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# Supply Chain Coordination for Blood at Loss Rate under Seasonal Fluctuation

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**Abstract.** In this paper, we thought that the supply chain management of blood is impacted both by the loss of products and the seasonal fluctuation of supply source. From practically-existed problem, with the hypothesis of two kinds of substitutable blood at different loss rates, and the impact on ordering strategy from seasonal fluctuation being expressed as the probability of products arrival, we constructed two ordering models respectively considering two situations of distributed decision making and centralized decision making. Through the solution, numerical simulation, and comparison analysis for the models, we concluded that both centralized decision making and distributed decision making could well reach the status of supply chain coordination.



## INTRODUCTION

Perishable products usually include some easily-natural-loss goods, such as fresh fruits, fresh vegetables, milk, yogurt, and clinically-used blood etc. In this paper, we concern blood, which was this kind of perishable product, of which there are not only natural loss in the logistics and warehousing, but also there are seasonal fluctuation impacts on the supply sources. On the study for supply chain management of perishable products, literature [1, 2] started research from newsboy problem, further study the decision making of perishable products ordering and pricing. Other literatures also carried out many systematic analyzes and researches, for example, researches for seasonal goods concerning the following aspects, twice ordering problem [3], sales game model [4], production size model and lead-time decision making model [5], dynamic pricing model [6], etc. Recently, there are some further work, the further research from the view of loss extent and fresh extent, the research on perishable product with short shelf life [7], the research on loss of perishable product [8], the research on fresh goods and their option contract [9], the research on production under option contract and order strategy of seasonal goods [10], etc. In this paper, we also started our research from that the feature of perishable product is expressed as loss rate, the point different from the above literatures is that, we made perishable products with different loss rates by different techniques and methods, and these perishable products can well be interchanged each other. The perishable products concerned in this paper are the following goods in real life, such as, yogurt, clinically-used blood, etc.

With respect to the research for integrated profit coordination of supply chain, there are also many important relevant literatures, in which the following are reported, the research on retailer-dominated coordination of supply chain when considering demand interrupt [11], the research on the risk of supply interrupt [12], the research on the supply chain coordination when considering wholesale price contract [13, 14], the research on the coordination of price time varying in uncertainty condition [15], the research on the coordination and efficiency in uncertain delivery date [16], the research on the coordination model for decision making of demand information renewal point [17], the research on the supply chain coordination when considering service ability [18] or quality assurance service contract [19], and the research on the coordination model when considering simultaneous deviation of demand and cost [20] or turbulence [21], etc. In this paper, we also consider supply chain coordination, that is, the coordination of supply chain overall profit when considering the coordination of optimal order size from distributed decision making to centralized decision making.

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We thought that clinically-used blood is impacted not only by products loss but also by seasonal fluctuation of supply source. In this paper, from practically existing problem, with hypothesizing there are two kinds of interchangeable perishable products with different loss rates, and expressing the impact on order strategy from seasonal fluctuation by goods arrival probability, we constructed two kinds of order models respectively for distributed decision making and centralized decision making of supply chain. Through the solution, numerical simulation, and comparison analysis for the models, we obtained some significant conclusions for supply chain management.

This paper is arranged as follows: in section 2, the relevant problem description and hypothesis for establishment of the models are described; in section 3 and 4, two kinds of order models respectively for distributed decision making and centralized decision making are constructed, and the models solutions are completed; in section 5, the optimal supply chain coordination of distributed decision making and centralized decision making are analyzed; in section 6, the simulation for the models and relative discussions are given; in section 7, the conclusions and summary of future research prospects are provided.

## PROBLEM DESCRIPTIONS AND HYPOTHESIS

The classical newsboy model is taken as basic model, and products loss rates $\beta$ is introduced, $\beta \in (0,1)$. In this paper, first of all, two kinds of interchangeable similar perishable products with different loss rates are concerned; second, about the impact factor of order, not only naturally deteriorating loss of goods themselves and damage loss in transportation, but also the impact on supply source because of seasonal fluctuation, are all taken into account. The key problem we concern is that, in the constraints of multiple impact factors, how manager can make a relatively scientific judgment and decision making.

Our idea of forming models is that, the terminal retailer order model is constructed when considering distributed decision making, simultaneously the integrated models of supply chain also established when considering centralized decision making, and the research conclusion is achieved through the solution and comparison of the models.

The variables in this paper are defined and symbolized as in Table 1.

Certainly, the model in this paper is established under the below assumptions: firstly, both in the circumstances of distributed and centralized decision making, lump sum order is assumed within the order cycle. Also, it is assumed that the lead time for the order is zero, at the initial stage of the order, the inventory is zero. Next, it is assumed that the residual value of the Blood is too small, which can be negligible, in this paper only the cost of carrying out the deterioration of the product due to excess is considered. Finally, to ensure that retailers are willing to place orders for the part of the Blood that may not be available under seasonal fluctuations, the formula $(1-r_2)w_{JS} < r_2 pm(1-\beta_L)$ is assumed to be true.

**TABLE 1.** Definitions and relevant explanations for variables

| Symbols used in distributed decision making | Definition | Symbols used in centralized decision making | Definition |
|---|---|---|---|
| $\beta$ | Blood loss rate $\beta \in (0,1)$ | $\beta$ | Blood loss rate $\beta \in (0,1)$ |
| In which, $\beta_L$ | Loss rate of Blood with long shelf life | In which, $\beta_L$ | Loss rate of Blood with long shelf life |
| $\beta_S$ | Loss rate of Blood with short shelf life | $\beta_S$ | Loss rate of Blood with short shelf life |
| $w_L$ | Unit cost of Blood with long shelf life | $w_{JL}$ | Unit cost of Blood with long shelf life |
| $w_S$ | Unit cost of Blood with short shelf life | $w_{JS}$ | Unit cost of Blood with short shelf life |
| $m$ | Order size proportion of long shelf life Blood to the total | $m_J$ | Order size proportion of long shelf life Blood to the total |
| $Q_L$ | Total order size in distributed decision making | $Q_{JL}$ | Total order size in centralized decision making |
| $x$ | Practical market demand of product | $x$ | Practical market demand of product |
| $\mu$ | Expected value of practical market demand $x$ | $\mu$ | Expected value of practical market demand $x$ |
| $f(x)$ | Probability density function of practical market demand, assuming it is differentiable and reversible | $f(x)$ | Probability density function of practical market demand, assuming it is differentiable and reversible |
| $F(x)$ | Cumulative distribution function of practical market demand, assuming it is differentiable and reversible | $F(x)$ | Cumulative distribution function of practical market demand, assuming it is differentiable and reversible |
| $I(t)$ | Inventory level at time $t$ | $p$ | Unit sales price |
| $T$ | Order cycle | $r_2$ | Blood arrival probability in seasonal fluctuation |
| $p$ | Unit sales price | | |
| $h$ | Unit holding cost | | |
| $g$ | Unit in-short-supply cost | | |
| $r_2$ | Blood arrival probability in seasonal fluctuation | | |



## SUPPLY CHAIN MANAGEMENT OF BLOOD IN THE CIRCUMSTANCES OF DISTRIBUTED DECISION MAKING

In the circumstances of distributed decision making, the expected profit of supply chain is the total profits of various members on the chain. In this paper, distributed decision making was analyzed from the view of retailers on the chain terminal.

After loss rate $\beta_L$ is introduced, the inventory model of perishable product can obtained as:

$$\frac{dI(t)}{dt} = -x - \beta_L I(t) \quad , \qquad 0 \le t \le T$$

Subsequently, the actual inventory level in order cycle $T$ is got as:

$$\int_0^T I(t)dt = (\frac{1}{\beta_L^2} e^{\beta_L T} - \frac{1}{\beta_L^2} - \frac{T}{\beta_L})x = k_L x \tag{1}$$

Then, the profit $\pi_L(Q_L)$ of retailer is further educed as follows:

$$\pi_L(Q_L)=\begin{cases} px-hk_Lx-(1-r_2)h(1-m)Q_L(1-\beta_S)-w_LmQ_L-w_S(1-m)Q_L, & x\le mQ_L(1-\beta_L) \\ r_2[pmQ_L(1-\beta_L)-g(x-mQ_L(1-\beta_L))]+(1-r_2)(px-hk_Lx) & \\ \quad -w_LmQ_L-w_S(1-m)Q_L, & mQ_L(1-\beta_L)<x\le mQ_L(1-\beta_L)+(1-m)Q_L(1-\beta_S) \\ r_2[pmQ_L(1-\beta_L)-g(x-mQ_L(1-\beta_L))]+(1-r_2)[(p+g)(mQ_L(1-\beta_L)+(1-m)Q_L(1-\beta_S))-gx] & \\ \quad -w_LmQ_L-w_S(1-m)Q_L, & x>mQ_L(1-\beta_L)+(1-m)Q_L(1-\beta_S) \end{cases} \tag{2}$$

From formula (1) and (2), the expected profit of the supplier is educed as follows:

$$\begin{aligned} E[\pi_L(Q_L)] &= \int_0^{aQ_L}[-(1-r_2)hcQ_L+r_2(p+g)(x-aQ_L)-r_2hk_Lx]f(x)dx \\ &+\int_0^{(a+c)Q_L}[(1-r_2)(p+g-hk_L)x-(1-r_2)(p+g)(a+c)Q_L]f(x)dx \\ &+(p+g)(a+c)Q_L-r_2(p+g)cQ_L-g\mu-w_LmQ_L-w_S(1-m)Q_L \end{aligned} \tag{3}$$

In which, $a=m(1-\beta_L)$, $c=(1-m)(1-\beta_S)$.

**[Lemma 1]** In the circumstances of distributed decision making, with seasonal fluctuation and loss being considered, the optimal order size and maximum expected profit of retailers for blood exist and are unique.

**Proof:**

For there is,

$$\begin{aligned} \frac{dE[\pi_L(Q_L)]}{dQ_L} &= -(1-r_2)hcQ_LF(aQ_L)-r_2(p+g)aQ_LF(aQ_L) \\ &-(1-r_2)(p+g)(a+c)Q_LF((a+c)Q_L) \\ &+(p+g)(a+c)-r_2(p+g)c-w_Lm-w_S(1-m) \end{aligned} \tag{4}$$

$$\frac{d^2E[\pi_L(Q_L)]}{dQ_L^2}=-(1-r_2)hcQ_Laf(aQ_L)-r_2(p+g)a^2Q_Lf(aQ_L)-(1-r_2)(p+g)(a+c)^2Q_Lf((a+c)Q_L)<0$$

Therefore, the expected profit $E[\pi_L(Q_L)]$ is the concave function of the order size $Q_L$. That is, In the circumstances of distributed decision making, with seasonal fluctuation and loss being considered, the optimal order size and maximum expected profit of retailers for blood exist and are unique. The maximum expected profit corresponding to the optimal order size also exists and is unique. Q.E.D.

**[Proposition 1]** In the circumstances of distributed decision making, with seasonal fluctuation and loss being considered, the optimal order size of retailer for blood is obtained by the following formula.

$$\begin{aligned} -(1-r_2)hcQ_LF(aQ_L)-r_2(p+g)aQ_LF(aQ_L)-(1-r_2)(p+g)(a+c)Q_LF((a+c)Q_L) \\ +(p+g)(a+c)-r_2(p+g)c-w_Lm-w_S(1-m)=0 \end{aligned} \tag{5}$$

**Proof:** Using lemma 1, and set $\frac{dE[\pi_L(Q_L)]}{dQ_L}=0$, so the formula of optimal order size of retailer for blood can be got. Q.E.D.

## SUPPLY CHAIN MANAGEMENT OF BLOOD IN THE CIRCUMSTANCES OF CENTRALIZED DECISION MAKING

The blood discussed in this study, of which actual sales amount is impacted by both seasonal fluctuation and product deteriorating loss. Thus, as the links between supply chains increase, naturally the order size is enlarged along the links. If centralized decision making is implemented on whole supply chain, optimal blood supply can be ensured and waste reduced through integrated coordination among chain members. The difference between centralized and distributed decision making is that, in the circumstances of centralized decision making, blood do not stop at intermediate suppliers, are directly delivered from original suppliers to ends retailers, of which the optimal aim is that the total profit of whole chain is maximum, the surplus and shortage of blood is avoided through the coordination among chain members.

Certainly, in the circumstances of centralized decision making, for intermediate suppliers being not responsible for the loading and unloading, and storing of blood, obviously whole price issued by suppliers would be promoted, that is, $w_{JL} > w_L$ , $w_{JS} > w_S$ .

The same method being introduced as that is used for modeling in the circumstances of distributed decision making, the formula of supply chain integrated profit is got as follows:

$$\pi_2(Q_{JL}) = \begin{cases} px - w_{JL}m_J Q_{JL}, & x \le m_J Q_{JL}(1-\beta_L) \\ r_2[pm_J Q_{JL}(1-\beta_L) - w_{JL}m_J Q_{JL}] + (1-r_2)(px - w_{JL}m_J Q_{JL} - w_{JS}(1-m_J)Q_{JL}), \\ \qquad m_J Q_{JL}(1-\beta_L) < x \le m_J Q_{JL}(1-\beta_L) + (1-m_J)Q_{JL}(1-\beta_S) \\ r_2[pm_J Q_{JL}(1-\beta_L) - w_{JL}m_J Q_{JL}] + \\ \quad (1-r_2)[pm_J Q_{JL}(1-\beta_L) + p(1-m_J)Q_{JL}(1-\beta_S)] \\ \qquad -w_{JL}m_J Q_{JL} - w_{JS}(1-m_J)Q_{JL}, & x > m_J Q_{JL}(1-\beta_L) + (1-m_J)Q_{JL}(1-\beta_S) \end{cases} \tag{6}$$

Therefore, basing on formula (6), the total expected profit of supply chain is got as follows:

$$\begin{aligned} E[\pi_2(Q_{JL})] = &-r_2\int_0^{aQ_{JL}} (pa + w_{JS}(1-m_J))Q_{JL} f(x)dx + (1-m_J)\int_0^{aQ_{JL}} w_{JS}Q_{JL} f(x)dx \\ &+ (1-r_2)p\int_0^{(a+c)Q_{JL}} (x-(a+c)Q_{JL}) f(x)dx \\ &+ p(a+c)Q_{JL} - r_2 pcQ_{JL} - w_{JL}m_J Q_{JL} - (1-r_2)w_{JS}(1-m_J)Q_{JL} \end{aligned} \tag{7}$$

In which, $a = m_J(1-\beta_L)$ , $c = (1-m_J)(1-\beta_S)$

**[Lemma 2]** In the circumstances of distributed decision making, with seasonal fluctuation and loss being considered, the optimal order size and maximum expected profit of retailers for blood exist and are unique.

**Proof:** Owing to

$$\begin{aligned} \frac{dE[\pi_2(Q_{JL})]}{dQ_{JL}} = &-r_2 paQ_{JL}F(aQ_{JL}) + (1-r_2)w_{JS}(1-m_J)Q_{JL}F(aQ_{JL}) \\ &-(1-r_2)p(a+c)Q_{JL}F((a+c)Q_{JL}) \\ &+ p(a+c) - r_2 pc - w_{JL}m_J - (1-r_2)w_{JS}(1-m_J) \end{aligned} \tag{8}$$

$$\begin{aligned} \frac{d^2E[\pi_2(Q_{JL})]}{dQ_{JL}^{\ 2}} = &-r_2 pa^2 Q_{JL}^{\ 2} f(aQ_{JL}) + (1-r_2)w_{JS}aQ_{JL}^{\ 2} f(aQ_{JL}) \\ &-(1-r_2)p(a+c)^2 Q_{JL}^{\ 2} f((a+c)Q_{JL}) \end{aligned} \tag{9}$$

And in the above the profit premise of retailer is hypothesized as $(1-r_2)w_{JS} < r_2 pm_J(1-\beta_L)$

So formula (9), it is got as follows:

$$\frac{d^2E[\pi_2(Q_{JL})]}{dQ_{JL}^{\ 2}} < 0;$$

Therefore, the expected profit $E[\pi_2(Q_{JL})]$ is the concave function of the order size $Q_{JL}$ . That is, in the circumstances of centralized decision making, with seasonal fluctuation and loss being considered, the optimal order size and maximum expected profit of retailers for blood exist and are unique. The maximum expected profit corresponding to the optimal order size also exists and is unique. Q.E.D.

**[Proposition 2]** In the circumstances of centralized decision making, with seasonal fluctuation and loss being considered, the optimal order size of retailer for blood is obtained by the following formula.

$$\begin{aligned} -r_2 paQ_{JL}F(aQ_{JL}) + (1-r_2)w_{JS}(1-m_J)Q_{JL}F(aQ_{JL}) - (1-r_2)p(a+c)Q_{JL}F((a+c)Q_{JL}) \\ + p(a+c) - r_2 pc - w_{JL}m_J - (1-r_2)w_{JS}(1-m_J) = 0 \end{aligned} \tag{10}$$

**Proof:** Using lemma 2, and set $\frac{dE[\pi_2(Q_{JL})]}{dQ_{JL}} = 0$ , so the formula of optimal order size of retailer for blood can be got. Q.E.D.

## OPTIMAL COORDINATION OF SUPPLY CHAIN SYSTEM IN THE CIRCUMSTANCES OF DISTRIBUTED AND CENTRALIZED DECISION MAKING

From proposition 1 and 2, in the circumstances of distributed and centralized decision making, the optimal order size of retailer for blood can be got. In order to achieve the coordination of supply chain system, set $Q_L^* = Q_{JL}^* = Q^*$ , then the below proposition is got.

**[Proposition 3]** if all the parameters meet the following equation, supply chain system reaches coordination status.

$$r_2 gaQ^* F(aQ^*) + (1-r_2)[w_{JS}(1-m_J) + hc]Q^* F(aQ^*) + (1-r_2)g(a+c)Q^* F((a+c)Q^*)$$
$$= g(a+c) - r_2 gc - w_L m - w_S(1-m) + w_{JL} m_J + (1-r_2) w_{JS}(1-m_J)$$

**Proof:** Using formula (5) and (10), the respective optimal order size $Q_L^*$ and $Q_{JL}^*$ are obtained.

And in order to meet the coordination of supply chain system reach, set $Q_L^* = Q_{JL}^* = Q^*$, then the below formula can be got.

$$r_2 gaQ^* F(aQ^*) + (1-r_2)[w_{JS}(1-m_J) + hc]Q^* F(aQ^*) + (1-r_2)g(a+c)Q^* F((a+c)Q^*)$$
$$= g(a+c) - r_2 gc - w_L m - w_S(1-m) + w_{JL} m_J + (1-r_2) w_{JS}(1-m_J)$$

Thus, both in the circumstances of distributed and centralized decision making, if only all parameters meet the above equation, supply chain system reaches optimal coordination. Q.E.D.

## NUMERICAL ANALYZES

If all parameters meet the equation in proposition 3, supply chain system reaches optimal coordination in the circumstances of distributed and centralized decision making, in this section, which is described through numerical analyzes.

For the simplicity and generality of the discussion, it is assumed that the market stochastic demand is uniformly distributed, that is, the distribution is met to formula $f(x) = 1/(b-d)$.

### Supply Chain Coordination in the Circumstances of Order Cost Changing

The function $f(x) = 1/(b-d)$ is substituted into formulas (5) and (10). In order to facilitate comparison, the values of parameters values are set as follows: $p = 80$, $g = 60$, $h = 1$, $b-d = 100$, $r_2 = 0.3$, $\beta_L = 0.4$, $\beta_S = 0.15$, $m_J = m = 0.2$.

In the circumstances of distributed decision making, the order cost is fixed, that is $w_L = w_S = 20$. On the other hand, in the circumstances of centralized decision making, order cost $w_{JL}$ and $w_{JS}$ changes respectively.

(1) When $w_{JS} = 4$, changing the value of $w_{JL}$, the numerical simulation result 1 of supply chain coordination in the circumstances of distributed and centralized decision making as Fig. 1.

As shown in Fig. 1, when order cost is fixed in the circumstances of distributed decision making, in order to reach supply chain coordination between centralized decision making and distributed decision making, it can be realized through changing the unit cost values $w_{JL}$ of long shelf life blood. The dotted line in figure is the optimal order sizes obtained from different cost values in the circumstances of centralized decision making. It can be seen that there is a point of intersection between the dotted line and the real line, of which the real line represents distributed decision making. The point of intersection is the coordination point of supply chain.

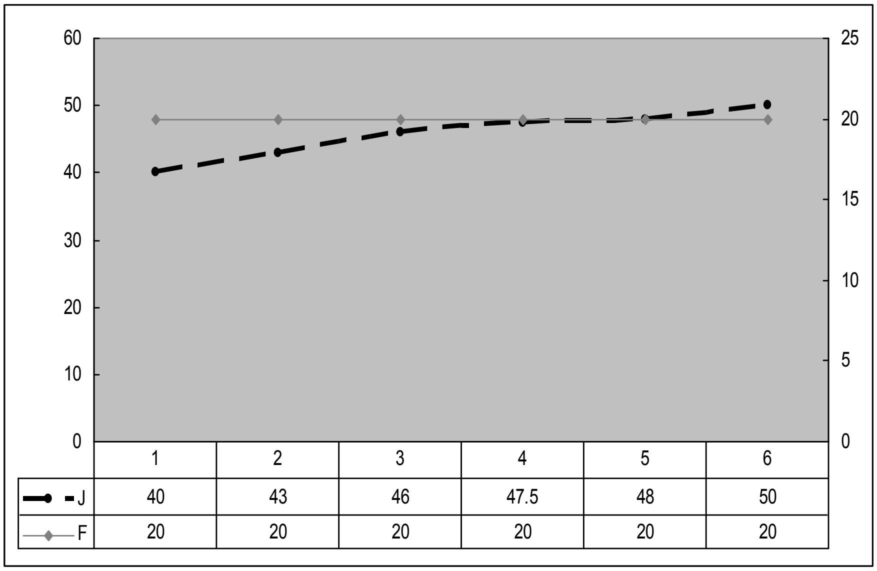



**FIGURE 1.** The numerical simulation result 1 of supply chain coordination in the course of order cost changing

(2) When $w_{JL} = 30$, changing the value of $w_{JS}$, the numerical simulation result 2 of supply chain coordination in the circumstances of distributed and centralized decision making as Fig. 2.

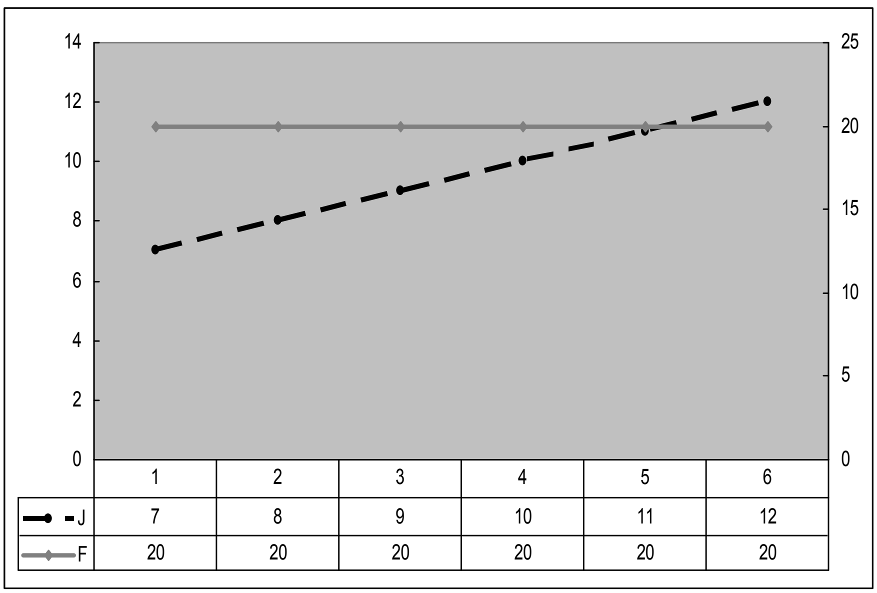


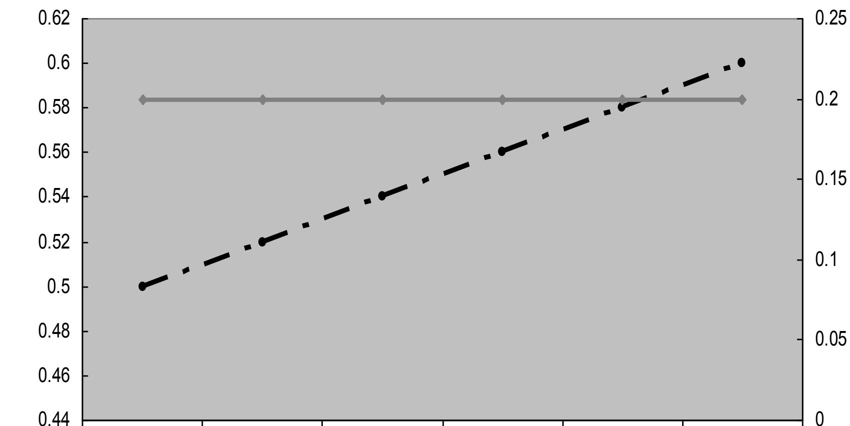

**FIGURE 2.** The numerical simulation result 2 of supply chain coordination in the course of order cost changing

As shown in Fig. 2, when order cost is fixed in the circumstances of distributed decision making, in order to reach supply chain coordination between centralized decision making and distributed decision making, it can be realized through changing the unit cost values $w_{JS}$ of short shelf life blood. The dotted line in figure is the optimal order sizes obtained from different cost values in the circumstances of centralized decision making. It can be seen that there is a point of intersection between the dotted line and the real line, of which the real line represents distributed decision making. The point of intersection is the coordination point of supply chain.

## Supply Chain Coordination in The Circumstances of Substitution Proportion Changing

Similarly, the function $f(x) = 1/(b-d)$ is substituted into formulas (5) and (10). In order to facilitate comparison, the values of parameters values are set as follows: $p = 80$, $g = 60$, $h = 1$, $r_2 = 0.3$, $b-d = 100$, $\beta_L = 0.4$, $\beta_S = 0.15$, $w_L = w_S = 20$, $w_{JL} = 26$, $w_{JS} = 9$.

When $m = 0.2$, changing the value of $m_J$, the numerical simulation result of supply chain coordination in the circumstances of distributed and centralized decision making as Fig. 3.




| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| J | 0.5 | 0.52 | 0.54 | 0.56 | 0.58 | 0.6 |
| F | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

**FIGURE 3.** The numerical simulation result of supply chain coordination in the course of substitution proportion changing

As shown in Fig. 3, when substitution proportion is fixed in the circumstances of distributed decision making, in order to reach supply chain coordination between centralized decision making and distributed decision making, it can be realized through changing the values $m_J$ that is the proportion of long shelf life blood's order quantity to total order. The dotted line in figure is the optimal order sizes obtained from different substitution proportion values in the circumstances of centralized decision making. It can be seen that there is a point of intersection between the dotted line and the real line, of which the real line represents distributed decision making. The point of intersection is the coordination point of supply chain.

When the stochastic demands of market are accorded with other distributions, we obtained similar results.

## CONCLUSIONS

In this paper, examples of blood with two different loss rates are presented, overall considering the effects of seasonal fluctuations, the profit models of supply chain in the circumstances of distributed and centralized decision making are established, also some significant conclusions are obtained as follows: (1) Both in the circumstances of distributed and centralized decision making, the optimal order amounts and its relative maximum profit can be obtained; (2) In the circumstances of distributed and centralized decision making, supply chain can reach coordination point through a formula; (3) It is clearly shown by numerical simulation that the coordination between distributed and centralized decision making can be reached through the changing of order cost or substitution proportion.

In this study, interchangeable blood with different loss rates being concerned, the probability of goods arrival being introduced to de describe seasonal fluctuation, and in numerical simulation the market demand of blood being taken as uniform distribution, which are simplified treatments of practical problems. In future research, the complexity of model variables might be increased, and the numerical simulation and analyzes for the models might be further developed, etc. so as to achieve more meaningful research conclusions.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