Production Cost Optimization Model Based on CODP in Mass Customization

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Abstract

The key for enterprises to implement the postponement strategy is the right decision on the location of Customer Order Decoupling Point (CODP) so as to achieve the scope economics of mass customization and scale economics of mass production fully. To deal with production cost optimization problem of postponement system based on various situation of CODP, a basic model of production cost and its M/M/1 extended model are proposed and compared so as to optimize the overall production cost of the postponement system. The production modes can be classified as MTS (make to stock), ATO (assemble to order), MTO (make to order) and ETO (engineering to order) according to the inventory location, and the postponed production system considered here includes manufacturing cost, semi-finished inventory cost and customer waiting cost caused by delaying delivery. By Matlab simulation, we can compute the optimal location of CODP in each production mode, which can provide some management insight for the manufacturer to decide the right production mode and utilize the resources efficiently.

Keywords: Mass customization, Postponed production, Production cost, Customer order decoupling point

1. Introduction

With the market changing frequently, more and more companies are starting to adopt mass customization (MC) to provide a larger degree of product customization to fulfill the various demands of increasingly differentiated market segments. The advanced information technique can also provide more companies with more possibility to interact with customers and obtain individual customer requirements effectively (Huang, 2008). Postponement strategies allow a company to be flexible in developing different versions of the product as needed, to meet changing customer needs, and to differentiate a product or to modify a demand function. As many researchers pointed out, the customer order decoupling point (CODP) technology as a technique of postponement is an effective way to achieve MC, and many firms made out the different location of CODP to revise their supply chain so as to meet various requirements of different customized extents, by doing this it can meet exact requirement and lessen the often-painful effects of upstream order magnification, i.e. “bullwhip effect” (Alessandro, 2009). CODP means customer order decoupling point, that is to say, the place in the supply chain where the customer requirements are permitted to penetrate up the value chain of supply before differentiation of the product is started (Ricardo, 2001). The manufacturing strategy planned based on the forecast started to customized production driven by customer order at CODP, i.e. CODP is related to manufacturing strategy with a distinction is necessary between pre-CODP and post-CODP operations, since these have fundamentally different characteristics. The post CODP means the product is linked to a specific customer order. Before CODP, the mass production can be implemented to achieve the high production efficiency and scale economy, and post CODP, the flexible manufacture process should be adopted to route greater volumes of compatible products through a fixed asset (Lee, 1996 and Lee, 1997). So in postponed production condition, there are two production stages, i.e. mass production before CODP and customized production after CODP, and the location of CODP is very important for the enterprise in terms of production cost.

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 under the centralized and decentralized decision mode is set in supply chain applying postponed strategy, but the total production cost was not considered (Shao and Ji, 2004). 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. Sun (2010) implemented the postponed production by restructure the product portfolio and set an simple model by combing the profit, cost and product

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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.

Garg (1997) studied the postponed production model with many potential CODPs. Swaminathan (1998) found out that the general components and modules can reduce the inventory cost of the postponed production system, but when the cost of design and manufacture is too high, it is uneconomic to implement the postponed production. Ma (2002) studied the multi-assembly postponed production problem under assemble to order mode, and he analyzed the relation between the general components /modules and production cost. Tibben and Bassok (2005) found out the postponed production can reduce the total production cost based on the inventory model when the postponed production was applied. Su (2005) set the model of time postponement and form postponement, and analyzed the implementation condition of these two postponement strategies. Dan (2009) studied the cost optimization model under mass customization for manufacture and supplier, and analyzed the influence of CODP on the systematic production cost and the key factors on the CODP location. Yang (2010) studied the cost evaluating model of mass customization based on CODP locating, and set the cost model reflecting the influence of multi-CODP on the assemble products.

Most of these researches focused on the postponed production system with fixing CODP location and without considering the production leading time or fixing the leading time, few referred to the multi-CODP location problem. Based on these researches, this paper will consider the manufacturing cost, semi-finished inventory cost and customer waiting cost caused by delaying delivery to set the cost optimization model of basic model its M/M/1 extended model so as to optimize the overall production cost of the postponement system. The production modes can be classified as MTS (make to stock), ATO (assemble to order), MTO (make to order) and ETO (engineering to order) according to the inventory location, and the postponed production system considered here includes manufacturing cost, semi-finished inventory cost and customer waiting cost caused by delaying delivery. By Matlab simulation, we can compute the optimal location of CODP in each production mode, which can provide some management insight for the manufacturer to decide the right production mode and utilize the resources efficiently.

2. The production modes under mass customization

The key to carry out postponement strategy in mass customization is CODP. Before CODP, enterprise mainly adopt push supply chain which mainly forecast market demand and implement large-scale production, and the goal is to improve supply chain efficiency and reduce the cost of the supply chain. After CODP, enterprise can mainly adopt pull supply chain which depend on customer orders and implement small-scale processing, and the goal is to improve the response speed of the supply chain as well as the ability to provide customers with customized products and service.

In general, supply chain activities include supply, design, manufacture, assembly and retail. The position of CODP is changeable. The more upstream of CODP in the supply chain, the more obvious pull supply chain, and the higher the degree of customer participation. The more downstream of CODP in the supply chain, the more obvious push supply chain, the lower the degree of customer participation. The different position of CODP lead to different modes of production, this is a new understanding of these four production modes based on cost and customization. As shown in Figure 1, the vertical axis represents the cost, and the horizontal axis represents customization level. When other conditions are same, scale advantage plays a very important role in reducing the production cost, but it also reduces customization level. At this point, the cost and customization level are in a low level, enterprises will adjust the position of CODP according to product characteristic and market demand characteristic, every points will result in corresponding changes about the costs and customization level. As shown in Figure 1, from MTS (Make to stock) to ETO (Engineer to order), the costs and customization level increase or improve gradually.

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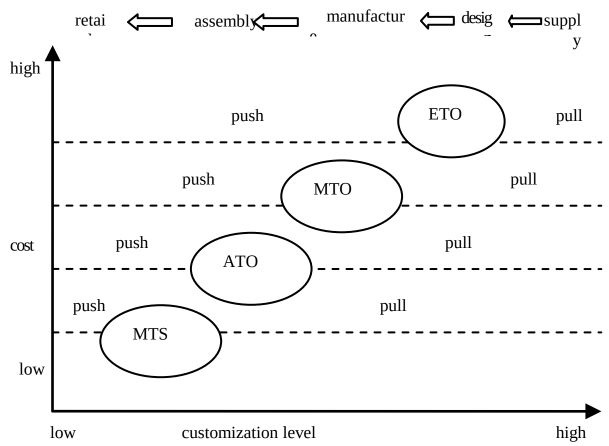

Fig.1 Four production mode based on different positioning of CODP

Under MTS, CODP is positioned in retail activity. Enterprises forecast products fully depend on market demand and arrange production according to their own inventory. In the supply chain, there is not the participation of customers from the supply to the retail, customers select their favorites in the final product, the entire supply chain can quickly and timely response to customer demands, and the costs is low, but the available choice of customers is very limited. Under this production mode, customization level is very low, and most of the products are popular consumable. Under ATO, CODP is positioned in assembly, enterprises produce large-scale standardized components and assemble existing standardized components and modules to meet customer order requirements after receiving customer orders, customers participate in assembly aspects. Under this production mode, production cycle is reduced and the response time to customers is prolonged, costs and customization level are both improved relatively. Enterprises can avoid overstock or out of stock, and they can also meet customers demand quickly. Most products are about electronic equipment, automobiles, etc. Under MTO, CODP is positioned in manufacture activity, enterprises arrange production plans with purchased components and modules to meet the needs of customers, customers participate in manufacture aspects. Under this production mode, advantages of scale economy is gradually weaken, the response time to customers are longer, cost and customization level are relatively higher. Enterprises will arrange production only receiving customer orders, not to make any inventory. Most products are about aircraft, ships, etc. Under ETO, CODP is positioned in design activity, enterprise entirely design product according to customer order, and then proceed to the procurement, production and other activities, and customers participate in design aspects from the beginning, enterprises meet the demand of customer service at the greatest degree. Under this production mode, production costs and customization level are highest. Such enterprises generally have a high degree of product design management capabilities, and most products are about complex structure, such as special test equipment, generator sets, etc (Qin and Geng, 2012).

3. The basic model under postponed production mode

3.1 Problem description

The manufacture will face the uncertain market demand and produce N kinds of customized products belonged to the same product family by postponed production with the same total production time S . Each final product will go through two production stage, i.e. mass production and customized production, and the first stage is the modular semi-finished production pushed by forecast information, and the second stage is the customized production pulled by order. r denote the customer order penetration point, i.e. CODP, which is key to implement postponed production and it will link the two production stages. r ($0 \le r \le 1$) can stand for the ratio of production time in stage 1 to total production time, and $r=0$ can indicate the manufacture to choose the ETO production mode, and all the production activities are driven by orders, but $r=1$ indicate the MTS should be applied, and all the products are produced according to the forecasting information and stored as inventory. The bigger value of r denotes the longer mass production time and shorter customized production time.

3.2 Assumption

(1) Whether 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 customer demand of the K th customized product is a random variable observing Poisson distribution whose average value is λ_k , and the variant value is σ_k^2 . λ_k means the average demand quantity of customized product K in unit time.

(3) 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.

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(4) For the CODP divide the production into two stages and in the second stage, the final product will delivered to customer directly once it is finished driven by order, so the there is no inventory in the second stage, and we only consider the buffer inventory at CODP.

3.3 Denotation and model

To better study the influence of CODP location on the production cost quantitatively, the production cost includes only the manufacture cost $M(r)$, inventory cost $H(r)$ and customer waiting cost $W(r)$. For the order delivery needs some lead time, and the longer the lead time is, the longer the waiting time is, leading to the more waiting cost, so time is the measure standard of the waiting cost. For the production cost can be divided as two parts: the manufacturing cost $M_1(r)$ in the stage 1 of mass production and the manufacturing cost $M_2(r)$ in stage 2 of customized production. So we can denote the production cost in postponed production as:

$$Z(r) = M_1(r) + M_2(r) + H(r) + W(r) \quad (1)$$

In the formula, the relative denotation in $M(r)$ is as following: $\lambda_{2,k}$ is the unit demand reaching ratio of the K th customized product, $c_1(r)$ is the unit average production cost in stage 1 when the CODP location is at r and $c_{2,k}(r)$ is the unit average production cost of the K th product in stage 2 when the CODP location is at r. The relative denotation in $H(r)$ is: $h_1(r)$ average inventory cost of semi-finished inventory in stage 1, $E[I_1](r)$ is the expected inventory amount of semi-finished inventory. So the cost optimization model can be transformed as:

$$\min Z(r) = \sum_{k=1}^{N} \lambda_{2,k} c_1(r) + \sum_{k=1}^{N} \lambda_{2,k} c_{2,k}(r) + h_1(r) E[I_1](r) + \sum_{k=1}^{N} w_{2,k} \lambda_{2,k} ET_{2,k}(r) \quad (2)$$

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

Each term in formula (2) is corresponding to the cost item in formula (1), and it means the total production cost in postponed production system. The first item in (2) is the manufacture cost in stage 1, the second item is the customization cost in stage 2, the third term is inventory cost of semi-finished product at CODP, and the forth item is the customer waiting cost in stage 2. Constraint (3) denotes the location of CODP can be at random stage in the whole production process.

4. The M/M/1extended model of postponed production

4.1 Assumption

(1) The production process is a value increasing process, so $c_1(r)$ is simple increasing function of r, and it will increase with delaying CODP to the downstream of production process, i.e. $\Delta M_1(r) = M_1(r+1) - M_1(r) \ge 0$. Besides, the inventory cost is increasing in the production process, so $h_1(r)$ is all simple increasing function of r, $\Delta H(r) = H(r+1) - H(r) \ge 0$.

(2) 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 and $c_{2,k}(r)$ is the simple decreasing functions of r, i.e. $\Delta M_2(r) = M_2(r+1) - M_2(r) \le 0$.

(3) Not all the customer would like to wait some time for the customized product, and the longer the waiting time, the bigger the lost order, so $w_{2,k}$ is decreasing functions of r, i.e. $\Delta W(r) = W(r+1) - W(r) \le 0$.

(4) All the customized products are belonged to the same product family, and thus each customized products are similar and have the same production time, so we can assume that k, $\lambda_{2,k}$, $c_{2,k}(r)$, $w_{2,k}$, $ET_{2,k}(r)$ can be equal to λ_2, $c_2(r)$, w and $ET_2(r)$ respectively.

(5) 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.

(6) The production process in stage 1 and stage 2 is smoothly, and the production time and customer order is independent.

(7) The manufacture will adopt the first come first service rule to finish the order, so the production system can be seen as an M/M/1 queuing system.

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4.2 Denotation and model

h is the basic inventory in stage 1, D is the average total demand and $D=\sum_{k=1}^{N}\lambda_{2,k}$, $\rho_1(r)$ is the amount of processing product, and $\rho_{2,k}(r)$ is the amount of processing product of the k th final product.

We can obtain the efficiency index before and after CODP according to the research of Buzacott and Shanthikumar (1993). 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 $\rho_{2,k}(r)$. So we can get the expected inventory in stage 1 and expected production time in stage 2 as following:

$$\rho_1=\lambda_1\mu_1^{-1}=rDS;$$

$$\rho_2=\lambda_2\mu_2^{-1}=(1-r)DS;$$

$$E[I_1]=h-\rho_1(1-\rho_1^{\,h})(1-\rho_1^{-1})$$

$$=h-[rDS-(rDS)^{h+1}](1-rDS)^{-1}$$

$$ET_2=(\mu_2-\lambda_2)^{-1}=N(1-r)S[1-D(1-r)S]^{-1}.$$

So the production cost model can be transformed as

$$\min Z(r)=Dc_1(r)+Dc_2(r)+h_1(r)[h-\frac{rDS-(rDS)^{h+1}}{1-rDS}]+\frac{NwD(1-r)S}{1-D(1-r)S} \quad (4)$$

$$s.t.\quad 0\le r\le 1 \quad (5)$$

$$0\le DS\le 1 \quad (6)$$

$$\frac{\partial c_1(r)}{\partial r}>0;\frac{\partial h_1(r)}{\partial r}>0 \quad (7)$$

$$\frac{\partial c_2(r)}{\partial r}<0 \quad (8)$$

$$h\in Z^+ \quad (9)$$

The formula (4) denotes the total production cost of postponed production in mass customization. In formula (4), the first item denotes the manufacturing cost in mass production of stage 1, the second item denotes the manufacturing cost in customized production of stage 2, the third item denotes the inventory cost in stage 1, and the forth item denotes the customer waiting cost. Constraint (5) denotes the location of CODP can be at random stage in the whole production process. Constraint (6) means that the overstock condition will not be appeared, because the production intension of manufacture is bigger than the reaching ratio of customer demand. In constraint (7) can be obtained easily by assumption (1), i.e. $c_1(r)$ is simple increasing function of r and $h_1(r)$ is all simple increasing function of r. Constraint (7) means that the product value is increasing with production time in stage 1, and the inventory cost of standard semi-finished product is increasing with its value. Similarly, constraint (8) means the product value in stage 2 is increasing with production time, when the production time in stage 2 is shortening, the product value increment will decrease. Finally, constraint (9) indicates the safety stock is an integer.

5. Simulation and computation

For further research, we will apply MATLAB software to simulate the influence of four production modes on the production cost and the optimal CODP location in each production mode. According to the case data in research of Rietze (2006), the value of each parameter is as following: $h=3$, $h_1(r)=0.6r$, $D=1000$, $S=0.0009$ and $N=10$. For the data in this research, the unit inventory cost and customer waiting cost has little influence on the total production cost, so we only consider the effect of unit manufacturing cost on the optimal CODP location. In the following simulation figures, the horizontal axis denote the CODP location, and with the CODP moving to the end of production process, the location on the axis is inclined to moving toward the right side. The vertical axis denotes the manufacturing cost.

5.1 The optimal CODP location in MTS

The products under MTS are about a large class of low complex standardized products, costs and delivery time are key factors in delivery process, which requires enterprises to produce and store large amounts of standardized products, such as the largest food and beverage manufacturer Wahaha, the species has been involved in the drinking water, carbonated drinks, tea drinks, milk drinks and other beverages industries to meet the diverse needs of customer. In the MTS, $c_1(r)=2r^2$, $c_2(r)=3-4r$.

$$Z(r)=1000(2r^2)+1000(3-4r)+1.8r-\frac{0.6r[0.9r-(0.9r)^4]}{1-0.9r}+\frac{4.5(1-r)}{1-0.9(1-r)}$$

The simulation result is shown in fig 2.

From fig 2, the manufacturing cost is decreasing with CODP moving to the end, and the optimal CODP location with the minimum cost is r=1 , i.e. all the production process is mass production with scale economics. For easy decision on the CODP location, the sensitive analysis of $c_1(r)$ and $c_2(r)$ is shown in table 1.

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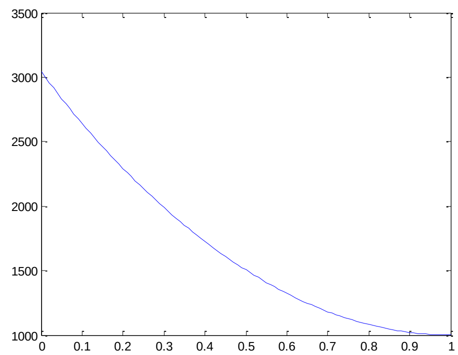

Fig.2 The trend of production cost changing under MTS

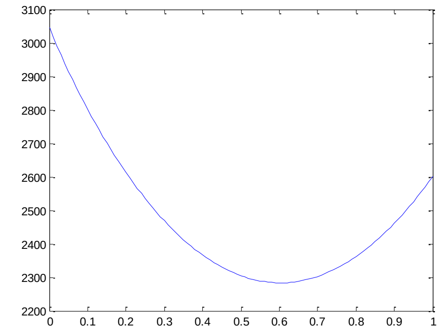

Fig. 3 The trend of production cost changing under ATO

From table 1, the production process in stage 1 is an value increasing process, i.e. $c_1(r)$ is an increasing function, its value will increase with CODP moving to the end process, and the manufacturing cost $M_1(r)$ will increase too. $c_2(r)$ is a decreasing function, its value will decrease with CODP moving to the end process, and the manufacturing cost $M_1(r)$ will decrease too. When $r \le 1$, c_1 will increase with CODP moving to the end process, but c_2 will decrease. For all the production process is mass production, there exits obvious scale economics, so $M(r)$ is decreasing, and $Z(r)$ is decreasing.

5.2 The optimal CODP location in ATO

When ATO is adopted, customization level is relatively low and the cost is relatively high. Under ATO, enterprises combine different standardized modules into a limited variety of products to meet customer demand, although choice of customers is limited, but it allows enterprises to produce mass standard parts and components to get the advantage of economies of scale, and it also allows enterprises to get components by outsourcing to provide a reasonable price to the customer, such as computer industry, enterprises use the advantages of manufacturing resources around the world to produce parts and to assemble in places close to the sale of land, For example, Dell put their main focus on co-operation with suppliers in order to share information with suppliers, purchase and organize production after receiving customer orders. Under ATO, $c_1(r) = 2r^2$ and $c_2(r) = 3 - 2.4r$.

$$Z(r) = 1000(2r^2) + 1000(3 - 2.4r^2)$$

$$+1.8r - \frac{0.6r[0.9r - (0.9r)^4]}{1 - 0.9r} + \frac{4.5(1-r)}{1 - 0.9(1-r)}$$

The simulation result is shown in fig 3.

In figure 3, the cost curve is concave in CODP location, and the optimal CODP location with minimum cost is r=0.6 . For the CODP is at the downstream of production process, so the mass production will take more ratio before CODP, and the sensitive analysis of $c_1(r)$ and $c_2(r)$ is shown in table 2.

From table 2, when $r \le 0.6$, c_1 will increase with CODP moving to the end process, but c_2 will decrease with CODP moving to the end process. For the mass production process is longer than the customization process, there exits some scale economics, so $M(r)$ is decreasing, and $Z(r)$ is decreasing. So for the electronic products, the optimal CODP location is r=0.6 .

5.3 The optimal CODP location in MTO

When MTO is adopted, customization level is relatively high, the cost is relatively low. Enterprises store a lot of raw materials and parts in order to obtain scale advantages, and the rest of the activities will be delayed until the customer orders. Amaretto is the cream liqueur produced in Italy, it can take different customer strategies according to different market demand. In the face of international market, the enterprise delay packaging and labeling, but in the local market, timely delivery does not allow the enterprise postpone any link. Procter & Gamble has adopted "Network order management" online system to complete the order request of the end retail link, whenever and wherever retail customers can be directly connected to the P & G. Under ATO, $c_1(r) = 2r^2$ and $c_2(r) = 3 - 1.2r$.

$$Z(r) = 1000(2r^2) + 1000(3 - 1.2r) +$$

$$1.8r - \frac{0.6r[0.9r - (0.9r)^4]}{1 - 0.9r} + \frac{4.5(1-r)}{1 - 0.9(1-r)}$$

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The simulation result is shown in fig 4.

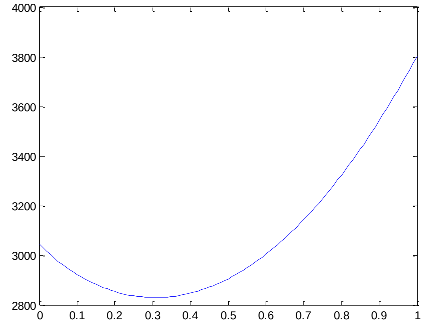

Fig. 4 The trend of production cost changing under MTO

In figure 4, the cost curve is concave in CODP location, and the optimal CODP location with minimum cost is 0.3. For the CODP is at the upstream of production process, so the mass production will take less ratio of the total production process, and the sensitive analysis of $c_1(r)$ and $c_2(r)$ is shown in table 3.

From table 3, when $r \leq 0.3$, c_1 will increase with CODP moving to the end process, but c_2 will decrease. For the mass production process is shorter than the customization process, there exits few scale economics, so $M(r)$ is decreasing, and $Z(r)$ is decreasing. So for Furniture products, the optimal CODP location is r=0.3.

5.4 The optimal CODP location in ETO

When ETO is adopted, customization level and costs are very high. The components have standard interfaces, so enterprise would assemble timely according to customer needs, and they have their own suppliers and distributors, and take flexible supply chain structures based on the expectations of the customer strategy. Toyota's production accounts for a substantial advantage in the automotive market driven by customer orders, and Trainer aircraft manufacturer Macchi aircraft can produce a variety of aircraft for special training according to the special needs. Under ETO, $c_1(r) = 2r^2$ and $c_2(r) = 3 + 0.5r^2$.

$$Z(r) = 1000(2r^2) + 1000(3 + 0.5r)$$
$$+1.8r - \frac{0.6r[0.9r - (0.9r)^4]}{1 - 0.9r} + \frac{4.5(1-r)}{1 - 0.9(1-r)}$$

The simulation result is shown in fig 5.

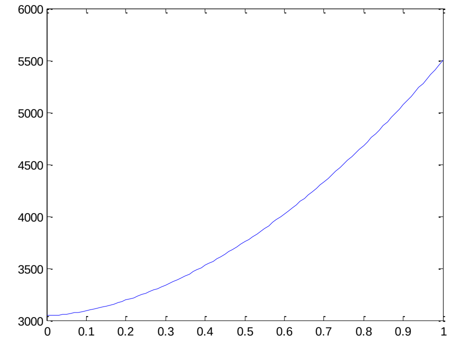

Fig. 5 The trend of production cost changing under ETO

In figure 5, the cost curve is increasing function of CODP location, and the optimal CODP location with minimum cost is 0. For the CODP is at the threshold of production process, so the whole production process is driven by customer order, and the sensitive analysis of $c_1(r)$ and $c_2(r)$ is shown in table 4.

For the mass production process is shorter than the customization process, there exits few scale economics, so $M(r)$ is decreasing, and $Z(r)$ is decreasing. For more technical, more complex structure of the product, the optimal CODP location is r=0 .

From table 3, c_2 will decrease with CODP moving to the end process. For the whole production process is, there is no scale economy, so $M(r)$ is increasing, and $Z(r)$ is increasing in the whole production process.

6. Conclusion

This paper studied the cost optimization problem under considering manufacturing cost, inventory cost of semi-finished product and customer waiting cost, and analyzed the optimal CODP under four production modes, i.e. MTS, ATO, MTO and ETO. The Matlab was applied to analyze the cost optimization under each production mode. When the products are a large class of low complex standardized products, such as Swiss coffee and the largest food and beverage Wahaha, the MTS will be chosen and the optimal CODP is r=1. When the products are electronic products of high customization level and low customization cost, e.g. Dell and GOME, the ATO will be chosen and the optimal CODP location is r=0.6 .When the products are Furniture products, the optimal CODP location is r=0.3 and the MTO will be applied. When the products are more technical, more complex structure of the product, e.g. aircraft and machine, ETO will be applied and the optimal CODP location is r=0 .So manufacture can choose the right

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production mode and make right decision on the optimal CODP according to its own characteristics and market demand characteristics. Besides, the shortness in this paper is that the basic cost model and its M/M/1extended model did not consider the other cost factors, such as holding cost of processing product, investment cost caused by redesign for the postponed production, and so on, which can be future research direction.

Table 1: The influence of unit manufacturing cost on the optimal CODP location under MTS

r	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
c_1	$0.4r^2$	$0.6r^2$	$0.8r^2$	r^2	$1.2r^2$	$1.4r^2$	$1.6r^2$	$1.7r^2$	$1.8r^2$	$1.9r^2$	$2r^2$
c_2	$3+0.3r$	3	$3-0.3r$	$3-0.6r$	$3-r$	$3-1.4r$	$3-2r$	$3-2.5r$	$3-3r$	$3-3.5r$	$3-4r$
M	3000.0	3006.0	2972.0	2910.0	2792.0	2650.0	2376.0	2083.0	1752.0	1389.0	1000.0
Z	3045.0	3027.5	2985.2	2919.0	2798.5	2654.8	2379.5	2085.6	1753.8	1390.0	1000.3

Table 2 The influence of unit manufacturing cost on the optimal CODP location under ATO

r	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
c_1	$0.4r^2$	$0.6r^2$	$0.8r^2$	$1.1r^2$	$1.4r^2$	$1.7r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$
c_2	$3+0.3r$	3	$3-0.3r$	$3-0.6r$	$3-1.1r$	$3-1.7r$	$3-2.4r$	$3-2.8r$	$3-3.2r$	$3-3.6r$	$3-4r$
M	3000.0	3006.0	2972.0	2919.0	2784.0	2575.0	2280.0	2020.0	1720.0	1380.0	1000.0
Z	3045.0	3027.5	2985.2	2928.0	2790.5	2579.8	2283.5	2022.6	1721.8	1381.0	1000.3

Table 3 The influence of unit manufacturing cost on the optimal CODP location under MTO

r	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
c_1	r^2	$1.5r^2$	$1.8r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$
c_2	$3+0.3r$	$3-0.2r$	$3-0.7r$	$3-1.2r$	$3-1.6r$	$3-2r$	$3-2.4r$	$3-2.8r$	$3-3.2r$	$3-3.6r$	$3-4r$
M	3000.0	2995.0	2932.0	2820.0	2680.0	2500.0	2280.0	2020.0	1720.0	1380.0	1000.0
Z	3045.0	3016.5	2945.2	2829.0	2686.5	2504.8	2283.5	2022.6	1721.8	1381.0	1000.3

Table 4 The influence of unit manufacturing cost on the optimal CODP location under ETO

r	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
c_1	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$	$2r^2$
c_2	$3+0.5r$	$3-0.3r$	$3-0.7r$	$3-1.1r$	$3-1.6r$	$3-2r$	$3-2.4r$	$3-2.8r$	$3-3.2r$	$3-3.6r$	$3-4r$
M	3000.0	2995.0	2932.0	2820.0	2680.0	2500.0	2280.0	2020.0	1720.0	1380.0	1000.0
Z	3045.0	3016.5	2945.2	2829.0	2686.5	2504.8	2283.5	2022.6	1721.8	1381.0	1000.3

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