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Research on Supplier Selection of Pharmaceutical Enterprises under the Dual Carbon Target

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Abstract: With the proposal of national carbon peak and carbon neutrality targets, green supply chain management has become one of the important means of reducing carbon emissions. Based on elaborating on the connotation of new quality productivity, this article analyzes the supplier selection problem of pharmaceutical enterprises under the dual carbon target. A pharmaceutical supplier evaluation index system has been established from five aspects related to low-carbon and environmental protection, including technological innovation, research and development capabilities, digitization, intelligent production, environmental protection technology, and so on, with five primary indicators and 18 secondary indicators. Secondly, a game theory combination weighting method combining the G1 method and entropy weight method is used to determine the weights of indicators. A pharmaceutical supplier evaluation model is established by combining the matter element extension model. A company is used as an example to evaluate its 8 candidate suppliers and select the best supplier. Finally, corresponding measures are proposed to promote the healthy and sustainable development of pharmaceutical enterprises.

Keywords: Dual carbon target; Pharmaceutical industry; Supplier selection; Matter element extensible model

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1. Introduction

With the proposal of national carbon peak and carbon neutrality targets and corresponding policies, green supply chain management has become one of the important means of reducing carbon emissions. The selection and evaluation of green suppliers are important links in supply chain management, and low-carbon, energy-saving, and environmental protection are inherent requirements and important focus points for promoting high-quality development. Although some pharmaceutical companies have started exploring and researching supply chain changes, their overall management level in the industry is not high, and they have not considered the impact of factors such as energy conservation and environmental protection technology innovation, research and development capabilities, resulting in current supplier management that is not conducive to the sustainable development of pharmaceutical companies. Therefore, the research on supplier selection for pharmaceutical companies under the dual carbon target is particularly important for high-quality development in the new era.

2. Construction of supplier evaluation index system for pharmaceutical enterprises

2.1. Methods of evaluation indicators

The application of low-carbon goals in the selection of suppliers in the pharmaceutical industry is reflected in various aspects such as technological innovation and research and development capabilities, digital and intelligent production, green pharmaceuticals and environmental protection technologies, cross-border integration, and innovation capabilities, as well as supply chain stability and reliability. When selecting a specific indicator system, the general factors affecting the supplier selection of pharmaceutical companies are mainly identified. Then, the supplier selection and evaluation indicators were revised through a questionnaire survey method to form a supplier evaluation indicator system.

2.2. Determination of evaluation indicators

Based on relevant literature, the following evaluation index system has been established

Digitalization and intelligent production: Intelligent production processes: Prioritize suppliers that have adopted intelligent production processes, such as optimizing production data through machine learning algorithms to predict and optimize equipment maintenance cycles, reducing failure rates, and enhancing production efficiency and product quality. Digital management tools: Focus on whether suppliers employ digital management tools for supply chain and inventory management to improve supply chain transparency and response speed. Design and manufacturing capabilities: Suppliers' design and manufacturing capabilities determine whether their products can meet project specifications and performance requirements. Management efficiency: Suppliers with high management efficiency can better adhere to delivery schedules, reducing delays caused by inefficient management.

Technological innovation and R&D capabilities: New drug R&D capabilities: Prioritize suppliers with robust capabilities in innovative drug R&D. Technological platforms and R&D facilities: Assess whether suppliers possess advanced and comprehensive technological platforms and R&D facilities, including laboratory equipment, R&D teams, and R&D processes. Quality certifications: Quality certifications not only reflect product quality but also indirectly indicate suppliers' quality management capabilities and technological innovation strengths.

Supply chain stability and reliability: Supply chain stability: Select suppliers with stable supply chains to ensure the quality of pharmaceutical products and the stability of supply. Production capacity: Reflects the supplier's ability to produce products as needed, encompassing not only production scale but also production efficiency, equipment modernization, the advancement of production technology, and so on. After-sales service: Pay attention to the supplier's after-sales service and technical support capabilities, including the provision of timely technical consultations, product training, and after-sales services. This will help resolve issues encountered during use customer satisfaction. Inventory control: Its indicator assesses the supplier's ability to manage product inventory, including optimizing inventory costs, managing risks of excess and shortages, and adapting to changes in market demand [1].

Costs and prices: Cost control capability: Its indicator measures the supplier's ability to control and optimize costs. Selecting suppliers with strong cost control capabilities can effectively avoid budget overruns and ensure project profit margins. Price competitiveness: Price competitiveness gauges the competitiveness of the supplier's products or services in comparison to similar products in the market. Price reduction capability: The ability to reduce prices is an indicator that assesses whether a supplier can lower sales prices through effective cost control and pricing management strategies.

Green pharmaceutical manufacturing and innovation capability: Environmental protection technology: When selecting suppliers, consider whether they employ environmentally friendly technologies and measures in production, such as utilizing bio-fermentation technology to replace chemical synthesis methods for drug production, thereby reducing environmental pollution [2]. Environmental protection measures: Evaluate whether suppliers adopt energy-efficient equipment and processes to reduce energy consumption [3]. Cross-boundary collaboration and resource integration: Choose suppliers capable of cross-boundary collaboration and resource integration with other sectors, such as research institutions, universities, and medical institutions. For instance, collaborating on new drug development and clinical trials. Innovation capability and forward-thinking: Focus on the supplier's innovation capability and forward-thinking, including their keen market insight, ability to predict industry trends, and early strategic positioning [4]. An evaluation index is illustrated in **Figure 1**.

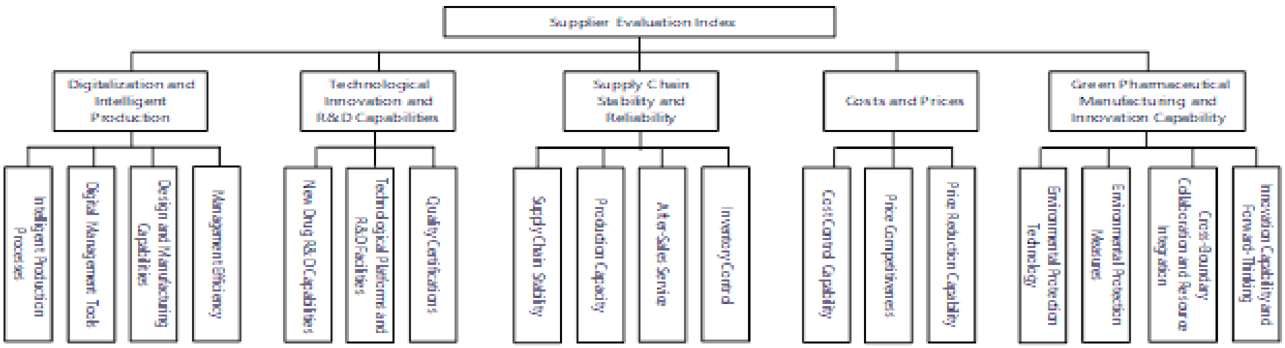

Figure 1. Supplier selection and evaluation index system

2.3. Description and quantification of indicators

The evaluation indicators can be quantified using both qualitative and quantitative methods. Such as R&D and manufacturing capability can be expressed as R.

$$R = \frac{f}{g} \times 100\% \quad (1)$$

Supply chain stability: The stability of raw materials is measured by the number of disruptions in raw material supply. The evaluation scoring table is shown in **Table 1**.

Table 1. The evaluation scoring for supply chain stability

Grade	Score	Qualitative description
Excellent	90–100	The number of supply disruptions within a certain period is less than 2 times
Good	75–89	The number of supply disruptions within a certain period is less than 8 times
Acceptable	60–74	The number of supply disruptions within a certain period is less than 15 times
Poor	Below 60	The number of supply disruptions within a certain period is more than 15 times

2.4. Calculation method for evaluation indicator weights

Due to game theory's ability to play a role in adjusting weight conflicts, the final conclusion can be drawn based on a comprehensive consideration of both subjective and objective weights. The game theory combined weighting method, which integrates the G1 method with the entropy weight method, is adopted to determine the indicator weights [5]. The steps for the game theory method are as follows.

W represents the weight set calculated by different methods, the number of indicators, and the method used for weight value calculation. Assuming that $\alpha = \{\alpha_1, \alpha_2\}$ represents the linear combination coefficient, any linear combination of the vectors can be expressed as:

$$W = \alpha_1 W_1^T + \alpha_2 W_2^T \tag{2}$$

Combining the Nash equilibrium theory with game theory, optimize the correlation coefficients to determine the minimum and optimal values. The calculation formula is:

$$min \left\| \sum_{k=1}^{L} \alpha_k W_k^T - W_k \right\|_2 \tag{3}$$

Referring to the differential properties of matrix, first-order derivative optimization process is:

$$\begin{aligned} \alpha_1 W_1 W_1{}^T + \alpha_2 W_1 W_2{}^T = W_1 W_1{}^T \\ \alpha_1 W_2 W_1{}^T + \alpha_2 W_1 W_1{}^T = W_2 W_2{}^T \end{aligned} \tag{4}$$

After arranging, a system of linear equations is obtained:

$$\begin{bmatrix} W_1 W_1^T & W_1 W_2^T \\ W_2 W_1^T & W_2 W_2^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} W_1 W_1^T \\ W_2 W_2^T \end{bmatrix} \tag{5}$$

From Formula 5, two optimal coefficients α_1 and α_2 can be obtained, the normalization results are:

$$\begin{cases} \alpha_1{}^* = \alpha_1/(\alpha_1+\alpha_2) \\ \alpha_2{}^* = \alpha_2/(\alpha_1+\alpha_2) \end{cases} \tag{6}$$

Apply the game theory combination to assign weights to the comprehensive weights, result being:

$$W = \alpha_1 * W_1^T + \alpha_2 * W_2^T \tag{7}$$

2.5. Comprehensive evaluation model for suppliers

The combination of quantitative and qualitative methods is currently one of the most widely used evaluation strategies. The evaluation process is as follows:

The structure of things in the basic model matter-element is typically composed of a triplet, which is usually in an ordered state R = (N, c, v). In R, the name of the object characteristic is c; the thing is N; and N's value regarding c is v, which is generally represented by a corresponding value or numerical interval. The three essential elements of the matter-element, namely, N, c, and v, can be expressed mathematically as follows:

$$R = \begin{bmatrix} N & c1 & v1 \\ & c2 & v2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} \tag{8}$$

The process of matter-element analysis is as follows.

2.5.1. Determination of the matter-element model

$$R = \begin{bmatrix} N_i & c1 & vi1 \\ & c2 & vi2 \\ & \vdots & \vdots \\ & c_n & v_{in} \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} \tag{9}$$

2.5.2. Identification of the classical domain

The classical domain refers to the value range of each evaluation grade corresponding to each factor among multiple evaluation indicators. The classical matter-element representation of the research object in the material system is: Where: c_k is the Kth evaluation parameter of the matter-element to be evaluated; N_i is the ith matter-element to be evaluated; R is the sub-matter-element of R_i; c_k is value related to v_{ik}.

$$R_j = \begin{bmatrix} N_j & c_1 & v_{j1} \\ & c_2 & v_{j2} \\ & \vdots & \vdots \\ & c_n & v_{jn} \end{bmatrix} = \begin{bmatrix} N_j & c_1 & \langle a_{j1}, b_{j1} \rangle \\ & c_2 & \langle a_{j2}, b_{j2} \rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{jn}, b_{jn} \rangle \end{bmatrix} \tag{10}$$

Where: a_{jn} is the upper limit of the value range; b_{jn} is the lower limit of the value range; and N_j is the grade of the research object j.

2.5.3. Determination of the joint domain matter-element

The joint domain matter-element refers to the range of values of all parameters from low to high. The following formula represents the joint domain matter-element:

$$R_p = \begin{bmatrix} N_p & c_1 & v_{p1} \\ & c_2 & v_{p2} \\ & \vdots & \vdots \\ & c_n & v_{pn} \end{bmatrix} = \begin{bmatrix} N_p & c_1 & \langle a_{p1}, b_{p1} \rangle \\ & c_2 & \langle a_{p2}, b_{p2} \rangle \\ & \vdots & \vdots \\ & c_n & \langle a_{pn}, b_{pn} \rangle \end{bmatrix} \tag{11}$$

Where: a_{p1} is the upper limit of the joint domain; b_{p1} is the lower limit of the joint domain; $v_{pn}$is the joint domain or the value corresponding to the P grade; and N_p is the subject of the evaluation grade.

2.5.4. Determination of the matter-element to be evaluated

The matter-element composed of the things to be evaluated is the matter-element to be evaluated. The following formula represents the matter-element to be evaluated:

$$R_m = \begin{bmatrix} N_m & c_1 & v_{m1} \\ & c_2 & v_{m2} \\ & \vdots & \vdots \\ & c_n & v_{mn} \end{bmatrix} \tag{12}$$

Where: v_{mk} is the corresponding value of the kth evaluation unit and the th influencing parameter; $c_k(k = 1,2, \ldots, n)$ is the kth indicator; and N_m is the th matter-element to be evaluated.

2.5.5. Calculation of the correlation function

Based on the aforementioned need for feature representation, the real-axis correlation function is established as follows:

$$K_j(x_i) = \begin{cases} \frac{\rho(x_i, X_{ji})}{\rho(x_i, X_{pi}) - \rho(x_i, X_{ji})}, x_i \notin X_{ji} \\ \frac{-\rho(x_i, X_j)}{|X_{ji}|}, x_i \in X_{ji} \\ -\rho(x_i, X_{ji}) - 1, \rho(x_i, X_{pi}) - \rho(x_i, X_{ji}) = 0 \end{cases} \quad (13)$$

The following formula represents the distance of a point on the real axis within the above formula:

$$\rho(v_i, V_{ij}) = \left|v_i - \frac{a_{ij}+b_{ij}}{2}\right| - \frac{b_{ij}-a_{ij}}{2} \quad (14)$$

The following formula represents the distance of $V_{ij} = (a_{ij}, b_{ij})$ and v_i:

$$\rho(v_i, V_{pj}) = \left|v_i - \frac{a_{pj}+b_{pj}}{2}\right| - \frac{b_{pj}-a_{pj}}{2} \quad |X_{ji}| = |b_{ji} - a_{ji}| \quad (15)$$

The evaluation results are determined. The specific correlation degree levels are: Value range of j is $0 < K_j(N) < 1$.

3. Case analysis

A pharmaceutical company A, needs to order raw materials for its drug production. After screening the suppliers listed in its vendor directory to meet the company's requirements, A has collected basic information from these suppliers. The comprehensive weights are determined based on the combination of subjective and objective methods using game theory, with k set to 2. The calculation is performed using the indicator weights obtained after weighting as the base data. Finally, the comprehensive weight values of the criteria-level indicators are presented in **Table 2**.

Table 2. Weights and data based on game theory

Level	Weight	Level	Weight	S1	S2	S3	S4	S5	S6	S7	S8
Digitalization and intelligent production	0.01	Intelligent production process	0.0229	62	54	68	57	50	56	51	53
		Digital management tools	0.0356	72	80	76	77	80	77	76	78
		Design and manufacturing capabilities	0.0154	43	45	40	47	47	48	45	46
		Management efficiency	0.0115	82	85	87	83	83	86	90	87
Technological innovation and R&D capabilities	0.25	New drug research and development capabilities	0.0870	87	90	86	84	85	89	92	87
		Technology and R&D facilities	0.1187	8	9	8	8	8	8	8	8
		Quality certification	0.0492	86	85	84	88	89	87	86	88
Supply chain stability	0.14	Supply chain stability	0.0270	90	87	92	89	89	85	87	86
		Production capacity	0.0397	99	99	99	99	99	99	99	99
		After-sales service	0.0178	86	82	80	89	92	89	84	88
		Inventory control	0.0594	81	80	79	84	78	86	75	84

Table 1 (Continued)

Level	Weight	Level	Weight	S1	S2	S3	S4	S5	S6	S7	S8
Cost and pricing	0.45	Cost control capabilities	0.1299	99	99	99	99	99	99	99	99
		Price competitiveness	0.2300	1.6	1.8	1.5	1.7	1.8	1.5	1.4	1.6
		Price reduction capabilities	0.0867	91	87	88	84	86	87	83	85
Green pharmaceutical manufacturing and innovation capabilities	0.15	Environmental protection technology	0.0137	2.3	5.6	4.6	3.9	5.2	4.9	6.3	5.1
		Environmental protection measures	0.0267	92	95	96	94	82	101	97	99
		Cross-boundary collaboration and resource integration	0.0182	77	83	76	80	82	84	83	79
		Innovation capabilities and forward-looking vision	0.0104	77	83	74	78	79	82	85	81

Based on the evaluation and analysis results, the results are as follows. Supplier 1 has the highest deviation characteristic value, j* = 3.53, which indicates that Supplier 1's overall performance is superior to other suppliers. Therefore, Enterprise A can consider selecting Supplier 1 as its partner for this collaboration.

4. Conclusion

Strategic emerging industries and future industries constitute the core areas for nurturing new productivity. As a crucial component of strategic emerging industries, the pharmaceutical industry is also a key direction for future industrial planning and layout. To propel the pharmaceutical industry towards a new stage of high-quality development, it is necessary to integrate key elements representing new productivity into the selection considerations of suppliers for pharmaceutical enterprises, thereby strengthening their capabilities in green technological innovation and promoting sustainable industrial development.

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Author contributions

Study idea conceptualization: Peng Wang
Study data analysis: Yongkun Wang
Study writing: Yongkun Wang

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