost is as following: $F(r) = 10 + r$, $m_1(r) = r$, $m_2(r) = 2 - 0.6r$, $D = 50$, $T = 0.018$, $v_1(r) = 0.5r$, $v_2(r) = 0.75r$, $h_1(r) = 0.6r$, $s_1 = 2$, $N = 50$, $w = 0.05$ and $h = 0.6$.

4.1 The simulation expression under non-postponed production

The unit inventory cost is 0.6, unit manufacturing cost and unit holding cost of processing product are all equal to that in $r = 0$ after CODP of postponed production mode. According to the assumption, the probability that the number of customer demand for the certain customized product is more than twice can be ignored, and thus the safety stock of each product under non-postponed production is $s = 1$. The production intension is equal to that in $r = 0$ after CODP of postponed production mode, i.e. $\rho = \frac{\lambda}{\mu} = DT$ and $E[I] = s - DT[1-(DT)^s]$. So the simulation expression under non-postponed production is

$$Z = Dm + DTv + Nh[s - DT + (DT)^{s+1}]$$
$$= 50 \times 2 + 0.9 \times 0.75 + 50 \times 0.6(1 - 0.9 + 0.9^2)$$
$$= 127.975$$

4.2 The simulation expression under postponed production

$$Z(r) = 10 + r + 50r + 50(2-0.6r) + 0.9r \times 0.5r + 45 \times 0.75(1-r) + 0.6r[3 - \frac{0.9r-(0.9r)^4}{1-0.9r}] + \frac{2.25(1-r)}{1-0.9(1-r)}$$

The simulation result on the compact of CODP location on the objective function is shown in fig.1, and the abscissa represents the position of the CODP, and when the position of CODP is more right means the CODP location is more inclined to the end of the production process. The vertical axis represents the manufacturing cost, and when the position of the CODP is higher, the total production cost is bigger. In the simulation figure, the production cost is at the lowest position at $r = 0.13$.

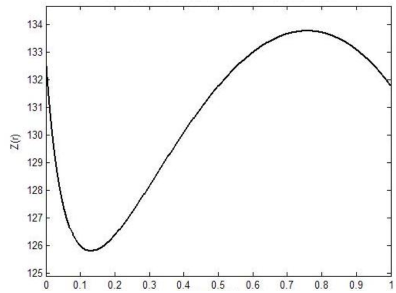

Fig.1 The effects of CODP on total production cost

4.3 Analysis of production cost in two different production modes

(1) Under non-postponed production mode, the total production cost $Z = 127.975$.
(2) Under postponed production mode, the total production cost is 132.5 at $r = 0$, which is bigger than that of non-postponed production mode. As CODP is moving to the end of production process, the production cost is decreasing and it will reach the lowest position at $r = 0.13$, $z = 125.799$, and later, because the rate of cost reduction before CODP is bigger than the rate of cost increasing after CODP, leading to the increasing production cost of the manufacturer. After the lowest point, when the CODP is continuing to move to the end of the production process, the customer waiting cost will continue to reduce gradually and the compact on the total production cost is gradually increasing, so the total production cost will reach a maximum value, and after that, it will decrease.

Reference to the above data, from the perspective of the total cost of the manufacturer, the implementation of the postponed production does not necessarily bring lower cost for manufacturer. If Manufacturer can't choose the right location of CODP, then the postponed production can't bring the cost advantage, or they can't achieve the overall optimization of resources.

4.4 The factor analysis of CODP location

(1) Customer waiting cost

$$Z(r) = 10 + r + 50r + 50(2 - 0.6r) + 0.9r \times 0.5r + 45 \times 0.75(1-r) + 0.6r[3 - \frac{0.9r - (0.9)^4}{1 - 0.9r}] + \frac{45w(1-r)}{1 - 0.9(1-r)}$$

In the above formula, the optimal position of CODP is $r^* = \arg\min\{Z(r) : 0 \le r \le 1\}$, and we can get the simulation result in table 1.

In table 1, when customer waiting cost increase, the objective function will also increase, but the trend of increase is continuously weakened, while optimal location of CODP is closer to the end of the production process. With customer waiting cost is rising, the compact of customer waiting cost on the total production cost is more obvious. The manufacturer will prefer to moving the CODP to closer to the end of the production process, and thus to shorten customer waiting time and reduce the growth rate of the total cost.

(2) The customized product variety
The simulation expression of product variety N on the optimal location of CODP is

$$Z(r) = 10 + r + 50r + 50(2 - 0.6r) + 0.9r \times 0.5r + 0.9 \times 0.75 \times N(1-r) + 0.6r[3 - \frac{0.9r - (0.9)^4}{1 - 0.9r}] + \frac{0.045 \times N(1-r)}{1 - 0.9(1-r)}$$

In the formula, the optimal location of CODP is $r^* = \arg\min\{Z(r) : 0 \le r \le 1\}$, and we can obtain the simulation result in table 2.

In table 2, when the product variety is increasing, the objective function will increase, but magnitude of increase in the objective function will decrease gradually, and the optimal position of CODP will be closer to the end of production process with the increasing of product variety. It indicates that when the product variety increase, the manufacture will increase the customized products to meet the more various customer demand, but for the uncertain market, the postponed production can reduce the uncertain risk of demand forecast and control the cost increase within the lower fluctuation range by scale economy of standard product.

5. Conclusion

This paper set the basic model and extended M/M/1 queuing model under non-postponed production and postponed production mode respectively. By solving the model and compare the total production cost, we found CODP location will bring the obvious influence on the production cost of manufacturer, and if the manufacturer can't choose the right CODP location in postponed production mode, then the production cost will exceed the cost of non-postponed production mode. In the simulation of customer waiting cost and product variety on the total production cost and optimal CODP location, we found that when the customer waiting cost and product variety increase, the total production cost will increase too, but the increase ratio will be controlled by moving CODP to the end of production process in postponed production. So when the manufacturers decide to apply postponed production mode, they should find out the right optimal CODP location, and consider the effects of each factors on the CODP location and total production cost, such as customer waiting cost, customized product variety, and so on.

Table1: The influence of customer waiting cost on optimal CODP

w	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
r^*	0	0.0318	0.068	0.1002	0.1302	0.1588	0.1867	0.2143	0.2485
Z	114.50	118.54	121.49	123.84	125.80	127.47	128.93	130.22	131.59

Table 2: The influence of product variety on optimal CODP

N	10	20	30	40	50	60	70	80	90
r^*	0.0269	0.0685	0.0952	0.1147	0.1302	0.1429	0.1537	0.1631	0.1714
Z	114.32	117.61	120.49	123.20	125.80	128.38	130.83	133.30	135.73

References

[1] J. C. P. Su, Y. L. Chang, and Ferguson Mark, "Evaluation of postponement structure to accommodate mass customization" [J], Journal of Operations Management, 23(3/4), 2005, 305-318.

[2] Z. L. Yang, and Y. M. Tian, "A study of partial backorder policy under random demand "[J], Journal of Systems & Management, 18, 6, 2009, 686-691.

[3] X. F. Shao, and J. H. Ji, "Research on impact of postponement strategies on inventory cost in mass customization" [J], System Engineering Theory Methodology Application, 13, 5, 2004, 385-389.

[4] X. J. Xu, and W. L. Zhou, "Simulation Study on Virtual Inventory Decision Making" [J], Industrial Engineering Journal, 12, 5, 2009, 76-81.

[5] Q. Jin, and Z. Zhang, "A visualized e-kanban system for small batch JIT production" [J], Industrial Engineering Journal, 14, 3, 2011, 137-145.

[6] H. L. Lee, and C. Tang, "Modeling the costs and benefits of delayed product differentiation" [J], Management Science, 43, 1, 1997, 40-53.

[7] Z. S. Hua, Flexible manufacturing systems and flexible supply chain—Modeling optimization [M], Beijing: Science Press, 2007.

[8] H. R. I. Van, "Logistics and virtual integration: postponement, outsourcing and the f1ow of information"[J], International Journa1 of Physical Distribution & Logistics Management, 28, 7, 1998, 508-523.

[9] L. Krajewski, J. C. Wei, and L. L.Tang, "Responding to schedule changes in build-to-order supply chains"[J], Journal of Operations Management, 23, 5, 2005, 452-469.

[10] K. Rao, B. Dan, and Y. Liu, "Research on cost optimization model of manufacturer implementation postponement strategy in mass customization"[J], Computer Integrated Manufacturing Systems, 13, 9, 2007, 1665-1671.

[11] Y. Y. Huang, and S. J. Li, "Suitable application situations of different postponements approaches: Standardization vs. Modularization"[J], Journal of Manufacturing Systems, 27, 2, 2008, 111-122.

[12] K. Rao, B. Dan, and Y. Liu, "Cost optimization model of supply chain implementation postponement strategy in mass customization"[J], Computer Integrated Manufacturing Systems, 15, 2, 2009, 287-291.

[13] D. D. Li, and J. X. Wang, "Customer order decoupling point position for mass customization"[J], Journal of Qingdao University (Natural Science Edition), 23, 2, 2010, 89-92.

[14] S. M. Rietze, "Case Studies of Postponement in the Supply Chain"[D], Cambridge: Massachusetts Institute of Technology. 2006.

[15]Mohamed Ramzi Bouzid, Naoufel Kraiem, "An Empirical Evaluation of a Reuse Based Approach for ERP Customization", International Journal of Computer Science Issues, Vol. 9, No. 3, 2012, pp. 17-26.

[16]Kompan Chomsamutr, Somkiat Jongprasithporn, "Optimization Parameters of tool life Model Using the Taguchi Approach and Response Surface Methodology", International Journal of Computer Science Issues, Vol. 9, No. 1, 2012, pp. 120-125.

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