On Postponed Production Optimization for Two-stage Supply Chain in Mass Customization

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Abstract

Cost models were built for both traditional supply chain environment and mass customization environment. Then, the queuing theory of extending M/M/1 model is used to optimize the total cost. Through simulations, the lowest cost for both situations was explored, and the results show that retailer's ordering strategy as well as the location of the CODP has significant influence on the total cost. It can provide theoretical support for manufacturers to locate the CODP point correctly, and also provide a basis for making a decision in implementing postponed strategy for manufacturers.

Keywords: *Postponed production, Supply chain, Cost Optimization, Queuing Theory, Customer order decoupling point*

1. Introduction

In the current market environment, consumer demand is becoming personalized and diversified increasingly with large fluctuations. In the traditional mode of production, supply chain node enterprises plan and arrange production according to market demand forecast and order information, so there are a lot of uncertainty factors. Postponement production is an effective strategy to achieve mass customization, which can delay the final customization activity until the certain order is received, and by doing this, the postponement strategy can provide the differentiated, low-cost, high-quality final products for final market, and improve the economy profit for each supply chain node enterprise (Su, 2005). As a well-known fashion brand, Levi is facing the rapid change of market demand and the shortening life cycle, it moves the CODP (Customer Order Decoupling Point, CODP) to the end of production process, that is to say, Levi produce the standard product in the first place, and then finish the customization activity according to the demand for color and size of pants, which can reduce the inventory level and the uncertain risk.

There have been many researches focusing on the 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. Due to postponed production will lead to additional packaging, storage, loading and unloading, as well as the need to increase the storage space to store custom parts and general intermediate products, and may need to introduce flexible equipment to complete the customized manufacturing at the location close to the customer, which makes postponed production cost may be higher than non-postponed production, so it is necessary to analyze and compare the cost under non-postponed production and postponed production in the supply chain made up of the manufacturer and retailer.

This paper will focus the two-stage supply chain made up of a manufacturer and a retailer based on the research of Dan (2009) and Li (2010), 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 total postponed production cost in supply chain and obtain the result that the order strategy of retailer and the optimal location of CODP will take important influence on the total cost of supply chain. Finally, the sensitive analysis of order strategy of retailer (safe inventory quantity and order quantity) and the optimal location of CODP on the total cost is provided.

2. The Basic Mode of Supply Chain Cost

2.1 Notation

(1) The notation relative to manufacture

λ_1, $m_1(r)$, $v_1(r)$, $h_{1,M}(r)$ and $E[I_{1,M}](r)$ is the unit average reaching ratio, unit average manufacture cost, average holding cost of processing product, average inventory cost and expected inventory level respectively. μ_1 is the expected demand of standard product. $\lambda_{2,k}$, $m_{2,k}(r)$, $v_{2,k}(r)$, $E[T_{2,k}](r)$ and $w_{2,k}$ is the average reaching ratio, unit average manufacture cost, average holding cost of processing product, expected production time and unit waiting cost of the K th final product , and $\mu_{2,k}$ is the expected demand of the K th final product. $F(r)$ denote the investment cost of implementing postponed production.

(2) The notation relative to retailer

b_k, $d_k(r,s,Q)$, h_{R_k}, $I_{R_k}(r,s,Q)$, a_k and $f_k(r,s,Q)$ denote the unit order cost, average order frequency, unit inventory cost, average inventory level, unit shortage cost and average shortage ratio of the retailer respectively.

2.2 The model under the non-postponed production mode

Assumption

(1) 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 $\lambda_{2,k}$, and the variant value is $\sigma^2_{2,k}$. The average demand amount of total customized products is $D=\sum_{k=1}^{N}\lambda_{2,k}$, where $\lambda_{2,k}$ is the unit demand reaching ratio of the K th product.

(2) The retailer face the final market directly, and the order strategy (s,Q) will be adopted, and P_i is the probability when the inventory is i ($i=0,1......s+Q$).

(3) Only the form postponement is considered, but not the time and place postponement, so the transportation time between two enterprises can be ignored. The location of CODP can be denoted as the ratio of production time of standard product to the total production time, i.e. $r(0\le r\le 1)$, and $r=0$ denote the non-postponement strategy.

Model

For quantitative research of cost optimization of production cost of supply chain, we consider the total cost in an order cycle including manufacture cost $C_{M_1}(r,s,Q)$ and retailer cost $C_{R_1}(r,s,Q)$. Under the non-postponement strategy, the cost model is as

$$C_{T_1}(r,s,Q)=C_{M_1}(r,s,Q)+C_{R_1}(r,s,Q) \tag{1}$$

The total cost of manufacture in a production cycle should include manufacture cost, holding cost of processing product and inventory cost. The cost of retailer should include order cost, inventory cost and shortage cost. So $C_{M_1}(r,s,Q)$ and $C_{R_1}(r,s,Q)$ can be denoted as

$$C_{M_1}(r,s,Q)=\sum_{k=1}^{N}\lambda_{2,,k}(r)m_{2,k}(r)+\sum_{k=1}^{N}\frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r)+\sum_{k=1}^{N}h_kQ_k \tag{2}$$

$$C_{R_1}(r,s,Q)=\sum_{k=1}^{N}b_kd_k(r,s,Q)+\sum_{k=1}^{N}h_{R_k}I_{R_k}(r,s,Q)+\sum_{k=1}^{N}a_kf_k(r,s,Q) \tag{3}$$

As a result, the formula (1) can be denoted as:

$$C_{T_1}(r,s,Q)=\sum_{k=1}^{N}\lambda_{2,,k}(r)m_{2,k}(r)+\sum_{k=1}^{N}\frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r)+$$

$$\sum_{k=1}^{N} h_k Q_k + \sum_{k=1}^{N} b_k d_k(r,s,Q) + \sum_{k=1}^{N} h_{R_k} I_{R_k}(r,s,Q) + \sum_{k=1}^{N} a_k f_k(r,s,Q) \quad (4)$$

$$\text{s.t.} \quad r = 0 \quad (5)$$

$$0 \le s \le Q \quad (6)$$

$$0 < \frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)} < 1 \quad (7)$$

In the formula (4)： $\lambda_{2,,k}(r)m_{2,k}(r)$, $\frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r)$ and $h_k Q_k$ is corresponding to manufacture cost of the K th customized product, holding cost of processing product and inventory cost. $b_k d_k(r,s,Q)$, $h_k I_{R_k}(r,s,Q)$ and $a_k f_k(r,s,Q)$ denote the order cost, inventory cost and shortage cost of the K th customized product. Constraint (5) denotes the initial stage of CODP in non-postponement, i.e. $r = 0$, and Constraint (6) denote the order quantity should be bigger than safety inventory under order strategy (s,Q) . Constraint (7) denotes the production rate is bigger than order reaching rate, so there is no backlog order.

2.3 The model under the postponed production mode

Assumption

(1) 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 $D = \sum_{k=1}^{N} \lambda_{2,k}$.

(2) 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 location of CODP can be denoted as the ratio of production time of standard product to the total production time, i.e. $r(0 \le r \le 1)$.

(3) The retailer implement zero inventory strategy, and he order product from manufacture according to customized customer order, and all the products produced by manufacture will sold by retailer.

Model

The cost model under postponement strategy is as

$$C_{T_2}(r,s,Q) = C_{M_2}(r,s,Q) + C_{R_2}(r,s,Q) \quad (8)$$

The manufacture should consider the total cost in a production cycle including investment cost, manufacture cost before and after CODP, holding cost of processing product and inventory cost. Retailer should consider the order cost and customer waiting cost, so $C_{M_2}(r,s,Q)$ and $C_{R_2}(r,s,Q)$ can be denoted as

$$C_{M_2}(r) = F(r) + \sum_{k=1}^{N} \lambda_{2,k}(r)m_1(r) + \sum_{k=1}^{N} \lambda_{2,k}(r)m_{2,k}(r) + \frac{\lambda_1(r)}{\mu_1(r)}v_1(r) + \sum_{k=1}^{N} \frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r) + h_{1,M}(r)E[I_{1,M}](r) \quad (9)$$

$$C_{R_2}(r) = \sum_{k=1}^{N} b_k \lambda_{2,k}(r) + \sum_{k=1}^{N} \lambda_{2,k}(r) w_{2,k}(r) E[T_{2,k}](r) \quad (10)$$

The formula (8) can be optimized and denoted as

$$C_{T_2}(r) = F(r) + \sum_{k=1}^{N} \lambda_{2,k}(r)m_1(r) + \sum_{k=1}^{N} \lambda_{2,k}(r)m_{2,k}(r) + \frac{\lambda_1(r)}{\mu_1(r)}v_1(r) + \sum_{k=1}^{N} \frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r) + h_{1,M}(r)E[I_{1,M}](r) + \sum_{k=1}^{N} b_k \lambda_{2,k}(r) + \sum_{k=1}^{N} \lambda_{2,k}(r) w_{2,k}(r) E[T_{2,k}](r) \quad (11)$$

$$\text{s.t.} \quad 0 \le r \le 1, \quad (12)$$

$$0 < \frac{\lambda_1(r)}{\mu_1(r)}, \frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)} < 1 \quad (13)$$

$$s = 0, \quad Q = 1 \quad (14)$$

In formula (11): $F(r)$ is the investment cost, $\lambda_{2,k}(r)m_1(r)$ and $\lambda_{2k}(r)m_{2,k}(r)$ is the manufacturing cost before and after CODP, $\frac{\lambda_1(r)}{\mu_1(r)}v_1(r)$ and $\frac{\lambda_{2,k}(r)}{\mu_{2,k}(r)}v_{2,k}(r)$ is the holding cost of processing product before and after CODP. $h_{1,M}(r)E[I_{1,M}](r)$ is the expected inventory cost of standard product, $b_k \lambda_{2,k}(r)$ is the order cost of the K th

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product, and $\lambda_{2,k}(r)w_{2,k}(r)E[T_{2,k}](r)$ is the customer waiting cost provided by retailer to keep customer.

Constraint (12) denotes the location of CODP can be at random stage in the whole production process. Constraint (13) 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 (14) denotes the zero inventory strategy of retailer, safety inventory is zero and only one product is ordered at one time.

3. M/M/1 model

3.1 Assumption

Demand for the product can be regarded as basic to meet independence, common characteristics and obey Possion distribution. The production rule adopts the first come first serve, and the second stage of manufacture can be seen as a M/M/1 queuing system. For simple analysis, we will add some assumptions:

(1) 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.

(2) 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. $m_1(r)$, $h_{1,M}(r)$ are the simple increasing functions of r, and $m_2(r)$ is the simple decreasing functions of r.

(3) The unit inventory cost of product in retailer and manufacture is same, so for random product, b_k, h_k, a_k, d_k, I_{R_k} and f_k is equal as b, h, a, d, I_R and f respectively.

3.2 Model

We can obtain the efficiency index before and after CODP according to the research of Buzacott and Shanthikumar (1993), such as order frequency, average inventory, shortage rate, expected inventory of standard semi-finished product and expected production time in customized production process as following:

$$\frac{\lambda_2(r)}{\mu_2(r)} = \frac{(1\text{-}r)\mathrm{DT}}{\mathrm{N}} \qquad (15)$$

$$d(r,s,Q) = \lambda_2 P_{s+1} = \frac{(1+\frac{1}{(1\text{-}r)\mathrm{DT}})^s}{\mathrm{T}(1\text{-}r)[1+\frac{Q}{(1\text{-}r)\mathrm{DT}}(1+\frac{1}{(1\text{-}r)\mathrm{DT}})^s]} \qquad (16)$$

$$I_R(r,s,Q) = \sum_{i=0}^{s+Q} iP_i = \frac{\{(1+\frac{1}{(1-r)\mathrm{DT}})^s[\frac{Q^2+2sQ+Q}{2(1-r)\mathrm{DT}} - Q] + Q\}}{1+\frac{Q}{(1-r)\mathrm{DT}}(1+\frac{1}{(1-r)\mathrm{DT}})^s} \qquad (17)$$

$$f(r,s,Q) = \lambda_2 P_0 = \frac{D}{\mathrm{N}[1+\frac{Q}{(1-r)\mathrm{DT}}(1+\frac{1}{(1-r)\mathrm{DT}})^s]} \qquad (18)$$

$$E[I_{1,M}](r) = s_M - \frac{\rho_1(1-\rho_1^{s_M})}{1-\rho_1} = s_M - \frac{rDT-(rDT)^{s_M+1}}{1-rDT} \qquad (19)$$

$$E_{T_2}(r) = \frac{1}{\mu_2-\lambda_2} = \frac{T(1-r)}{1-DT(1-r)} \qquad (20)$$

s_M is the safety factor relative to inventory before CODP.

The queuing model under non-postponed production

The queuing model under non-postponed production can be extended as following:

$$C_{T_1}(r,s,Q) = Dm_2(r) + Dv_2(r) + NQh + Nbd(r,s,Q) + NhI_R(r,s,Q) + Naf(r,s,Q) \qquad (21)$$

$$\text{s.t.} \quad r = 0 \qquad (22)$$

$$0 \le s \le Q, \quad s \in Z^+ \qquad (23)$$

$$0 < DT < 1 \qquad (24)$$

In the formula (21): the first three items denote the manufacture cost, holding cost of processing product and inventory respectively. The forth item denote the order cost, fifth item denote the holding cost and the sixth item is the shortage cost. Constraint (22) denotes the location of CODP can be at random stage in the whole production process. Constraint (23) denotes the zero inventory strategy of retailer, safety inventory is a positive integer.

Constraint (24) 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.

The queuing model under postponed production

The queuing model under postponed production can be extended as following:

$$C_{T_2}(r) = F(r) + Dm_1(r) + Dm_2(r) + rDTv_1(r) + (1\text{-}r)DTv_2(r) + h_{m_1}(r)E[I_{1,M}](r) + Db_k + DwE_{T_2}(r,s,Q) \quad (25)$$

$$\text{s.t.} \quad 0 \le r \le 1 \quad (26)$$

$$s = 0, \quad Q = 1 \quad (27)$$

$$0 < DT < 1 \quad (28)$$

$$v_1(r) < h_1(r) < v_2(r) \quad (29)$$

$$\frac{\partial F(r)}{\partial r} > 0\,; \quad \frac{\partial m_1(r)}{\partial r} > 0\,; \quad \frac{\partial h_1(r)}{\partial r} > 0\,; \quad \frac{\partial m_2(r)}{\partial r} < 0 \quad (30)$$

In formula (25), $F(r)$ is the investment cost caused by customization, the second and third item is the manufacturing cost before and after CODP, the fourth and fifth item is the holding cost of semi-finished product before and after CODP, the sixth item is the inventory cost before CODP, seventh item is the order cost of retailer, and the eighth item is the customer waiting cost provided by retailer to keep customer.

4. Simulation

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: $F(r) = 12 + 0.5r$, $m_1(r) = r$, $m_2(r) = 5 - r$, $D = 1000$, $T = 0.0008$, $v_1(r) = 0.4r$, $v_2(r) = 2\text{-}0.4r$, $h_M(r) = 0.5r$, $s_M = 2$, $N = 8$, $w = 0.5$, $h_R = 0.5$, $b = 0.2$, $a = 0.6$.

4.1 The simulation expression under non-postponed production

The cost simulation is shown in figure 1, and the axis X denotes the safety inventory, Y denotes the order quantity of retailer, and Z denote the total cost of supply chain. The cost in non-postponed production is relative to the inventory strategy of retailer, and when the safety inventory and order quantity change, the total cost of supply chain will change, and it will increase as they increase. The minimum cost is7085.9, the safety inventory is 1, and the order quantity is 10.

4.2 The simulation expression under postponed production

The cost simulation is shown in figure 2, X denote the CODP location and Y denote the total cost of supply chain. The total cost of supply chain is a decreasing function of r .

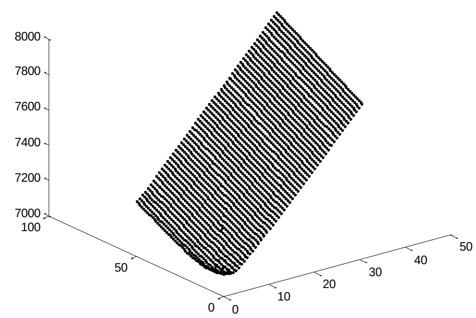

Fig.1 Cost change of supply chain in non-postponed production

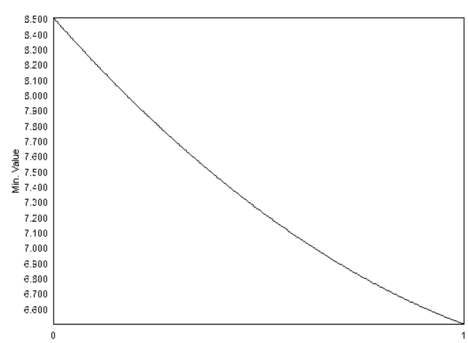

Fig.2 Cost change of supply chain in postponed production

4.3 Cost analysis in two production modes

The influence of order strategy of retailer on the total cost

From the simulation result, the optimal inventory strategy of retailer is $s = 1$ and $Q = 10$, so we can let $s = 1, 2 \ldots\ldots 6$, and analyze the total cost of supply chain. The obvious factor influencing the total cost of supply chain is the order strategy of retailer, and the total cost change with the order strategy, i.e. safety inventory and order quantity. When $S = 1$ and $Q = 10$, the minimum cost of supply chain is7085.9. Given the same order quantity, if the safety inventory level is higher, then the total cost of supply chain will be higher, and the inventory cost of retailer will increase. When the safety inventory level is lower, the total cost of supply chain will decrease with order quantity in advance and then increase with order quantity increasing, because when the order quantity is small, the order frequency of retailer will increase, which will lead to the increment of order cost exceeding the saving of decreased inventory, so after the optimal point with minimum cost, as the order frequency deceases in a order cycle, the saving of order cost is smaller than the increment of inventory cost, so the total cost will increase as order quantity increase. When the safety inventory is high, under the given inventory level, the total cost of supply chain will increase as order quantity increase.

The influence of CODP on the total cost

From the simulation, the optimal location of CODP is at the end of production process, so we can let $r = 0, 0.2, 0.4, 0.6, 0.8, 1$ to analyze the total cost of supply chain.

In table 2, under postponed production, the key factor influencing the cost of supply chain is CODP location, and when the CODP location moves to the end of production process, the customer waiting cost will decrease, and the increment of other cost of supply chain is smaller than the saving caused by customer waiting cost, so the total cost of postponed production system will decrease and postponed production can reduce the cost of supply chain. By comparing the table 1 and table 2, the minimum cost and maximal cost under non postponed production mode is 7085.9 ($s=1$, $Q=10$) and 7313.5($s=1$, $Q=1$) respectively, and the corresponding data under postponed production is 6506.3 ($r=1$) and 8513.8 ($r=0$). The cost under postponed production is not always smaller than the cost under non postponed production, for example, when $r \le 0.4$, the cost under postponed production will be bigger than 7313.5, which is bigger than 7313.5($s=1$, $Q=1$) under non postponed production, so the manufacture should choose the right CODP so as to reduce the cost of supply chain and improve the efficiency of production.

Table 1: The influence of order strategy of retailer on the total cost of supply chain under non-postponed production

C_{T_1} s / Q	1	2	3	4	5	6
1	7313.5	-	-	-	-	-
2	7190.5	7155.2	-	-	-	-
3	7144.3	7118.1	7107.6	-	-	-
4	7122.1	7101.7	7094.2	7093	-	-
5	7110.5	7094.1	7088.5	7088.2	7090.3	-
6	7104.3	7090.8	7086.7	7087.1	7089.4	7092.7
7	7101.5	7090.1	7087.1	7087.9	7090.5	7093.9
8	7100.8	7091.1	7088.8	7090	7092.8	7096.2
9	7086.2	7093.2	7091.6	7093	7095.9	7099.4
10	7085.9	7096	7094.9	7096.6	7099.6	7103.2
11	7086.4	7099.4	7098.7	7100.6	7103.7	7107.3
12	7087.5	7103.3	7102.9	7105	7108.1	7111.8

Table 2 : The influence of CODP on the total cost of supply chain under postponed production

r	0	0.2	0.4	0.6	0.8	1
C_{T_2}	8513.8	7947.8	7466.1	7065.8	6745.9	6506.3

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 the order strategy of retailer is the key factor influencing the total cost of supply chain under non postponed production, so we can implement effective order strategy, such as make sure the right safety inventory level and order quantity to control the cost within a lower level. Under the postponed production, 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. So the manufacturer should make right decision on the postponed production and choose the right CODP location according to the characteristic of product and market demand. Besides, we only consider the form postponement, the combination of form postponement and time postponement should be considered into the model in the future research.

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