Research on Secondary Cold Chain Inventory Strategy of Fresh Meat Products

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Abstract: The inventory of cold chain logistics has always been a bottleneck restricting the development of cold chain enterprises. Temperature has a significant impact on cold chain logistics. Taking the secondary cold chain inventory composed of one supplier and one retailer as the research object, the inventory holding cost model of Weibull function with temperature-dominated metamorphism with three-parameter distribution was constructed. The optimal inventory strategy was determined from the perspective of minimum system cost. Through the case analysis, the correctness of the inventory strategy was verified, and the decision-making reference for the inventory decision makers in this mode was provided.

1. Introduction

With the improvement of people's living standards and the improvement of consumption structure, more and more cold chain products have entered the public's field of vision. Consumers are not only demanding more volume, but also increasingly demanding quality. The freshness of cold products has become one of the core competitive factors of similar products. Due to the short shelf life and perishable quality of cold chain products, certain deterioration or loss will occur even if stored in a suitable temperature environment. Temperature can not only affect the product's deterioration rate, but also affect the company's inventory costs. Therefore, the study of the rate of deterioration of temperature effects is very important.

For the cold chain inventory research, the deterioration rate is one of the important factors that must be considered. Wagner and Whitin [1] first introduced metamorphic rate into inventory strategy research in 1958. In 1963, Ghare and Schrder [2] studied the order quantity of perishable goods and derived the inventory model of perishables, which laid the foundation for later research. However, most of the cold chain inventory models are dominated by constant metamorphism. Dave U et al. [3] constructed a single-level inventory model with a constant metamorphism rate under time-varying demand, and proposed an inventory management strategy for (T, Sₜ). Huang Y.S. et al. [4] constructed a two-level inventory model with a constant metamorphism constant, a supplier and a retailer, and gave a price discount coordination mechanism based on lead time. In 2006, Yang [5] constructed two warehouse perishables models with constant metamorphism rate. The model considered inflation and partial delays, and proved the correctness and uniqueness of the optimal solution. An Qia and Luo Jianwen [6] constructed a two-stage cold chain inventory system with distributors as the lead, price discount as the coordination mechanism, and a deterioration rate and demand rate are constant. Zhao Zhong [7] constructed a two-stage cold chain inventory with a metamorphism constant, a distributor and a retailer, and obtained the best order cycle and batch based on credit payment. Hao Xiuju, Qi Jinjin [8]...
studied the coordination mechanism of integrated inventory cold chain investment apportionment mechanism, quantity elasticity mechanism, revenue sharing and repurchase mechanism. Huo Jiazhen et al. [9] studied the joint pricing and production strategy of perishable products with partially delayed ordering under the condition of constant productivity and metamorphism rate.

However, the fixed deterioration rate does not reflect well the deterioration of cold products. Chang et al. [10], Yang et al. [11] proposed a perishable inventory model with exponential metamorphic rate. Skouria et al. [12], Fariborz et al. [13], and Wee [14] studied the perishable inventory model with metamorphic rate obeying the two-parameter Weibull distribution. Chakrabarty T. et al. [15] constructed a single-level inventory model with a three-parameter distribution of metamorphic rate, and obtained the best EOQ in the case of out-of-stock. On the basis of his 2006 work, Yang [16] established a perishable product inventory model with a metamorphic rate obeying the three-parameter Weibull distribution and two warehouses, which made the original model more perfect. Wang Daoping [17] also studied the problem of perishable product inventory strategy with metamorphic rate obeying the three-parameter Weibull distribution, but its model is limited to single-level retailer inventory. Wang Shuyun et al. [18] constructed an integrated three-stage cold chain inventory model with metamorphic rate obeying the three-parameter Weibull distribution, and obtained the best replenishment strategy for each member of the supply chain in a limited period.

By considering the influence of temperature and deterioration trend on the deterioration rate, this paper analyzes the change of inventory cost, constructs a secondary cold chain inventory model consisting of one supplier and one retailer, and analyzes its inventory strategy.

2. Problem Description

Weibull distribution is commonly used for reliability analysis and life testing, and is widely used in the research of mechanical and electronic engineering products. In 1975, Gacula first introduced the concept of engineering failure into the food field to describe the deterioration of food and was fully verified.

Compared with the two-parameter Weibull distribution, the three-parameter Weibull function can describe the metamorphic rate relatively comprehensively from different angles. The mathematical expressions of the density function and the distribution function can be written as:

\[ f(t) = \alpha(c)\beta(t-\gamma)^{\beta-1}e^{-\alpha(c)(t-\gamma)^{\beta}} \]
\[ F(t) = 1-e^{-\alpha(c)(t-\gamma)^{\beta}} \]

where the deterioration of the product as a function of temperature is the same within a certain range. Therefore, it is a piecewise function of temperature with a constant value of the function. For different products, the function values are different and the range of the variables is different. Its function [21] for the deterioration rate is:

\[ \theta(t) = \frac{f(t)}{1-F(t)} = \alpha(c)\beta(t-\gamma)^{\beta-1} \]

\[ \theta(t) \] is the deterioration trend of the product at time \( t \). \( \alpha(c) \), \( \beta \), and \( \gamma \) are the temperature factor, shape factor and trend factor of the Weibull function, respectively.

When \( \alpha(c)=0 \), \( \theta(t)=0 \), the product does not deteriorate; when \( \alpha(c)>0 \), the product deteriorates. In Figure 1 [21], the \( \beta \) value is greater than 0. Different values of \( t \) makes the \( \theta(t) \) curve shows different rising or falling trend. When \( \beta=1 \), the deterioration rate is constant. The state factor \( \gamma \) describes the state of the product when it is put into storage. When \( \gamma=0 \), the time when the goods are put into storage begins to deteriorate. At time \( \gamma>0 \), there is still a certain shelf life after the goods are put into storage, and at the time \( \gamma<0 \), it indicates that the trend of deterioration after storage is obvious or deteriorates drastically.
3. Model assumptions and parameters

According to Goyal and Giri [19], the literature on perishable inventory research found that there are two ways to define the rate of deterioration. One is the proportion of the amount of commodity deterioration to its total inventory, and the other is the degree of deterioration of the unit commodity relative to its intact condition. Among them, most of the studies use the first definition. That is to say, the commodity with a small proportion of deterioration rate is completely corrupted or invalid, and other commodities are still in a relatively intact state. To simplify the computational complexity, this model uses the first definition.

The research content of this model is based on the following basic assumptions: (1) the final customer's demand is randomly distributed; (2) the system is not allowed to be out of stock; (3) the target product is a single fresh product, and the product's deterioration rate obeys the function; (4) the loading and unloading activities of the products during the handling process are not considered for loss; (5) in the transportation activities of the system, the same type of refrigerated vehicles are used, and there is only a difference in the rated cargo load between the vehicles; (6) the products are in the transportation process. In the case of deterioration, the deterioration is in accordance with the deterioration of the supplier; (7) when the product is stored at the supplier, the parameters of the deterioration rate are written as $\alpha(c) > 0 \ 1 < \beta \leq 2 \ \gamma_1 > 0$; (8) when the product is stored at the retailer, the parameters of the deterioration rate are written as $\alpha(c) > 0 \ 1 < \beta \leq 2 \ \gamma_2 < 0$; (9) the inventory management mode is the inventory mode under the management of the supplier, regardless of the retailer's ordering cost and the supplier's production cost; (10) when the commodity is distributed to the supply chain node, the deteriorated commodity is destroyed, so that it is no longer in circulation.

It is assumed that retailers and suppliers adopt a fixed-cycle ordering inventory strategy with no fixed ordering costs. The $h$ and $p$ are the storage cost and loss cost of the retailer unit product respectively; $H$ and $P$ are the storage cost and the loss cost of the supplier unit product, respectively, and are constant. Assume that the retailer's order period is $TR$, the supplier's order period is $TS$, and the retailer and supplier's lead time are $LR$ and $LS$, respectively, each of which has a lead time that is less than the respective order period; Unit vehicle is described as $vc_j$, $vm_j$ is unit vehicle transportation cost.

4. Order model

Consider a two-tier supply chain model consisting of one supplier and one retailer [20], which sets the external customer demand $D_t$ faced by the retailer at the time $t$, satisfying the process (1), i.e.,

$$D_t = d + \rho D_{t-1} + \varepsilon_t \quad (1)$$

Where $d$ is a constant, and $d > 0$, $\rho$ is an autocorrelation parameter, where $-1 < \rho < 1$. $\varepsilon_t$ is a random error term, which obeys a normal distribution with a mean of 0 and a variance of $\sigma^2$. The

![Figure 1. Curve of metabolite function of three-parameter Weibull distribution](image)

Figure 1. Curve of metabolite function of three-parameter Weibull distribution
mean and variance of $D_t$ are $\frac{d}{1-\rho}$ and $\sigma^2 / (1 - \rho^2)$ respectively. Product at the supplier, the rate of deterioration is $\theta_s$, and at the retailer, the rate of deterioration is $\theta_r$. At time $t$, the retailer forecasts the total demand for the next order cycle. According to the demand of the previous cycle, the customer demand of this period is determined, so as to determine the corresponding order quantity $Z_t$. The corresponding goods will arrive at the end of the $t + L_R$ period and will be used to meet the market demand for the $L_R + T$ period. As shown in Fig. 2.

As can be seen from Fig. 2, at the initial moment, the retailer still has the remaining inventory, which satisfies the demand for waiting for the lead time. At the time of $L_R$, the goods arrive and meet the demand for the next order period $T$. As can be seen from the graph, the order cycle of the model is fixed, but the order quantity is not necessarily the same. This figure also applies to the description of the supplier's order status. For the convenience of calculation, the starting point of calculation of this model is the replenishment time point of the retailer.

4.1. Retailer's ordering strategy

Considering the problem of metamorphic rate, the following equation is satisfied throughout the model:

Retailer order quantity = statistics of customer demand / (1 - deterioration rate)

Retailer order quantity = actual shipment quantity × (1 - deterioration rate)

The retailer predicts the total demand from the $t$ to the $t + T_R$ periods during the $t$ period, and determines the order quantity at the end of the TR period [20]. Reusing the iterative relationship in equation (1), the total demand that can be predicted as:

$$
\sum_{i=0}^{T_R} D_{t+i} = \frac{1}{1-\rho} \left[ d \sum_{i=0}^{T_R} (1-\rho) + \rho (1-\rho^{T_R}) D_t \right] + \sum_{i=0}^{T_R} \sum_{k=0}^{T_R} \rho^{k-1} v_{t+i-k+1}.
$$

(2)

The retailer estimates the mean and variance of $D_{t+i}$ in equation (2), as following shows, respectively.

$$
M_i = \frac{d}{1-\rho} (T_R - \sum_{i=0}^{T_R} \rho^i) + \rho (1-\rho^{T_R}) D_t
$$

$$
v_i = \frac{\sum_{i=0}^{T_R} (1-\rho)^i}{1-\rho^2} \sigma^2.
$$

During the time that $LR$ of the retailer waiting for the replenishment of the goods, the deterioration rate of the goods is taken as the average value, which can be written as

$$
E(\theta_R) = \int_0^L \theta_R(t) dt
$$

Then, according to this inventory strategy, the retailer’s next cycle order quantity is

$$
Z_t = M_i / (1 - E(\theta_R))
$$

Actual quantities of shipments are $Q = Z_t / (1 - E(\theta_S))$, during transportation, the loss quantities of supplier are $Q^S = Q \times E(\theta_S)$, and the loss of the retailer in one cycle is $Q^S = Z_t E(\theta_R)$. 

![Figure 2. Inventory changes of retailers in each cycle T](image-url)
4.2. Supplier’s ordering strategy

For the supplier, the retailer’s order is the external demand. When \( T_S \geq T_R \), the supplier predicts the period from \( t \) to \( t+TS \) in the \( t \) period, and the order quantity of the retailer is as shown in equation (4):

\[
Q^R_t = \sum_{i=0}^{t} Q_i
\]

(4)

\[ x = a\left[\frac{T_S}{T_R}\right] \]

In equation (4), \( x \) is a rounded up function. The supplier calculates the corresponding order quantity based on the information situation at the end of the \( t \) period. As shown in the equation (5).

\[
Z^S_t = \frac{Q^S}{1-E(\theta_s)}
\]

(5)

\[ E(\theta_s) = \int_0^{\theta_s} \theta \phi(t) dt \]

In this equation, \( \phi(t) \).

At the time of \( T_S < T_R \), the supplier predicts the period from \( t \) to \( t+TS \) period in the \( t \) period, and the order quantity of the supplier is as shown in equation (6).

\[
Z^S_t = \frac{Q}{1 - E(\theta_s)}
\]

(6)

And the amount of loss of the supplier during this period is \( Z^S_t E(\theta_s) \).

4.3. Cost Estimation

Due to the special nature of cold chain logistics, temperature requirements and costs are inextricably linked. In this model, the inventory holding cost per unit of product is a decreasing function that decreases with increasing temperature. Storage cost of supplier unit products can be written as

\[ H(c) = A(1 - e^{Bc}) \]

where the \( A \), \( B \), and \( \omega \) are constant, and the \( \omega \) is the number of segments of function of \( \alpha(c) \). The storage cost of the retailer’s unit product can be expressed as \( h(c) = 2H(c) \).

For retailers, the cost includes the following aspects.

The holding cost: \( C^{R_t} = hZ^R_t / 2 \).

The losing cost: \( C^{S_t} = pQ^R_t \).

The total cost: \( TC^{R_t} = C^{R_t} + C^{S_t} \).

For supplier, the cost includes the following aspects.

The holding cost: \( C^{S_t} = HZ^S_t / 2 \).

The losing cost: \( C^{S_t} = (Z^S_t E(\theta_s) + Q^S_t)P \).

The translation cost: \( VC = a[Z^S_t] \).

The total cost: \( TC^{S_t} = C^{S_t} + C^{S_t} + VC \).

The model determines the optimal inventory strategy from the perspective of minimizing system cost. Therefore, the objective function of the model is

\[ \text{Min } TC = TC^{R_t} + TC^{S_t} \quad (\delta \leq c \leq \delta, \text{ the c is constant}) \]

The piecewise function can be shown as follow:
5. Case analysis

Y Company is a well-known cold chain logistics company in China. It mainly deals with cold meat products. It analyzes the data of a certain period as an example to explain the impact of temperature requirements on costs to select the optimal inventory strategy. The external demand parameters are: $d = 100$, $\rho = 0.6$, $\sigma = 30$. The value of the range of temperature $c$ is $-18^\circ C$ $-$ $10^\circ C$. The two functions about $c$ are shown as follows.

$$
\alpha(c) = \begin{cases} 
\alpha_1 & [\delta_1, \delta_2] \\
\alpha_2 & [\delta_3, \delta_4] \\
\alpha_3 & [\delta_5, \delta_6] 
\end{cases}
$$

$$
H(c) = 6(1 - e^{-\frac{c}{5}})
$$

For the convenience of calculation, each 10 kg of product is recorded as one unit. Other numerical specific parameters are shown in Table 1, Table 2, and Table 3.

| Table 1. Vehicle model and price list |
|--------------------------------------|
| $j$ | $vm_j$ | $vc_j$ |
| 1  | 150/unit | 100    |
| 2  | 200/unit  | 130    |
| 3  | 300/unit  | 150    |

| Table 2. Supplier's parameter table |
|-------------------------------------|
| parameters | $\beta$ | $\gamma_1$ | $T_S$ | $L_S$ | $P$ |
| value      | 1.4     | 0.5         | 4     | 2     | 6   |

| Table 3. Retailer's parameter table |
|-------------------------------------|
| parameters | $\beta$ | $\gamma_2$ | $T_R$ | $L_R$ | $p$ | $D_r$ |
| value      | 1.4     | -0.6        | 5     | 3     | 10  | 0     |

According to the constructed model, EXCEL is used to find its cost, and the total cost is the minimum temperature and model, which is the best inventory decision-making scheme. The calculation results are shown in Table 4 - Table 8.

| Table 4. Supplier’s Parameter Calculation Table |
|-----------------------------------------------|
| $c$ | $\alpha(c)$ | $\beta$ | $\gamma_1$ | $T_S$ | $L_S$ | $H$ | $P$ |
| -18 | 0.010 | 1.4 | 5.8         |
| -17 | 0.015 | 1.4 | 5.7         |
| -16 | 0.020 | 1.4 | 5.6         |
| -15 | 0.020 | 1.4 | 5.4         |
| -14 | 0.015 | 1.4 | 5.4         |
| -13 | 0.015 | 1.4 | 5.2         |
| -12 | 0.010 | 1.4 | 4.9         |
| -11 | 0.010 | 1.4 | 4.4         |
| -10 | 0.020 | 1.4 | 3.8         |

6
Table 5. Supplier’s Cost Results Table

| \(\alpha(c)\) | \(Q_i^s\) | \(Z_i^s\) | \(Z_i^s E(\theta_s)\) | \(vm_1\) | \(vm_2\) | \(vm_3\) | \(C_s^s\) | \(C^s\) | min\((VC)\) | \(TC^s\) | \(j\) |
|----------|-----------|------------|-------------------|--------|--------|--------|--------|--------|-----------|--------|------|
| 0.010    | 79        | 1702       | 201               | 150    | 200    | 300    | 1678   | 4937   | 7515      | 900    | 7430 | 3   |
|          |           |            |                   |        |        |        |        | 4766   | 7345      | 112269 |      |
| 0.015    | 171       | 2630       | 465               | 150    | 200    | 300    | 3817   | 6839   | 1350      | 12006  | 3    |
|          |           |            |                   |        |        |        |        | 6444   | 11611     | 22529  |      |
| 0.020    | 392       | 4876       | 1150              | 150    | 200    | 300    | 9252   | 9264   | 2550      | 21066  | 3    |
|          |           |            |                   |        |        |        |        | 7070   | 18872     |         |      |

Table 6. Retailer Parameter Calculation Table

| \(c\) | \(\alpha(c)\) | \(\beta\) | \(\gamma_2\) | \(T_R\) | \(L_R\) | \(h\) | \(p\) |
|------|--------------|-----------|-------------|--------|--------|------|------|
| -18  | -18          | 1.4       | 11.6        |        |        |      |      |
| -17  | 0.010        | 1.4       | 11.4        |        |        |      |      |
| -16  | -16          | 1.4       | 11.2        |        |        |      |      |
| -15  | -15          | 1.4       | 10.8        |        |        |      |      |
| -14  | 0.015        | 1.4       | -0.6        | 5      | 3      | 10.4 | 10   |
| -13  | -13          | 1.4       | 9.8         |        |        |      |      |
| -12  | -12          | 1.4       | 8.8         |        |        |      |      |
| -11  | 0.020        | 1.4       | 7.6         |        |        |      |      |
| -10  | -10          | 1.4       | 5.8         |        |        |      |      |

Table 7. Retailer Cost Results Table

| \(\alpha(c)\) | \(Z_t\) | \(Q_t^R\) | \(Q\) | \(C_t^R\) | \(C_s^R\) | \(TC_t^R\) |
|----------|--------|-----------|------|--------|--------|----------|
| 0.010    | 1423   | 518       | 1501 | 8108   | 5184   | 13292    |
|          |        |           |      | 7966   |        | 21156    |
|          |        |           |      | 10768  |        | 21668    |
| 0.015    | 1994   | 1090      | 2165 | 10369  | 10900  | 21269    |
|          |        |           |      | 9771   |        | 20671    |
|          |        |           |      | 14668  |        | 38964    |
| 0.020    | 3334   | 2430      | 3726 | 12668  | 24296  | 36964    |
|          |        |           |      | 9668   |        | 33963    |

Table 8. Total Cost Table

| \(c\) | -18 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \(T_c\) | 20949 | 20722 | 20494 | 33936 | 33275 | 32282 | 61493 | 58030 | 52836 |

The data in Table 8 is obtained from Table 5 and Table 7. The optimal solution is: when the temperature is controlled at -16 °C, the vehicle model is a refrigerated truck with a load of 300.

6. Conclusion

Through the study of the secondary cold chain inventory model and the case analysis of the Weibull distribution with the three parameters of the metamorphic rate, the following conclusions can be drawn:

1) With the goal of minimizing costs and considering the influence of temperature, an
An integrated secondary cold chain inventory model consisting of one supplier and one retailer is constructed.

2) The model's metamorphic rate obeys the three-parameter Weibull distribution of temperature, shape and state, which can reflect the actual situation of cold chain logistics.

3) The total cost of the system is minimized by performing an example application analysis of the constructed model at a temperature of -16 °C and a vehicle model of a refrigerated truck with a load of 300.

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