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The Optimal Supplier Selection Strategy for Enterprises Based on Entropy Weight TOPSIS

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Abstract: *This study aims to select the optimal suppliers of production raw materials. Due to the specificity, diversity, and real-time nature of raw materials, it is crucial for enterprises to make comprehensive considerations when choosing suppliers. Therefore, establishing a comprehensive supplier evaluation system and formulating the best ordering plan is extremely important to ensure the production of enterprises. Based on the historical ordering data of a certain company, we extracted multiple supply digital features and comprehensively evaluated the suppliers from three aspects: supplier strength, supply-demand fit, and corporate ordering preferences. Specifically, we used five evaluation indicators, including average weekly supply volume, supply-demand curve similarity, supply compliance rate, average annual growth rate of order volume, and preference variation coefficient. Specifically, the entropy method was used to determine the weights of each indicator, and the TOPSIS method was used to score the suppliers. Next, we used 0-1 integer programming to minimize the total number of suppliers as the goal, and calculated the constraints for each week in turn to solve for the optimal 20 raw material suppliers.*

Keywords: *Supplier evaluation system, TOPSIS method, 0-1 integer programming*

1. Introduction

In modern manufacturing, raw material supply chain management [1] is critical to both production efficiency and cost control. This is particularly true in the construction and decoration industry, where ensuring stable production while optimizing raw material procurement and supplier selection has become key to enhancing a company's competitiveness.

In this context, this paper proposes a comprehensive evaluation and optimization model to address the challenges of supplier selection[2] optimization for raw materials. Using the data from Problem C of the 2021 National Undergraduate Mathematical Contest in Modeling (sponsored by Higher Education Press) as a research sample, we first establish a supplier evaluation system and rank the suppliers using the entropy-weighted TOPSIS[3] method to identify the optimal suppliers. Subsequently, we formulate the optimal supplier selection plan to meet the basic production needs of the enterprise using 0-1 integer programming[4] and dynamic linear programming.

This study provides a scientific method for supply chain management in the construction and decoration industry and serves as a reference for raw material management in other manufacturing sectors, helping companies improve production efficiency, reduce costs, and enhance competitiveness in a complex and volatile market environment.

2. Establishment of evaluation index system

To ensure stable production, the mathematical model established in this study must reflect the critical factors that contribute to the continuous operation of the enterprise. In this context, it is assumed that the manufacturing company is aware that material losses during transportation will impact the final quantity of materials received. Therefore, when placing orders with suppliers, the company has already accounted for potential in-transit losses. Consequently, the key factors in model development primarily pertain to the supplier selection process during the raw material procurement phase.

(1) Supply capability

The supply capability of a supplier can be assessed based on the volume of goods they provide. In this study, the total supply volume and the average weekly supply volume over the past five years are

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selected as indicators to measure a supplier's supply capability.

Total supply volume refers to the cumulative amount of raw materials a supplier has delivered to the manufacturing enterprise each week over the past five years. A higher total supply volume indicates a larger production and operational scale of the supplier. The specific calculation formula is $S_{ti} = \sum_{w=1}^{W} S_{wi}$, where S_{ti} represents the total supply volume of supplier i, and S_{wi} denotes the supply volume of supplier i in week w. Average weekly supply volume refers to the average quantity of raw materials provided by a supplier to the manufacturing enterprise on a weekly basis over the past five years. This metric reflects the supplier's long-term supply capacity and, by extension, their overall strength. The calculation formula is $\bar{S}_{ti} = \frac{S_{ti}}{W}$, where $\bar{S}_{ti}$ represents the average weekly supply volume of supplier i.

(2) Supply Stability

The impact of raw material suppliers on the stable production activities of manufacturing enterprises can be reflected in the stability and timeliness of their supply. Supply stability can be assessed by analyzing the regularity or variability of the supplier's weekly deliveries. Therefore, this study selects the supply regularity and the coefficient of variation in supply volume over the past five years as indicators to measure a supplier's supply stability.

Supply regularity refers to the consistency in the quantity of goods delivered by suppliers during transactions with the enterprise. The stronger the regularity, the more stable the supply, and the lower the risk that the manufacturing enterprise will face shortages in raw materials. In this paper, supply regularity is defined as the mean variance of the amplitude spectrum obtained from the Fourier transform of the total supply quantity provided by each supplier to the enterprise. The specific calculation formula is as follows:

$$\begin{cases} R = \frac{\sum_{i=1}^{I} S^2}{I} \\ S^2 = \frac{\sum_{i=1}^{I} (abs - \overline{abs})^2}{B}, \end{cases}$$

where S^2 represents the variance of the amplitude spectrum obtained from the Fourier transform of the total quantity of raw materials supplied by a given supplier to the enterprise. abs denotes the amplitude spectrum after the Fourier transform of the total supply quantity provided by the supplier, $\overline{abs}$ is its mean value, and B is the total number of supply occasions from the supplier to the enterprise. Supply Standard Deviation is used to measure the degree of variation in the quantity supplied by the supplier. By calculating the coefficient of variation in supply volume for each supplier, it is possible to compare the fluctuation levels across suppliers. A larger standard deviation indicates greater fluctuation in supply volume, implying lower supply stability. The specific calculation formula is

$$\sigma_i^1 = \sqrt{\frac{\sum_{w=1}^{W} (S_{wi} - \bar{S}_{ti})^2}{W-1}} ,$$

where σ_i^1 represents the standard deviation of the supply volume for supplier i.

(3) Supply-Demand Matching Degree

The supply-demand matching degree reflects the credibility of a supplier. Given the order quantity from the enterprise, the closer the actual supply volume from the supplier is to the order quantity, the more the supplier adheres to the contract. When the supply volume exceeds the order quantity, the excess raw materials may incur additional transportation and storage costs. Conversely, if the supply volume is less than the order quantity, it may fail to meet the prerequisites for stable production.

The supply-demand curve similarity is an indicator used to measure the supply-demand matching degree. The specific calculation formula is $D_i = \sum_{w=1}^{W} (S_{wi} - O_{wi})^2$, where D_i represents the supply-demand curve similarity of a supplier, and O_{wi} denotes the order quantity placed by the enterprise to supplier i in week w. The smaller the value of D_i , the higher the similarity. The supply fulfillment rate is another indicator used to measure the supply-demand matching degree. The specific calculation formula is

$$Q_i = \frac{\sum_{w=1}^{W} Q_{wi}}{W_{i\,effective}},$$

$$Q_{wi} = \begin{cases} 0, S_{wi} < O_{wi} \\ 1,\ S_{wi} \geq O_{wi} \end{cases},$$

where Q_i denotes the fulfillment rate of a supplier i, used to assess whether the supplier meets the standards, i.e., whether the supply volume Q_{wi} is not less than the order quantity. The value $W_{i\,effective}$ represents the total number of weeks during which the supplier i has supplied over the five-year period.

(4) Corporate Ordering Preference

Corporate ordering preference, which indicates the relative importance of each supplier to the enterprise, can be reflected in the demand for raw materials ordered from each supplier. Therefore, this study uses the data of raw material order quantities submitted by the enterprise to each supplier on a weekly basis over the past five years as an indicator to measure the enterprise's ordering preference.

Ordering preference rate refers to the proportion of orders placed by the enterprise with each supplier on an average weekly basis. This metric directly reflects the importance of each supplier in the enterprise's raw material procurement. The specific formula is

$$\begin{cases} \overline{P_i} = \frac{\sum_{w=1}^{W} P_{wi}}{W} \\ P_{wi} = \frac{O_{wi}}{\sum_{i=1}^{I} O_{wi}} \end{cases},$$

where $\overline{P_i}$ represents the average weekly order proportion of the enterprise for supplier i, and P_{wi} represents the order proportion of the enterprise to supplier i, in week w. The coefficient of variation in preference is used to reflect the changes in the enterprise's preference for each supplier over the five-year period. The specific formula is $C_i^2 = \frac{\sigma_i^2}{\mu_i^2}$, where C_i^2 represents the coefficient of variation in preference for supplier i, σ_i^2 is the standard deviation of the preference rate, and μ_i^2 is the mean preference rate. The average annual growth rate of order quantity indicates the enterprise's increasing subjective preference for a supplier as they gain more understanding of the supplier. The specific formula is

$$\overline{G_i} = \frac{\sum_{y=1}^{Y-1} G_{yi}}{Y-1},$$

where G_{yi} represents the growth rate of the total raw materials ordered from supplier i between year y and year $y+1$, and $Y = 5$ represents the total number of years.

Subsequently, a correlation analysis is conducted on the above indicators to refine the evaluation index system, making it more concise and effective. By calculating the correlation coefficients between the indicators within the same criterion layer, those with high correlation coefficients, such as total supply volume, supply regularity, and ordering preference rate, are removed. In this context, ordering preference rate, supply fulfillment standard deviation, and the remaining five indicators are taken as examples, and a correlation heatmap is provided, as shown in *Fig. 1*.

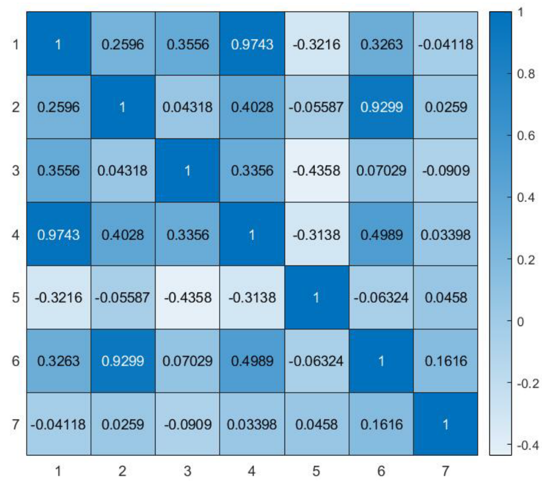

Figure 1: Correlation Heatmap.

In summary, through the analysis of the research data, this paper identifies five indicators across three key dimensions that comprehensively evaluate the suppliers. Based on these indicators, a comprehensive supplier evaluation system can be established, as shown in *Fig. 2*.

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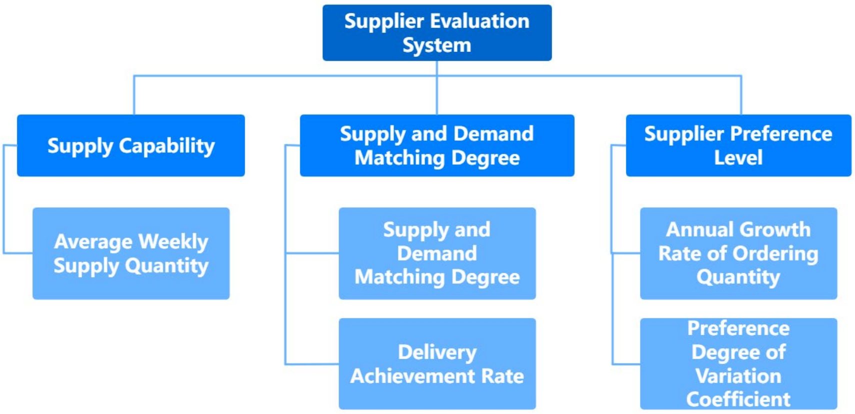

Figure 2: Comprehensive Supplier Evaluation System.

3. Determination of weights

Based on the indicators selected in the previous section for quantifying the supply characteristics of suppliers, this paper establishes a corresponding comprehensive supplier evaluation model. To do this, it is first necessary to determine the weights of the evaluation indicators. To avoid subjective bias in the final evaluation results, the entropy weight method is employed to determine the weight of each indicator, based on the calculated values for the 402 suppliers. Following this, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is used to perform a comprehensive evaluation of each supplier.

(1) Entropy Weight Method

Step 1: Standardize the data for the corresponding indicators of the suppliers.

Step 2: Calculate the weight of the ith supplier under the jth evaluation indicator:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{I} z_{ij}}$$

where z_{ij} represents the value of the j_{th} evaluation indicator for the i_{th} supplier.

Step 3: Calculate the information entropy for each indicator. The larger the information entropy, the less information the indicator provides:

$$E_j = -\ln(I)^{-1} \sum_{i=1}^{I} p_{ij} \ln p_{ij}$$

Determine the weight of each indicator:

$$w_j = \frac{1 - E_j}{\sum_{j-1}^{J} (1 - E_j)}$$

where J is the total number of evaluation indicators.

(2) TOPSIS Ideal Solution Method

The TOPSIS Ideal Solution Method is a technique that ranks alternatives based on their closeness to an ideal solution. In this study, an idealized target is set by assuming positive and negative ideal solutions, and the proximity of each supplier to the ideal supplier is measured to determine the final ranking of suppliers. The specific steps are as follows:

Step 1: Identify the maximum and minimum values for each evaluation indicator, forming the vectors Z^+, Z^- respectively.

Step 2: Calculate the distance between each supplier and the positive and negative ideal solutions:

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$$\begin{cases} D_i^+ = \sqrt{\sum_{j=1}^{J}\left(z_{ij} - z_j^+\right)^2} \\ D_i^- = \sqrt{\sum_{j=1}^{J}\left(z_{ij} - z_j^-\right)^2} \end{cases}, (i = 1, \dots, I)$$

Step3: Calculate the closeness coefficient of each supplier to the ideal supplier:

$$A_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

Where $A_i \in [0,1]$ represents the closeness coefficient, and the closer A_i is to 1, the closer the supplier is to the ideal supplier, resulting in a higher final score.

4. Evaluation Results

By substituting the obtained relevant data into the established comprehensive supplier evaluation model, the final supplier selection results can be obtained. To achieve this, the entropy weight method is first used to calculate the weights of each indicator, as shown in the table below in *Table 1*:

Table 1: The evaluation indicators and weights.

Indicator	Weight
Average Weekly Supply Quantity	0.2619
Supply and Demand Matching Degree	0.4679
Delivery Achievement Rate	0.0168
Annual Growth Rate of Ordering Quantity	0.0228
Preference Degree of Variation Coefficient	0.2305

Subsequently, the TOPSIS Ideal Solution Method is applied to determine the most important suppliers. The main text will present the selection results for the top 30 most important suppliers in *Table 2*.

Table 2: The evaluation score of all suppliers.

Supplier	Score	Supplier	Score	Supplier	Score	Supplier	Score	Supplier	Score
S273	0.7850	S356	0.7121	S307	0.7016	S380	0.6948	S294	0.6922
S229	0.7351	S268	0.7120	S395	0.7002	S040	0.6947	S005	0.6920
S361	0.7339	S306	0.7114	S247	0.6993	S338	0.6942	S186	0.6918
S108	0.7244	S330	0.7091	S154	0.6984	S364	0.6941	S244	0.6917
S340	0.7184	S374	0.7073	S037	0.6977	S367	0.6936	S086	0.6916
S282	0.7181	S194	0.7073	S284	0.6974	S157	0.6936	S218	0.6915
S275	0.7165	S308	0.7054	S112	0.6971	S055	0.6930	S064	0.6911
S329	0.7162	S352	0.7052	S365	0.6965	S346	0.6930	S003	0.6910
S139	0.7135	S143	0.7036	S031	0.6965	S333	0.6923	S138	0.6910

5. Optimization Model

To reduce the number of selected suppliers and maximize economic benefits, the final number of selected suppliers N is set as the objective function. Under the premise of ensuring stable production, the decision is made whether to select a supplier for procurement. Let the variable represent the final selection decision for the *i*th supplier by the enterprise, then the model is formulated as follows:

$$S_i = \begin{cases} 0, the\ ith\ supplier\ is\ not\ selected \\ 1, the\ ith\ supplier\ is\ selected \end{cases}$$

Therefore, the final number of selected suppliers can be expressed as $N = \sum_{i=1}^{I} S_i$.

(1) Determination of Constraints

This paper imposes the following constraints on the raw material inventory: $St = 5.64 \times 10^4 m^3$.

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The initial inventory is set to be equivalent to the enterprise's total production capacity for two weeks, denoted as $Wa = 5\%$.

According to the condition that the enterprise must maintain a raw material inventory sufficient for at least two weeks of production, the minimum number of suppliers and total supply volume for week are determined first. Based on the minimum remaining inventory constraint for week w' , the optimal selection of suppliers and supply volume for week w is then made. Therefore, this constraint can be expressed as:

$$St_{w'} \geq St, w' \in [1,23]$$

$$St_{w'+1} = St_{w'} + \sum_{i=1}^{I} \frac{Re_{w'i}}{Me_i} - 2.82 \times 10^4$$

Where $Re_{w'i}$ represents the quantity received from the ith supplier in week w' , Me_i represents the amount of raw materials from supplier i_{th} consumed per unit of product, and $St_{w'}$ represents the remaining inventory in week w'. The specific calculation formula is as follows:

$$Re_{w'i'} = S_{w'i} \times (1 - Wa)$$

$$Me_i = \begin{cases} 0.6, Supplier\ i\ supplies\ Type\ A \\ 0.66, Supplier\ i\ supplies\ Type\ B \\ 0.72, Supplier\ i\ supplies\ Type\ C \end{cases}$$

(2) Supplier Selection Optimization Model

In summary, the supplier selection optimization model can be formulated as follows:

$$\min N = \sum_{i=1}^{I} S_i$$

$$s.t. \begin{cases} St_{w'} \geq St, w' \in [1,23] \\ St_{w'+1} = St_{w'} + \sum_{i=1}^{I} \frac{Re_{w'i}}{Me_i} - 2.82 \times 10^4 \\ Re_{w'i} = S_{w'i} \times (1 - Wa) \\ St = 5.64 \times 10^4 m^3 \\ Wa = 5\% \end{cases}$$

The algorithm for solving the model follows these steps:

Step 1: Rank the weekly maximum expected supply volumes of each supplier based on their scores, denoting them as $w' = 1, i = 1$.

Step 2: In descending order of the supplier rankings, select the suppliers in sequence from the highest-ranked i and add their corresponding maximum expected supply volume for week w' to the ordering plan for week w.

Step 3: Check whether the total raw material received by the enterprise in the current week meets the constraint conditions. If it does, store the supplier ID and proceed to Step 4; otherwise, increment $i = i + 1$ and return to Step 2.

Step 4: If $w' > 24$ is the final week), stop and calculate the total number of distinct supplier IDs stored N; otherwise, increment $w' = w' + 1$ and return to Step 2.

By substituting the analyzed data into the established supplier selection optimization model, the results indicate that the enterprise must select at least 20 suppliers to meet its production needs. The final 20 selected suppliers are as follows in *Table 3*:

Table 3: The final 20 selected suppliers.

S229(A)	S282(A)	S330(B)	S194(C)
S361(C)	S275(A)	S356(C)	S352(A)
S108(B)	S329(A)	S268(C)	S143(A)
S151(C)	S139(B)	S308(B)	S307(A)
S340(B)	S131(B)	S306(C)	S395(A)

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6. Conclusion

This paper primarily investigates how manufacturing enterprises can select the optimal suppliers. We began by analyzing and quantifying supplier data, extracting key indicators that represent supplier strength. The analysis identified supply capability and supply-demand matching degree as the most critical indicators. To maximize economic benefits and minimize the number of selected suppliers, we employed integer programming for modeling and solution. The final selection resulted in 20 suppliers being chosen to supply the enterprise under study. Future research will focus on exploring ways to further enhance the profit margins for such enterprises.

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