Research on Quality Control Modeling of Tobacco Production Supply Chain Based on House of Quality

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Abstract. Based on the tobacco management information system, this project establishes a double-loop quality feedback control model for a single logistics link and the whole chain in the tobacco processing and production supply chain. The quality control standard is introduced into the house of Quality, and the hierarchical house of quality control model of supply chain for tobacco.

1. Introduction

With the development of economic globalization, the competition among existing enterprises has shifted from the competition among individuals to the competition among supply chains. Therefore, many researchers have studied the quality control of supply chain.

Jinyou Hu et al.[1] through the analysis of the quality decision-making of each participant in the agri-food supply chain based on the Game Theory, a multi-strategy combination model composed of profit sharing, quality commitment and risk sharing is proposed, so as to coordinate the quality control in the agricultural food supply chain. Fernando Lejarza et al.[2] establish a dynamic quality control model for closed-loop supply chain (CLSC) under the condition of product demand fluctuation and product quality change with time, taking into account the product quality dynamics and environmental conditions. Shanshan Wang[3] proposed an ontology-based approach and combined it with principal-agent contract to effectively reduce the Information asymmetry and moral hazard in supply chain quality control. Qiang Shen[4] puts forward a quality control supply chain model based on internet + considering reputation loss caused by inferior products and external responsibility identification. Liu Di[5] analysed the delivery process of dairy logistics service quality in the supply chain, and established a logistics service quality deviation delivery model based on quality control priority factors, so as to determine the key elements and quality deviation sources in the logistics deviation network and reduce the diffusion of logistics service quality problems.

To sum up, researches on supply chain quality control have been abundant. On the basis of the predecessors, this paper takes the tobacco processing and production supply chain as the research background, and further studies the quality control of the supply chain.

2. Transfer Logic of Quality Deviation in Tobacco Production Supply Chain

The product quality transfer logic in the tobacco processing and production supply chain network structure is shown in Figure 6-7.
Figure 1. The quality transfer logic diagram for Enterprise $i$.

The input quality characteristic value $X_p(i-1)$ in the upstream of enterprise $i$, through the quality control function $\omega(i)$ of enterprise $i$, gets the product quality characteristic $X(i)$ of the enterprise.

$$X(i) = f(X_1(i-1), X_2(i-1), ..., X_5(i-1), \omega(i))$$  \hspace{1cm} (1)

The total deviation $\Delta X(i)$ of product quality characteristic output by the enterprise $i$ is related to the deviation $\Delta X_p(i-1)$ of product quality characteristic of the upstream enterprise, the deviation quality coefficient $\alpha_{i,p}$ of the upstream enterprise, and the deviation $\epsilon_{\omega(i)}$ in the manufacturing process of the enterprise $i$.

3. Tobacco Logistics Quality Deviation Control Technology Based on House of Quality

3.1. Double-loop Closed-loop Feedback Control Model for Tobacco Production Supply Chain Quality

From suppliers of raw and auxiliary materials, raw and auxiliary materials logistics service providers, manufacturers, finished product logistics service providers, to tobacco commercial companies, there is a positive accumulation and amplification phenomenon of supply chain quality deviation, called positive bullwhip effect of supply chain quality. The quality deviation transmission and amplification should be controlled through the quality feedback between the main body of the supply chain and the whole chain.

Figure 2. Quality double-loop closed-loop feedback control model for supply chain enterprises.
Among them, $F_i(X), (i = 1, 2, 3)$ represents the enterprise $i$ self-feedback quality control function in the supply chain; $G_i(X), (i = 1, 2, 3)$ represents the collaborative feedback quality control function of the subject $i$ of the supply chain.

Each enterprise in the supply chain controls the product quality through the self-feedback control function $F_i(X), (i = 1, 2, 3)$, and transmits the quality information of each link to the quality control module of the management information system; The quality control module analyzes the quality information of each link and carries out feedback control through the collaborative feedback quality control function $G_i(X), (i = 1, 2, 3)$.

### 3.2. Modeling of Hierarchical Quality House Control of Supply Chain Based on Simultaneous Equations

The hierarchical quality house control model for tobacco production supply chain is shown in Figure 3. The arrow represents the relationship between the extended quality house of each link in the supply chain. The quality demand of the tobacco processing and production supply chain is the output, and the engineering characteristics of each business link in the supply chain are regarded as the input. The hierarchical quality house control model of the supply chain is a multi-input and multi-output system.

**Figure 3.** Hierarchical quality house control logic model of tobacco processing and production supply chain.

Among them, the business link $i$ of the quality house control model of tobacco processing and production supply chain is shown in Figure 4.

**Figure 4.** Quality house control model of single link $i$ of tobacco production supply chain.
D, W, B, X, H, E and Q respectively represent quality requirements, quality assessment, auto-correlation matrix of quality requirements, business engineering characteristics, business engineering characteristics weight, auto-correlation matrix of business engineering characteristics and transformation matrix of quality/business.

\[ D_i = \{ D'_i, D''_i, \ldots, D'_m \} \]

represents the quality demand index. The greater the quantity value is, the greater the user demand index value will be. There are three columns on the right wall of quality assessment. The first column is real-time quality \( M = [m_1, m_2, \ldots, m_m]^T \), the second column is quality control standard \( O = [o_1, o_2, \ldots, o_m]^T \), and the third column is improvement weight \( V = [v_1, v_2, \ldots, v_m]^T \). \( X_i = \{ X'_1, X'_2, \ldots, X'_m \} \) represents business engineering characteristics. The greater the quantity value is, the higher the technical characteristic index value will be; \( H_i = \{ h'_1, h'_2, \ldots, h'_m \} \) represents the weight of the business engineering characteristic index. The larger the quantity value is, the greater the influence of the business engineering characteristic on the quality requirement is.

\[
B' = \begin{bmatrix}
1 & \beta'_{12} & \beta'_{13} & \ldots & \beta'_{1m} \\
\beta'_{21} & 1 & \beta'_{23} & \ldots & \beta'_{2m} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\beta'_{m1} & \beta'_{m2} & \beta'_{m3} & \ldots & 1
\end{bmatrix}
\]

is the correlation matrix of various quality demands, namely the roof part of the quality house, \( \beta'_{ij} \) is the correlation degree between the quality demand \( j \) and the quality demand \( k \), \( \beta'_{jk} \) is the correlation degree between the quality demand \( k \) and the quality demand \( j \), so \( \beta'_{jk} = \beta'_{kj} \); \( Q = \begin{bmatrix}
\gamma'_{11} & \gamma'_{12} & \ldots & \gamma'_{1m} \\
\gamma'_{21} & \gamma'_{22} & \ldots & \gamma'_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\gamma'_{m1} & \gamma'_{m2} & \ldots & \gamma'_{mm}
\end{bmatrix} \)

is the correlation matrix between quality demand and business engineering characteristics, that is, the room part of the quality house, \( \gamma'_{jk} \) is the transformation relationship between quality demand and business engineering characteristics, and \( \gamma'_{jk} \) represents the change in business engineering characteristics caused by the change of quality demand index by 1 grade.

Using simultaneous equations to model the hierarchical house of mass of supply chain:

1. Standardization of business engineering characteristics and quality requirements.

The dimensionless treatment is carried out for the satisfaction level of engineering characteristics of business links and quality requirements. The normalized engineering characteristics of business links \( X_j, (j = 1, 2, \ldots, n) \); The satisfaction level of normalized quality requirements is \( Y_i, (i = 1, 2, \ldots, m) \).

The engineering characteristics have the Larger the Better, Smaller the Better and Nominal the Best, which are standardized according to formula (2), formula (3) and formula (4) respectively.

\[
X_j = \frac{I_j - I_{j_{\min}}}{I_{j_{\max}} - I_{j_{\min}}} \quad (2)
\]

\[
X_j = \frac{I_{j_{\max}} - I_j}{I_{j_{\max}} - I_{j_{\min}}} \quad (3)
\]

\[
X_j = 1 - \frac{I_{o} - I_j}{I_{o}} \quad (4)
\]

Quality requirements have the Larger the Better, standardized according to Formula (5).
The least square estimation of the simplified formula is obtained

\[ Y_i = \frac{k_i - k_{i_{\text{min}}}}{k_{i_{\text{max}}} - k_{i_{\text{min}}}} \]  

(5)

(2) Model establishment.

According to the relationship between quality requirements and other quality requirements and business engineering characteristics, the following model is established:

\[
\begin{align*}
Y_1 &= \beta_{12}Y_2 + \beta_{13}Y_3 + \cdots + \beta_{1m}Y_m + \gamma_{11}X_1 + \gamma_{12}X_2 + \cdots + \gamma_{1n}X_n + \mu_1 \\
Y_2 &= \beta_{21}Y_1 + \beta_{22}Y_2 + \cdots + \beta_{2m}Y_m + \gamma_{21}X_1 + \gamma_{22}X_2 + \cdots + \gamma_{2n}X_n + \mu_2 \\
&\vdots \\
Y_m &= \beta_{m1}Y_1 + \beta_{m2}Y_2 + \cdots + \beta_{mm}Y_m + \gamma_{m1}X_1 + \gamma_{m2}X_2 + \cdots + \gamma_{mn}X_n + \mu_m
\end{align*}
\]

Collated:

\[
\begin{align*}
Y_1 - \beta_{12}Y_2 - \beta_{13}Y_3 - \cdots - \beta_{1m}Y_m - \gamma_{11}X_1 - \gamma_{12}X_2 - \cdots - \gamma_{1n}X_n &= \mu_1 \\
- \beta_{21}Y_1 + Y_2 - \beta_{23}Y_3 - \cdots - \beta_{2m}Y_m - \gamma_{21}X_1 - \gamma_{22}X_2 - \cdots - \gamma_{2n}X_n &= \mu_2 \\
&\vdots \\
- \beta_{m1}Y_1 + Y_2 - \beta_{m3}Y_3 - \cdots + \beta_{mm}Y_m - \gamma_{m1}X_1 - \gamma_{m2}X_2 - \cdots - \gamma_{mn}X_n &= \mu_m
\end{align*}
\]

(6)

The matrix form is:

\[ BY + \Gamma X = U \]  

(8)

(3) Model parameter estimation.

The structural model is transformed into the simplified model, and the least squares estimation is carried out, and the formula (5) is sorted out to get:

\[ Y + B^{-1}\Gamma X = B^{-1}U \]  

(9)

\[ Y = B^{-1}\Gamma X + B^{-1}U \]  

(10)

\[ Y = \Pi X + V \]  

(11)

Among them:

\[ \Pi = B^{-1}\Gamma, V = B^{-1}U \]  

(12)

The least square estimation of the simplified formula is obtained:

\[ \hat{Y} = \hat{\Pi}X + V \]  

(13)

\[ Y_i = \hat{Y} + e_i, i = 1, 2, \ldots, m \]  

(14)

The right-hand side of the above equation replaces the endogenous explanatory variables in the structural equation to be estimated, and then:

\[
\begin{align*}
Y_1 - \beta_{12}\hat{Y}_2 - \beta_{13}\hat{Y}_3 - \cdots - \beta_{1m}\hat{Y}_m - \gamma_{11}X_1 - \gamma_{12}X_2 - \cdots - \gamma_{1n}X_n &= \hat{\mu}_1 \\
- \beta_{21}\hat{Y}_1 + Y_2 - \beta_{23}\hat{Y}_3 - \cdots - \beta_{2m}\hat{Y}_m - \gamma_{21}X_1 - \gamma_{22}X_2 - \cdots - \gamma_{2n}X_n &= \hat{\mu}_2 \\
&\vdots \\
- \beta_{m1}\hat{Y}_1 + Y_2 - \beta_{m3}\hat{Y}_3 - \cdots + \beta_{mm}\hat{Y}_m - \gamma_{m1}X_1 - \gamma_{m2}X_2 - \cdots - \gamma_{mn}X_n &= \hat{\mu}_m
\end{align*}
\]

\[
\hat{\mu}_i = \beta_{i2}e_2 + \beta_{i3}e_3 + \cdots + \beta_{im}e_m + \mu_i, i = 2, \ldots, m
\]

(15)

(16)

(17)
(4) Model test method.

In this project, the integral test is used to test the fitting degree of the equation:

Step 1: Assign the sample value \( X_{i_t}, X_{2_t}, \ldots, X_{n_t} \) of the pre-fixed variable of phase \( t \) to the corresponding component \( X_1, X_2, \ldots, X_n \) in \( X \);

Step 2: After assignment is denoted as \( X_i \), then the estimated value vector \( \hat{Y}_i = \hat{f}(X_i) \) of the endogenous variable is obtained, and its components are \( \hat{Y}_{i_1}, \hat{Y}_{i_2}, \ldots, \hat{Y}_{i_m} \) in turn;

Step 3: Get the fitting error \( \epsilon_{i_t} = Y_{i_t} - \hat{Y}_{i_t} \) of endogenous variable \( i \) in phase \( t \), where \( T \) is sample size;

Step 4: Do this test for the samples in each period, and the overall fitting error of all endogenous variables in each period is obtained as \( \epsilon_{it} = \sum_{j=1}^{T} \epsilon_{ij} / Y_{it} \).

Statistics used to evaluate the degree of fitting include: root mean square of simulated error \( \hat{\sigma} \), mean value of simulated error \( \bar{\epsilon} \), ratio of simulated error mean value \( \hat{\zeta} \), Theil inequality coefficient \( U \), as shown in formula (18), formula (19), formula (20), formula (21):

\[
\hat{\sigma} = \sqrt{\frac{1}{T} \sum_{i=1}^{T} (\epsilon_{it} / Y_{it})^2} / T \tag{18}
\]

\[
\bar{\epsilon} = \frac{1}{T} \sum_{i=1}^{T} \epsilon_{it} \tag{19}
\]

\[
\hat{\zeta} = \frac{1}{T} \sum_{i=1}^{T} \epsilon_{it} / Y_{it} \tag{20}
\]

\[
U = \sqrt{\frac{1}{T} \sum_{i=1}^{T} \epsilon_{it}^2} \left( \sqrt{\frac{1}{T} \sum_{i=1}^{T} Y_{it}^2} + \frac{1}{T} \sum_{i=1}^{T} \hat{Y}_{it}^2 \right) \tag{21}
\]

(5) Measure the improvement priority of improvement business engineering in each link of the supply chain.

In the supply chain hierarchical quality house, each business link on the supply chain will transfer quality data \( C_i \) to the quality control subsystem of the management information system. According to the operation of the whole supply chain, the quality control subsystem puts forward the quality requirements \( D_i \) and control standards \( E_i \) for the links \( i \), so as to carry out the collaborative control of the whole supply chain. The improved weight \( V_t = [v_{t1}, v_{t2}, \ldots, v_{tm}]^T \) of the right wall of quality assessment of each quality house is synthesized according to real-time quality \( M = [m_{t1}, m_{t2}, \ldots, m_{tm}]^T \), quality control standard \( O = [o_{t1}, o_{t2}, \ldots, o_{tm}]^T \) and control rules of quality control subsystem. The improvement priority for the business engineering characteristics is \( X_i = V_t \ast B \), and the improvement priority for the business engineering \( i \) is \( x_i = \sum_{j=1}^{n} v_j b_{ji} \).

Taking the quality control house of tobacco industrial and commercial distribution link as an example, it is illustrated that the priority factors of quality improvement are found through simultaneous equations in the house of Quality.
Table 1. Quality control room for tobacco industrial and commercial distribution.

| Distribution of freight | System assigned vehicle | The finished smoke leaves the warehouse | Specify platform storage | Delivery vehicle arrival | Loading | Print out bills | Nuclear single | Lock and start | Real time quality | Standard quality | Quality improvement weight |
|-------------------------|-------------------------|----------------------------------------|--------------------------|--------------------------|---------|----------------|---------------|---------------|------------------|-----------------|-----------------------------|
| Order receiving capacity |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Storage demand fulfillment rate |                 |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Order execution rate |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Vehicle response speed |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Emergency response speed |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Probability of delivery vehicles arriving on time |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| RFID bar code scanning accuracy probability |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Rate of undamaged goods |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Probability of accurate delivery of goods |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Probability of timely delivery |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Probability of safe delivery of goods |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Total logistics cost of a single carton of cigarette |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Transport cost of a single carton of cigarettes |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Total logistics costs of per customer |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Delivery time requirement satisfaction rate |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Number of vehicle distribution households per vehicle |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
| Priority value of service quality improvement |                         |                                        |                          |                          |         |                |               |               |                  |                 |                             |
4. Conclusion
By analyzing the transfer logic of quality deviation in the tobacco production supply chain, this paper finds that the total deviation of product quality characteristic output by the enterprise is related to the deviation of product quality characteristic of the upstream enterprise, the deviation quality coefficient of the upstream enterprise and the self-owned deviation in the manufacturing process of the enterprise. To control the quality deviation transfer amplifier, management information system based on tobacco, tobacco processing production oriented supply chain is established on a single logistics links and double circuit quality feedback control model of the whole chain, should be through the supply chain between the main body quality feedback and the quality of the whole chain feedback to control the quality deviation transfer amplifier. Then, the quality control standard is introduced into the house of Quality, and the hierarchical house of quality control model of supply chain for tobacco processing and production enterprises is established. The priority factors of quality control are found by studying the hierarchical house of quality expansion method based on simultaneous equations.

5. References
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