Ordering and transportation of raw materials for manufacturing enterprises

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Abstract. As the necessities of production and life, construction and plate have always played an important role in China's national economy. It is also an important industry affecting China's economic development. The unit price of raw materials and the cost of transportation and storage have always been the main expenses of enterprises. Therefore, it is particularly important to study how to reduce the ordering cost and transshipment cost of raw materials. This paper makes a quantitative analysis on the supply characteristics of 402 suppliers. According to the supply quantity of suppliers, the orders with an order quantity of 0 are excluded, so as to extract the variance, range and real average value of each supplier's orders in five years. The difference between the enterprise's order quantity and the supplier's supply quantity is extracted, so that they represent four indicators: supplier reliability, sustainability and stability, And the supply intensity of the supplier. After the data is normalized through AHP, the weight of the index is assigned, the index is weighted in combination with TOPSIS, and finally the score is calculated. Then, the 0-1 programming model is established. The coefficient of the objective function is the maximum supply of each supplier every week. After analysis, it is concluded that the maximum supply is two-thirds of the average value plus one-third of the maximum value. The constraint conditions are established so that the sum of the supply of the selected suppliers is greater than the weekly capacity required by the enterprise. The 240 weeks are divided into five years. Considering the influence of practical factors, when predicting the supply of suppliers in the next 24 weeks, only the first half of each year is selected, and the grey prediction method is used to predict the average weekly supply of each supplier in the next 24 weeks. After the prediction, the grey prediction of the existing data is not ideal, and the BP neural network is used to re predict this kind of data. After the prediction, a multi-objective programming model is established to ensure the minimum sum of ordering cost and transshipment cost. Under this scheme, the minimum supply corresponding to a, B and C is calculated.

Keywords: AHP, TOPSIS, comprehensive evaluation, multi-objective programming, BP neural network, grey prediction.

1. Introduction

With the deepening of China's economic system reform and the accelerating pace of product upgrading, China's competitive advantage as a "world factory" is weakening. Now, due to the increase of raw materials, energy, land prices and labor costs, the business environment faced by Chinese manufacturing enterprises has changed greatly, and the market competition is very fierce. If enterprises want to survive, they must control the product cost more deeply [1]. In practice, the product cost to be considered includes the ordering cost and transshipment cost of raw materials. Due to the particularity of raw materials and in order to ensure the normal production of the enterprise, the enterprise needs to order raw materials in advance. In order to ensure the inventory of raw materials, it is necessary to purchase all the raw materials provided by the supplier, and determine the transshipper to store the raw materials in the enterprise warehouse. In order to ensure the production efficiency of the enterprise, it is necessary to formulate the ordering and transshipment plan in advance.

2. Determination of index weight by analytic hierarchy process

In the late 1970s, T.L. Saaty, an American operations research scientist and professor at the University of Pittsburgh, proposed the analytic hierarchy process (AHP). It divides people's thinking process into target level, criterion level and scheme level, and analyzes it with the help of
mathematical model. It is a practical decision analysis method that effectively combines qualitative judgment and quantitative calculation of decision makers [2].

Through the analysis and calculation of the data, if the value is 0, there is no order, so the order should be eliminated. SPSS software is used to calculate the difference between the order parameter and the supply quantity, the average value and variance of the supply quantity of each supplier in recent five years, and the range of the supply quantity to represent the four indicators of the supplier: reliability, supply intensity, sustainability and stability. The more the difference is, the more reliable the supplier is. The more obvious the variance is, the stronger the sustainability is, the more obvious the range is, the more stable the supplier is, and the greater the average value indicates the greater the supply intensity of the supplier.

Construct the judgment matrix M-C, in which the target layer is m, and the indicators are reliability C1, sustainability C2, stability C3 and supply intensity C4 respectively.

<table>
<thead>
<tr>
<th>M</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>1/2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>C2</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>C3</td>
<td>1/3</td>
<td>1/6</td>
<td>1</td>
<td>2/3</td>
</tr>
<tr>
<td>C4</td>
<td>1/2</td>
<td>1/4</td>
<td>3/2</td>
<td>1</td>
</tr>
</tbody>
</table>

Check the consistency of the judgment matrix. According to the formula

\[
CR = \frac{CI}{RI}, \quad CR = 0 < 0.1
\]

is obtained from the consistency index 

\[
CI = \frac{\lambda_{max} - n}{n-1}
\]

The judgment matrix passes the consistency test.

After passing the test, considering the deviation of different calculation methods, the weights are calculated by arithmetic average method, geometric average method and eigenvalue method respectively, and then averaged to obtain the final weight, as shown in Table 1:

<table>
<thead>
<tr>
<th>index</th>
<th>Arithmetic mean</th>
<th>Geometric</th>
<th>Eigenvalue</th>
<th>Average weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>0.2609</td>
<td>0.2609</td>
<td>0.2609</td>
<td>0.2609</td>
</tr>
<tr>
<td>Sustainability</td>
<td>0.5217</td>
<td>0.5217</td>
<td>0.5217</td>
<td>0.5217</td>
</tr>
<tr>
<td>Stability</td>
<td>0.087</td>
<td>0.087</td>
<td>0.087</td>
<td>0.087</td>
</tr>
<tr>
<td>Supply intensity</td>
<td>0.1304</td>
<td>0.1304</td>
<td>0.1304</td>
<td>0.1304</td>
</tr>
</tbody>
</table>

### 2.1 Weighted TOPSIS evaluation model

TOPSIS is a multi criteria decision-making method. Its core idea is to calculate the relative distance ranking between the scheme to be evaluated and the combination of the optimal solution and the worst solution by fictitious the combination of the optimal solution and the worst solution of the decision matrix [3]. In this paper, four weighted indexes are obtained when processing the data. Compared with other evaluation methods, TOPSIS method is more suitable for this problem [4].

Take each index as the evaluation index to build the original index matrix:

\[
X = \begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}
\]

Reliability, sustainability and stability need to be positively treated in the index:

\[
M = \max - x
\]

And standardize the matrix to obtain the matrix:
\[
Z = \begin{bmatrix}
z_{11} & z_{12} & \cdots & z_{1n} \\
z_{21} & z_{22} & \cdots & z_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
z_{m1} & z_{m2} & \cdots & z_{mn}
\end{bmatrix}
\]

(3)

\[Z^+ = (Z^*_1, Z^*_2, \ldots, Z^*_m)\]

Maximum:

\[= \left( \max \{Z_{i1}, Z_{i2}, \ldots, Z_{in}\}, \max \{Z_{i2}, Z_{i2}, \ldots, Z_{in}\}, \ldots, \max \{Z_{im}, Z_{im}, \ldots, Z_{im}\} \right)\]  

(4)

\[Z^- = (Z^-_1, Z^-_2, \ldots, Z^-_m)\]

Minimum:

\[= \left( \min \{Z_{i1}, Z_{i2}, \ldots, Z_{in}\}, \min \{Z_{i2}, Z_{i2}, \ldots, Z_{in}\}, \ldots, \min \{Z_{im}, Z_{im}, \ldots, Z_{im}\} \right)\]  

(5)

The distance between the ith object and the maximum and minimum values is obtained by using the Euclidean distance calculation formula

\[D^+_i = \sqrt{\sum_{j=1}^{m} \omega_j \left( z^+_j - z^-_j \right)^2}, \quad D^-_i = \sqrt{\sum_{j=1}^{m} \omega_j \left( z^-_j - z^-_j \right)^2}\]

Then score 402 suppliers. These suppliers score \(T_i \in [0,1]\), and the greater the , the closer to the maximum.

### 2.2 Solution of model

Using MATLAB to solve the score, first forward the analyzed indicators, and then sort the results in descending order to get the most important 50 suppliers, as shown in Table 2:

<table>
<thead>
<tr>
<th>ranking</th>
<th>supplier</th>
<th>TOPSIS score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S201</td>
<td>0.0119</td>
</tr>
<tr>
<td>2</td>
<td>S229</td>
<td>0.0071</td>
</tr>
<tr>
<td>3</td>
<td>S361</td>
<td>0.0066</td>
</tr>
<tr>
<td>4</td>
<td>S140</td>
<td>0.0062</td>
</tr>
<tr>
<td>5</td>
<td>S395</td>
<td>0.0051</td>
</tr>
<tr>
<td>6</td>
<td>S108</td>
<td>0.005</td>
</tr>
<tr>
<td>7</td>
<td>S151</td>
<td>0.0041</td>
</tr>
<tr>
<td>8</td>
<td>S340</td>
<td>0.004</td>
</tr>
<tr>
<td>9</td>
<td>S282</td>
<td>0.004</td>
</tr>
<tr>
<td>10</td>
<td>S282</td>
<td>0.004</td>
</tr>
</tbody>
</table>

### 3. Supplier selection based on 0-1 programming model

#### 3.1 Data processing and feature extraction

According to the weekly production capacity of the enterprise and the three raw materials consumed per cubic meter are different, it is necessary to control the cost and achieve production benefits. On the basis of selecting the most important 50 suppliers, the maximum and average supply volume of the 50 suppliers are calculated by SPSS software, and the broken line diagram of the two groups of data is as follows[5]:

---

490
Figure 1 Comparison of maximum and average supply volume of the most important 50 suppliers

It can be seen from the above figure that the maximum supply quantity Max is much larger than the average avr\[6\]. The formula for the maximum supply quantity of suppliers is

$$M_i = \frac{1}{3} \text{Max} + \frac{2}{3} \text{avr}$$  \hspace{1cm} (6)

3.2 Election of suppliers

For the selection of suppliers, there are two cases: select or not, and solve it with 0-1 programming model. Set $x_i$ as the i supplier selected\[7\],

$$x_i = \begin{cases} 0, & \text{the } i\text{th supplier is not selected} \\ 1, & \text{the } i\text{th supplier is selected} \end{cases} \quad (i = 1, 2, \cdots, 50)$$  \hspace{1cm} (7)

According to the supplier's maximum weekly supply, $M_i$, where $C_i$ is the volume of three raw materials consumed per cubic meter of product, and $Y$ is the sum of suppliers.

The weekly order quantity should meet the weekly production capacity of the enterprise to obtain production benefits. The following models can be listed\[8\]:

$$\text{min } Y = \sum_{i=1}^{50} x_i$$

$$\text{s.t. } \sum_{i=1}^{50} \frac{x_i}{C_i} M_i \geq 2.82 \times 10^4$$

Using MATLAB to solve the function, it is obtained that at least two suppliers are s126 and s348\[9\].

3.3 Forecasting supply quantity based on Grey Model

This paper formulates the weekly ordering scheme for the next 24 weeks. Using the supply volume of the most important 50 suppliers selected above in recent 5 years, taking the first half of each year as a node, and taking the average value of the supply volume of 24 weeks, five samples can be obtained, and there is only one variable. Grey prediction can be used to predict the average value of the supply volume of the next 24 weeks\[10\]. The average value is the real sample in which the total supply volume in the first half of every 24 weeks is not 0 compared with the previous order. In order to ensure the robustness of the prediction results, this paper adopts the traditional grey model, new information grey model and new town metabolism grey model. After substituting the data, SSE is obtained through three models, and the smallest model is selected as the prediction model.
3.3.1 The principle of grey model GM (1,1) is:

Set \( x^{(0)}(k) = \left( x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n) \right) \) as the original data and accumulate the \( x^{(0)} \) to obtain the 1-AGO sequence:

\[
x^{(1)}(k) = \left( x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n) \right)
\]

Among them, \( x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), (k = 1, 2, 3, \ldots, n) \)

Generate a sequence of immediate mean values:

\[
z^{(1)}(k) = \left[ z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n-1) \right]
\]

Among them, \( z^{(1)}(k) = \sigma x^{(1)}(k) + (1 - \sigma) x^{(1)}(k+1), \text{ and } \sigma = 0.5 \)

Establish whitening differential equation

\[
\frac{dx^{(1)}(t)}{dt} + x^{(1)}(t) = b
\]

The original intention of grey modeling is to establish an approximate differential equation model for the sequence of numbers. However, because the differential equation is only suitable for continuous differentiable functions, and the time series data is discontinuous, let alone differentiable, the approximate differential equation obtained by grey prediction modeling is called grey differential equation

\[
x^{(0)}(k) + \alpha z^{(1)}(k) = b
\]

Where, \( b \) is the action amount and \( a \) is the development coefficient

Order \( \hat{u} = (a, b)^T, Y = \begin{bmatrix} x^{(0)}(1) \\ x^{(0)}(2) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, B = \begin{bmatrix} -z^{(1)}(2) \\ -z^{(1)}(3) \\ \vdots \\ -z^{(1)}(n) \end{bmatrix} \)

Then the grey model can be expressed as

\[
Y = Bu
\]

The estimation of parameters can be obtained by the least square method

\[
\hat{u} = \begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = (B^T B)^{-1} B^T Y
\]

Put the latest information \( x^{(0)}(n+1) \) into \( x^{(0)} \), then use the newly formed original sequence to establish the new information \( GM(1,1) \); Put in the latest information \( x^{(0)}(n+1) \), remove the oldest information \( x^{(0)} \) and establish metabolic \( GM(1,1) \).

If the initial value \( x \) is taken \( x(1) \) for \( t = 1 \) \( x(0) \), the corresponding solution can be obtained as

\[
\hat{x}^{(1)}(t) = \left[ x^{(0)} - \frac{b}{a} \right] e^{-a(t-1)} + \frac{b}{a}
\]

Further, the solution of GM (1,1) model is

\[
\hat{x}^{(1)}(t) = \left[ x^{(0)} - \frac{b}{a} \right] e^{-at} + \frac{b}{a}, m = 1, 2, \ldots, n-1
\]
3.3.2 Supplier model solving

In MATLAB, substitute the data, fit the image of data and prediction data, and select 50 suppliers, some of which get the prediction results, as shown in Figure 2:

![Figure 2](image)

Figure 2 partial chart of supply volume forecast results of 50 suppliers in the next 24 weeks

Due to too much data, take the prediction result of supplier s005 as an example to obtain the quasi exponential law test chart, as shown in Figure 2:

![Figure 3](image)

Figure 3 smoothness ratio

The images of the fitted data and the original data under the three grey models are shown in Figure 4:

![Figure 4](image)

Figure 4 predicted values under three grey models

3.3.3 Correctness verification

In the grey prediction of the data, it is found that some data can not fully achieve a good goodness of fit. For this part of data, this paper uses BP neural network alone for re verification
3.3.4 Determining the maximum supply quantity of suppliers based on multi-objective programming model

Production cost Z consists of ordering cost Z1 and transshipment cost Z2. According to the data in the question, the price of raw materials a and B is higher than that of class C, and the quantity of three raw materials required per unit of product also has corresponding data, which can be summarized as a multi-objective programming problem. The multi-objective model is established as follows:

\[ \alpha_1 \] is the ratio of the unit price of A to the minimum unit price of raw materials, \( \alpha_2 \) is the ratio of the unit price of B to the minimum unit price of raw materials, \( \alpha_3 \) is the ratio of the unit price of C to the minimum unit price of raw materials, and u is the unit value to establish the minimum ordering cost:

\[
\min Z_1 = (\alpha_1 A + \alpha_2 B + \alpha_3 C) \times U
\]  
(18)

Establish the minimum transshipment cost, where J is the transshipment cost per cubic meter:

\[
\min Z_2 = (A + B + C) \times J
\]  
(19)

The constraint condition is that the total supply of a, B and C shall not be less than the weekly production capacity of the enterprise, and the maximum supply of a shall not be higher than the total supply of type a raw materials Q1, B and C in the forecast. Similarly, it is obtained:

\[
\begin{align*}
\frac{A}{0.6} + \frac{B}{0.66} + \frac{C}{0.72} &\geq 2.82 \times 10^4 \\
A, B, C &\geq 0 \\
s.t. & \\
A &< Q_1 \\
B &< Q_2 \\
C &< Q_3
\end{align*}
\]  
(20)

The multi-objective problem can be transformed into a single objective problem by weighting. The purchase unit price of raw materials can be estimated through market research. The transshipment unit price of raw materials can be estimated by using the midway truck as the standard through data
query. The two unit prices are compared to determine the weight of the objective function. Because the units of the two objective functions are the same, the influence of dimension should not be considered. The objective function is weighted, and the order quantity shall ensure the capacity of the next week, so as to obtain the single objective planning function:

\[
\min Z = (\alpha_1 A + \alpha_2 B + \alpha_3 C) \times 250 + \left( \frac{A}{0.6} + \frac{B}{0.66} + \frac{C}{0.72} \right)
\]

(21)

3.3.5 Solution results

Using MATLAB to solve the single objective function, it is obtained that the quantity of a, B and C raw materials required at least is 11246 cubic meters of class a raw materials, 810.15 cubic meters of class B raw materials and 5925 cubic meters of class C raw materials.

3.4 Formulate transshipment plan

In the actual transportation, the raw materials will have a certain loss. If the value mentioned in the data description is "0", there is no transportation. To select the order with the least loss, first eliminate the order with the transportation of 0 to obtain the quantity \( m \) of effective orders. Sum the loss rate \( \beta \) of each forwarder to obtain the total loss rate \( \beta_{\text{sum}} \) and the average loss rate \( \bar{\beta} \).

\[
\bar{\beta} = \frac{\beta_{\text{sum}}}{\beta}
\]

(22)

In order to formulate the scheme with the least loss rate, arrange the average loss rate of the eight transporters in ascending order, and then calculate the minimum of the three raw materials required according to the above, and the transportation capacity of each transporter is 6000 cubic meters per week. In order to meet the production efficiency of the enterprise, the transporter with low loss rate is preferred to transport the raw materials this week.

The implementation of this scheme will reduce the cost while meeting the required weekly capacity. When selecting the forwarder, give priority to the forwarder with low average loss rate, which can further reduce the cost.

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