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Study on Response Time Decision of Supply Chain Based on Instant Customerization

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Abstract: Under the production mode of instant customization, customers are more and more strict to the requirement of response time and how enterprises response to customer demand quickly has become the focus of the time based competition. In order to satisfy the demand, an innovative "one-to-many" supply chain system which composed of one supplier and N retailers is designed. Considering the demand is sensitive to price and time, at the same time, price is affected by the response time, the reasonable response time of centralized and decentralized supply chain have been determined respectively. Finally, through example analysis and comparison, it verifies that centralized decision-making is more conducive to the development of the supply chain. It is significant to provide decision-making tools and reference for enterprises to win in the market competition.

Key words: Instant customerization, centralized supply chain, decentralized supply chain, response time, decision

INTRODUCTION

With the heterogeneity of the customer requirements, the development of niche products and the fierce competition of customer resources, it's impossible for single company to meet the demand of customers and survive in the market relying on his own resources completely. Since Stalk (Stalk, 1988) put forward the concept of time competition for the first time in 1988, competition based on time has attracted widespread attention. Maybe it's impossible to achieve zero time or JIT, but it's the efforts direction of the supply chain enterprises and the key to win for them to make reasonable decisions about time (Chen and Hu, 2008). At present, response time decision of supply chain has been studied. Abroad, Ray and Jewkes (2004) discussed the problem of optimal decisions for the enterprise when price is influenced by response time and they put forward that we would get suboptimal decision making if we ignore the relationship between price and response time. Liu *et al.* (2007) studied that different decision making of supply chain impacts the performance of it when demand is sensitive to price and time. In the domestic, Wang *et al.* (2005) built a two-stage supply chain consisting of a manufacturer and a distributor. Yang and Li (2006) built models of general cooperation contract and discussed the influence of the two contracts on the collaboration of supply chain.

In conclusion, researchers have begun to study the response time and collaboration of "one-to-one" supply chain and they have already made some achievements. Under the guidance of IC, customers are willing to pay a higher price for a shorter response time. So, it builds a "one-to-many" supply chain system in this paper. Considering that in the case of multiple retailers, demands of customers are influenced by price and response time. Meanwhile, price is affected by response time. It studies how enterprises make decisions to meet the demand rapidly and what is the different influence of centralized and decentralized supply chain.

PROBLEM DESCRIPTIONS

It begins with a two-stage MTO(Make to order) supply chain, named "one-to-many" supply chain system that is shown in Fig. 1, which composed of one supplier and N retailers as research subject. Retailers place orders to the supplier with a wholesale price P_S and

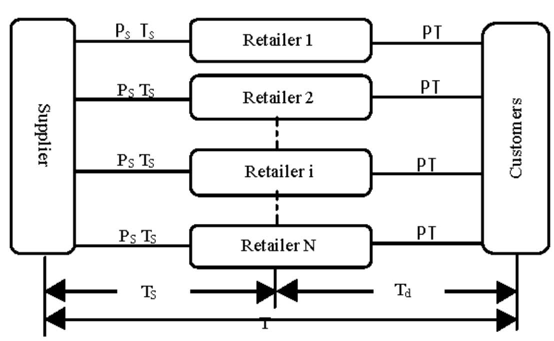

Fig. 1: "One-to-many" structure model of supply chain

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internal response time T_S according to the customer demand D per unit time, then provide to customer with retail price P and response time T after receiving goods. The response time of customer requirements is composed of the response time of supplier T_S and that of retailers Td. So, $T = T_s+T_d$ in which T_d is the shipping time.

PRESUMPTIVE MODELS

Basic prerequisite hypotheses:

- The supplier and retailers are risk neutral and completely rational and information is completely symmetry
- All retailers have the same status and competing relationship
- Market demand faced by retailers is random and generally, we assume that the market demand rate and product price have a negative correlation. The market demand rate and commitment response time change in the opposite direction.
- Product price increases linearly as the commitment response time become short
- Suppliers and retailers have to pay a penalty because of late delivery, which increases with the delay time, besides, other unit cost of the supply chain are not affected by response time
- Early delivery is allowed to each link in the supply chain

Symbolic meaning

D: Rate of market demand
P: Supply chain product price, which is the unit price retailers provide to the customers
P_s: Unit price supplier provides to the retailers
P_0: The highest unit product price that retailers provide to the customers
P_1: The highest wholesale price retailers are willing to accept
T: Commitment response time retailers promise to customers
T_s: Commitment response time supplier promises to retailers
T_d: Commitment response time retailers promise to customers, that is transportation time
C_s: Marginal unit cost of supplier
C_d: Marginal unit cost of retailers
T_s, t_d: Actual response time of supplier and retailers, F (t) is the density function, F(t) is the distribution function. The average response time is $1/\theta_s$ and $1/\theta_d$ respectively
a: Forecasted product market demand
b: Market demand--price elasticity coefficient
c: Market demand--response time elasticity coefficient
d: Price -- response time elasticity coefficient
α: Delay penalty cost per unit time and product for supplier
β: Delay penalty cost per unit time and product for retailers
$\prod$: Overall profits of centralized supply chain
$\prod_s$: Profit of supplier in decentralized supply chain
$\prod_d$: Profit of retailers in decentralized supply chain

Basic function: According to the basic hypothesis (3), the market demand rate is:

$$D = a\text{-}b\,P\text{-}cT \quad (1)$$

The response time of supply chain is:

$$T = T_s+T_d \quad (2)$$

According to the basic hypothesis (4) the relationship between P and $_T$ is:

$$P = P_0\text{-}dT \quad (3)$$

The relationship between supplier's wholesale price and response time is:

$$P_S = P_1\text{-}dT_S \quad (4)$$

In order to complete orders, the supplier need to process orders, purchase raw materials and so on. This process involves multiple business sectors and contains many uncertainties, so the actual response time t of completing orders is a random variable. According to the research, the actual response time t obeys asymptotic exponential distribution (Karmarkar, 1993). Assuming that it obeys exponential distribution with parameter λ, then the density function is:

(5)

The relevant distribution function is:

(6)

$1/\lambda_s$ and $1/\lambda_d$ are the average response time of supplier and retailers to complete the order.

ESTABLISHMENT OF RESPONSE TIME MODEL

Decision model of supply chain can be divided into centralized and decentralized decision making. The only maker in the centralized supply chain is standing in the global point of view, so as to maximize the overall profits of supply chain; in decentralized supply chain, suppliers and retailers develop response time to maximize their own profits as rational-economic man.

The overall profit function of centralized supply chain: In centralized supply chain, each enterprise is a kind of unity and cooperation partnership, sharing information. The overall profit function of supply chain is:

$$\Pi = \left[P\text{-}C_d - C_s - (\alpha+\beta)\int_T^{\infty}(dt) \right] \bullet Q \tag{7}$$

with:

$$(\alpha+\beta)\int_T^{\infty}(t-T)f(t)dt$$

the delay penalty cost for supply chain.

The profit function of decentralized supply chain: In decentralized supply chain, suppliers and retailers make decisions to maximize their own profit respectively. The profit function of supplier is:

$$\Pi_s = \left[P_s - C_s - \alpha\int_T^{\infty}(t_s - T_s)f(t_s)dt_s \right] \bullet Q \tag{8}$$

with:

$$\alpha\int_T^{\infty}(t_s - T_s)f(t_s)dt_s$$

the delay penalty cost for supplier. The profit function of retailer i is:

$$\Pi_s = \left[P{=}P_s - C_d - \beta\alpha\int_T^{\infty}(t_{di} - T_{di})f(t_{di})dt_{di} \right] \bullet Q \quad (i = 1, 2, \ldots, N) \tag{9}$$

with:

$$\beta\int_T^{\infty}(t_{di} - T_{di})f(t_{di})dt_{di}$$

the delay penalty cost for retailer i.

SOLUTION OF THE RESPONSE TIME MODEL

Solution of the centralized supply chain response time: Centralized supply chain's overall goal is to achieve the optimal profit level of supply chain, which can be represented as:

$$\max_{T\geq 0}\left[P - C_d - C_s - (\alpha+\beta)\int_T^{\infty}(t-T)f(t)dt \right] \bullet Q$$

Putting the formula (1) and (3) into formula (7) can achieve the overall income function, which is:

$$\Pi = \left[P - C_d - C_s - (\alpha+\beta)\int_T^{\infty}(t-T)f(t)dt \right].(a - bP_0 + bdT - cT)$$

Asking about first and second derivative of T by using Matlab 7.0 will conduct below formulas:

$$\frac{\partial\Pi}{\partial T} = \left[-d + (\alpha+\beta).e^{-\lambda T} \right](a - bP_0 + bdT - cT) + \left[P_0 - dT - C_d - C_s - (\alpha+\beta).e^{-\lambda T}/\lambda \right](bd - c)$$

$$\frac{\partial^2\Pi}{\partial T^2} = -(\alpha+\beta).e^{-\lambda T}.(a - bP_0 + bdT - cT) + 2\left[-d + (\alpha+\beta).e^{-\lambda T}/\lambda \right](bd - c) < 0$$

From the foregoing, supply chain overall profit function ∏ is a convex function of the response time T, so an optimal solution which makes the overall profit function ∏ reach the maximum value exists in the defined range of T $[0, \infty)$. Making its derivative equal to zero, but because of too complicated, it can't calculate the specific value of T. In order to simplify the problem further and calculate the value of, T.

we assume that the demand rate D is determined. Then asking about first and second derivative of T by using Matlab 7.0 with respect to formula (7):

$$\frac{\partial\Pi}{\partial T} = \left[-d + (\alpha+\beta).e^{-\lambda T} \right].D$$

$$\frac{\partial^2\Pi}{\partial T^2} = -(\alpha+\beta)\lambda.e^{-\lambda T}.D < 0$$

From the foregoing, to determined rate of demand D, just as any rate of demand D, let $\partial\prod/\partial T = 0$, then:

$$T^* = F^{-1}\left[1 - \frac{d}{\alpha+\beta} \right] \tag{10}$$

The overall profits of supply chain at this point is:

$$\Pi = \left[P_0 - \frac{d}{\lambda}\left(1 - \text{in}\frac{d}{\alpha+\beta}\right) - C_d - C_s \right].D \qquad (11)$$

Solution of the decentralized supply chain response time of retailers: In the decentralized supply chain, retailers are to maximize its own profit as the goal. First calculate the optimal reaction of retailers to any response time of supplier which can be expressed as:

$$\underset{T_{di}\geq 0}{\text{Max}}\,\Pi_{di} = \left[P - P_s - C_d - \beta\int_T^{\infty}(t_{di} - T_{di})f(t_{di})dt_{di} \right]\bullet Q_i$$
$$(i\,1, 2, \ldots, N)$$

The competition between retailers is a typical Cournot game, according to the Nash equilibrium existence theorem, in the strategy game of n people, if the pure strategy space S_i of each participant is a non-empty, closed and bounded convexset on the European space and the payoff function u_i (s) is continuous and an quasi concave function of s_i, then, there is a pure strategy Nash equilibrium in the game (Xiao, 2004). Therefore, the response time of all the retailers exist an unique Nash equilibrium $(T^*_{d1}, T^*_{d2}, \ldots, T^*_{di}, \ldots, T^*_{dN})$, among which $T^*_{d1} = T^*_d / N$ (Li *et al*., 2013).

Asking about the first and second derivative of T by using Matlab 7.0 with respect to formula (9)will conduct below formulas:

$$\frac{\partial \Pi_{di}}{\partial T_{di}} = \left(-d + \beta.e^{-\lambda T_{di}}\right).\left[a - bP_0 + (bd - c)(T_{di} + T_{-di} + T_s)/N\right]$$
$$+\left[P_0 - d(T_{di} + T_{-di} + T_s) - P_1 + dT_s - C_d - \beta.e^{-\lambda T}/\lambda\right].(bd - c)/$$
$$\frac{\partial^2 \Pi_{di}}{\partial {T_{di}}^2} = \left(-\beta\lambda.e^{-\lambda T_{di}}\right).\left[a - bP_0 + (bd - c)(T_{di} + T_{-di} + T_s)\right]$$
$$+2\left[-d + \beta.e^{-\lambda T_{di}}/\lambda\right].(bd - c)/N < 0$$

T_{-di} is the sum of the response time of N-1 retailers expect for the retailer I. From the foregoing, the retailers' profit $\prod_{di}$function is a convex function of the retailers' response time T_{di}, so an optimal solution which makes the retailer's profit function $\prod_{di}$ reach the maximum value exists on the defined interval of T_{di} $[0, \infty)$. Making its derivative equal to zero, but because of too complicated, it can't calculate the specific value of T. In order to simplify the problem further and calculate the value of T_{di}, we assume that the demand rate is determined, then asking about the first and second derivative of T_{di} by using Matlab 7.0 with respect to formula (9):

$$\frac{\partial \Pi_{di}}{\partial T_{di}} = \left(-d + \beta.e^{-\lambda_d T_{di}}\right).\frac{D}{N}$$

$$\frac{\partial^2 \Pi_{di}}{\partial {T_{di}}^2} = -\beta + \lambda.e^{-\lambda_S T_S}.D/N < 0$$

From the foregoing, to determined rate of demand D, just as any rate of demand D, let $\partial\Pi_{di}/\partial T_{di} = 0$, then:

$$T^*_{di} = T^*_{d2} = \ldots = T^*_{dN} = 1/F^{-1}\left[1 - \frac{d}{\beta}\right] \qquad (12)$$

Solution of the decentralized supply chain response time of supplier: In the decentralized supply chain, supplier is to maximize its own profit as the goal. First calculate the optimal reaction of supplier to any response time of retailers which can be expressed as:

$$\frac{\partial^2 \Pi_s}{\partial {T_s}^2} = -\alpha + \lambda.e^{-\lambda_S T_S}.D < 0$$

Asking about the first and second derivative of T_S by using Matlab 7.0 with respect to formula (8) will conduct:

$$T^* = F^{-1}\left[1 - \frac{d}{\alpha}\right]$$

below formulas,

$$T^*_d + T^*_s = F^{-1}\left[1 - \frac{d}{\beta}\right] + F^{-1}\left[1 - \frac{d}{\alpha}\right]$$

From the foregoing, the profit function of supplier $\prod_s$ is a convex function of the supplier's response time T_S, so an optimal solution which makes the supplier's profit function T_s reach the maximum value exists on the defined interval of T_S $[0, \infty)$. Making its derivative equal to zero, but because of too complicated, it can't calculate the specific value of T_S. In order to simplify the problem further and calculate the value of T_S , we assume that the demand rate is determined, then asking about first and second derivative of $_{TS}$ by using Matlab 7.0 with respect to formula (8):

$$\frac{\partial \Pi_s}{\partial T_s} = \left(-d + \alpha.e^{-\lambda_S T_S}\right).D$$

$$\frac{\partial^2 \Pi_s}{\partial T_s} = \left(-\alpha + \lambda_s.e^{-\lambda_S T_S}\right).D < 0$$

From the foregoing, to determined rate of demand D, just as any rate of demand D, let $\partial \Pi_{di} / \partial T_{di}$, then:

$$T_S^* = F^{-1}\left[1-\frac{d}{\alpha}\right] \tag{13}$$

So, the response time of decentralized supply chain is:

$$T_d^* + T_S^* = F^{-1}\left[1-\frac{d}{\beta}\right] + F^{-1}\left[1-\frac{d}{\alpha}\right] \tag{14}$$

Now the overall profit function of supply chain is:

$$\Pi = \left[P_0 + \frac{d}{\lambda_s}\ln\frac{d}{\alpha} - \frac{d}{\lambda_d}\left(1-\ln\frac{d}{\beta}\right) - C_d - C_s\right] - D \tag{15}$$

EXAMPLE ANALYSIS

According to the above, it shows that decentralized decision making reduced the profit level of the whole supply chain. In order to confirm the conclusion further, the related parameters were assignment and a calculation analysis was carried out in this paper. Company A is a machinery supplier, whose products are geared to the individual users. Company B, C and D are retailers for the machine. The operational data of the supply chain are in Table 1.

The optimization results are shown in Table 2. By comparing, it has been seen that the centralized and decentralized supply chain was similar in price and that the response time of decentralized supply chain which is 18 days is greater than the centralized supply chain of 17 days. However the centralized supply chain profit is RMB 9.24×106, much higher than the decentralized supply chain profit of RMB 8.49×106 which has fully demonstrated the conclusion that centralized supply chain is superior to the decentralized one.

In the centralized supply chain, the relationship between overall profits and response time is shown in Fig. 2. In the decentralized supply chain, the relationship between retailers' profits and its response time is shown in Fig. 3. And relationship between profits of supplier and its response time is shown in Fig. 4. With the number of retailers in the supply chain changing, the relationship between each retailer's profit and response time is shown in Fig. 5.

Comparing Fig. 2, 3 and 4, no matter in centralized or decentralized supply chain, profit increases first with the response time increasing, that is because longer response time means supply chain costs reducing correspondingly; However after reaching a certain height, profits reach the maximum; Then the profits begin to fall. This is because too long response time can cause delay penalty costs in the supply chain, resulting in a decline in profits. From Fig. 5, we can see with the increasing in

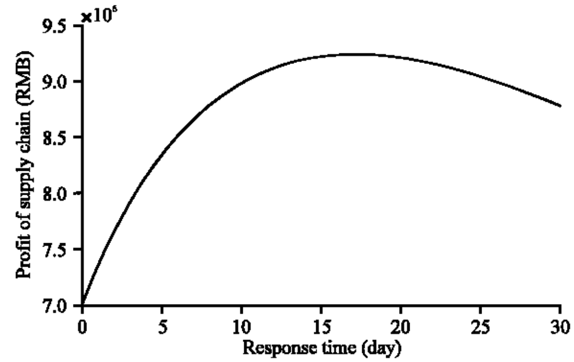

Fig. 2: Centralized supply chain profits-response time

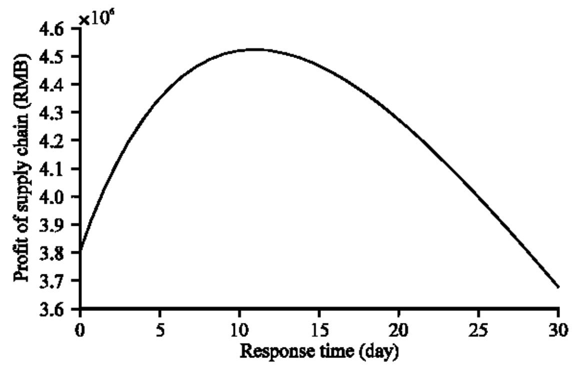

Fig. 3: Decentralized supply chain retailers' profits-response time

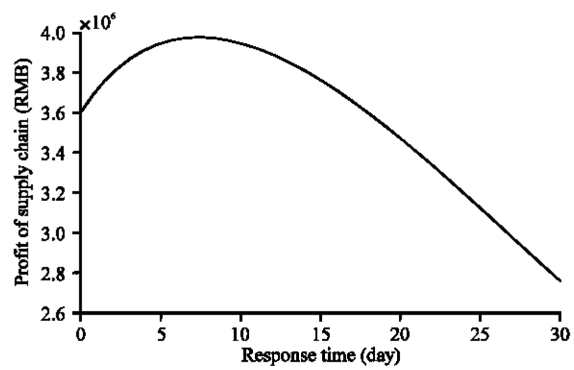

Fig. 4: Decentralized supply chain supplier's profits-response time

Table 1: Supply chain operation data list

Parameter	value	Parameter	value	Parameter	value	Parameter	value
P_0	90000 (RMB unit^{-1})	d	200 (RMB day^{-1})	C_d	1500 (RMB unit^{-1})	λ_d	0.1
P_1	73000 (RMB unit^{-1})	α	500 (RMB day^{-1})	D	400 (unit day^{-1})	λ_s	0.125
C_s	60000 (RMB unit^{-1})	β	600 (RMB day^{-1})				

Table 2: Results of two kinds of decision model

Decision model	Price P	Response time T	Profits of supplier $\prod_s$	Profits of retailer $\prod_d$	Profits of supply chain $\prod$
Centralized supply chain	86600 (RMB/unit)	17 (days)	/	/	9.24×106 (RMB)
Decentralized supply chain	86400 (RMB/unit)	18 (days)	3.97×106 (RMB)	4.52×106 (RMB)	8.49×106 (RMB)

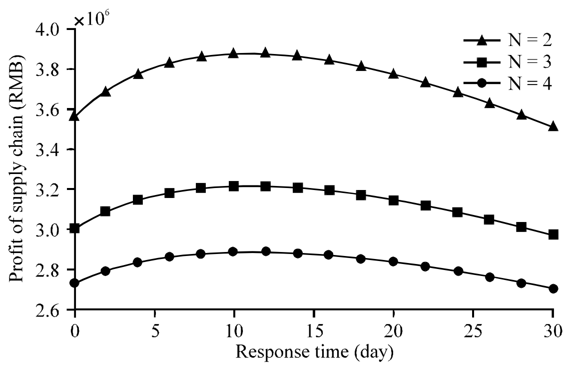

Fig. 5: Decentralized supply chain each retailer's profits response time for different N

number of retailers,a single retailer's profit is on the decline. This is due to the increase in the number of retailers has shared the profits of retailers throughout the supply chain, resulting in a decline in single retailer's profits.

CONCLUSIONS

With the rapid development of technology and the rapid changes in consumer demand, instant customer customization has become advanced production methods. In this paper, with the guidance of IC, a two-stage supply chain model consisting of one supplier and N retailers is established. The centralization decision-making is more conducive to the overall development of the supply chain. Finally, with an example we further validate the centralized and decentralized decision-making influence on decision outcomes. I believe that future research questions should be changed from the "one to many" expanded to "many to many", discussing the supply chain response time decision-making with multiple suppliers and retailers.

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