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Discussion and Application Analysis of Supply Chain Partner Selection Method Based on AHP

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Abstract: Supply chain management is the key to success in modern business competition, and the selection of supply chain partners is the starting point for building efficient management. Enterprises need to set up a partner evaluation index system based on development needs and adopt reasonable methods for selection. The Analytic Hierarchy Process (AHP) is one of the partner selection methods that are easy to master and use at the undergraduate level. Based on existing research, this paper first analyses the influencing factors of supply chain partner selection and expounds the key points of constructing the index system; then discusses the basic ideas and implementation steps of AHP; finally, it sets up an application scenario and analyses the application process of AHP. The research in this paper is helpful for the teaching, learning, and application of the AHP.

1. Introduction

The core idea of supply chain management is that each node enterprise focuses on its core business and outsources non-core business to other enterprises, through "strong alliance", to reduce the total cost of the entire supply chain and increase the total value. Therefore, the selection and management of partners in the supply chain are crucial[1,2]. Since the screening of partners and the management of partnerships require costs, and the benefits of partnerships often do not occur immediately, enterprises need to carefully select partners to achieve a win-win cooperation. Many scholars have proposed that the types of cooperation should be divided based on the competitiveness of partner enterprises, the impact of partner enterprises on the value-added of the enterprise, etc., and different types of partners should be selected based on the enterprise development strategy, different stages of development goals, etc.

In summary, partners are key to a company's success in competition within the context of supply chain management. Companies should determine reasonable evaluation criteria based on development strategies, market environment, and other factors to select suitable partners. AHP is a partner selection method suitable for undergraduate learning[3]. This article will explore the AHP-based supply chain partner selection method and apply the process using case analysis.

2. Evaluation Indicator System for the Selection of Supply Chain Partners

When evaluating partners, enterprises need to consider their current situation, long-term development strategies, and comprehensive factors such as demand analysis, product functions, and cost-benefit analysis. Special attention should be paid to the consistency of strategic thinking and values between partnering enterprises.

In practice, due to differences in product types, production processes, and development stages of different enterprises, the importance of indicators varies in the process of partner selection, and some indicators can even be ignored. In recent years, especially since 2020, due to the impact of the pandemic, climate change, political and economic relations among countries, the global market has fluctuated greatly and uncertainty has increased. To prevent the risk of supply chain disruption, supplier emergency response capabilities, supplier reliability, and other factors have become important factors affecting the selection of partners. A comprehensive evaluation index system is showed in table 1 [3-7].

Table 1: Comprehensive Evaluation Index System for Supply Chain Partners.

First level indicator	Secondary indicators	Third level indicators
External Environmental Assessment	social environment	social stratum; family structure; consumption structure, etc
	geographical environment	Topographical conditions; climatic conditions; water resource conditions; mineral resource conditions, etc
	economic environment	Market size; transportation conditions; population size; technological level, etc
	Policy and Regulation Environment	Policy system status; legal document status; industry standard status, etc
enterprise performance evaluation	Enterprise development prospects	Asset target; Profit target; Market share target, etc
	Corporate reputation	product reputation; service reputation; financial reputation; bank reputation, etc
	Delivery quality	On-time delivery rate; delivery accuracy rate; acceptance rate; average return rate, etc
	cost analysis	Product price; order discount rate, etc
Production Capacity Evaluation	Production status	enterprise scale; annual output; annual output value, etc
	Equipment condition	The level of equipment progressiveness; the number of equipment; equipment capacity, etc
	Financial situation	Asset volume; Liability volume; Cash flow; Cost; Profit, etc
	human resources	Number of employees; proportion of employee structure; technical levels and proportions of employees; educational levels and proportions, etc
	technical cooperation	R&D investment; number of R&D personnel; level of cooperative enterprises, etc
Emergency response capability evaluation	Emergency capability	Emergency organization system; Emergency plan composition; Rescue preparation, etc
	Inventory backup	Warehouse capacity; inventory level; safety stock level, etc
	Emergency logistics	Emergency logistics organization system; emergency logistics personnel; emergency logistics funds; emergency logistics channels, etc

The first-level indicators are the influencing factors from a macro perspective, generally including enterprise environment, performance, production capacity, emergency response capability, etc. The second-level indicators are the decomposition descriptions of the macro influencing factors.

The third-level indicators are the subdivision explanations of some or all of the second-level indicators. Based on the basic principles of setting evaluation system indicators, the general evaluation system can be set to the second or third level indicators to avoid being complicated; the meaning of indicators should be clear and non-overlapping, and the end-level indicators should be measurable to avoid subjectivity.

3. The Idea and Steps of AHP

3.1. Algorithmic Thought

Procurement personnel intuitive judgment method, bidding method, negotiation selection method, procurement cost comparison method, activity-based costing method, analytic hierarchy process, neural network algorithm, etc. In the 1970s, the famous operations researcher T. L. Satty proposed the AHP, which is a mathematical method for selecting the optimal one from candidate solutions based on multiple criteria or factors. For example, when an enterprise chooses a logistics service provider, it needs to consider the service content, service network layout, service level, service price, etc. of the logistics provider, and compare and select different businesses. When there are many solutions and many factors that affect decision-making, using qualitative methods for comparison and selection not only has strong subjectivity but is also complex and difficult to describe, confusing and unable to make optimal judgments. AHP divides complex decision-making problems into three levels: the goal level, the criterion level (influencing factors), and the solution level. First, it analyzes the influence of influencing factors on the final decision, that is, calculates the weight of influencing factors; then it analyzes the advantages and disadvantages of alternative solutions under each influencing factor, that is, calculates the weight of each solution under each criterion, and finally obtains the weight of alternative solutions in the final decision.

3.2. Specific Steps of the Algorithm

3.2.1. Establishing a hierarchical structure model

It is important to establish a hierarchical structure model to clarify the target layer, criteria layer, and scheme layer of decision-making. The target is the decision-making problem. The criteria are the indicators for decision-making basis, which can have only one layer, or can be refined into two or three levels of indicators according to needs. For example, service quality can be refined into secondary indicators such as service timeliness, reliability, safety, and convenience. The scheme level is an alternative scheme for the final goal.

3.2.2. Determining the weight of single-factor and conduct a test

When comparing multiple factors (criteria) or comparing and ranking multiple schemes, how much weight should be assigned to each factor (criterion) or scheme? It is difficult and overly subjective to directly assign weights to all factors or schemes, but by comparing pairs of different factors or schemes to form a pairwise comparison matrix, one can utilize the relevant properties of the matrix to obtain the weight ranking of each element. AHP uses a scale of 1 to 9 to measure the relative importance of two indicators which shows in table 2.

Decision makers need to conduct at least two levels of analysis before selecting the final implementation plan for the final goal. The first level involves determining the weight of each influencing factor at the criteria level, and the second level involves determining the weight of each alternative at the scheme level under a single criterion. Based on the weights determined at these two levels, the final weight and ranking of each alternative for the ultimate goal are obtained. The specific calculation process is as follows:

Table 2: Scale of Importance of Elements.

scale	meaning
1	The influence of the i-th element is the same as that of the j-th element
3	The influence of the i-th element is slightly greater than that of the j-th element
5	The influence of the i-th element is greater than that of the j-th element
7	The influence of the i-th element is significantly greater than that of the j-th element
9	The influence of the i-th element is absolutely greater than that of the j-th element
2, 4, 6, 8	You can also take the middle value by comparing the two with the actual situation

1) Determine the weight value of single-layer factors

Suppose there are n criteria in the criteria layer, which are respectively, the impact degree on the target $A_i$layer. Based on the basic idea of the AHP, to determine the impact degree of each element and rank them, pairwise comparisons need to be carried out. As shown in Table 3, the relative ratio of the impact degree of the i-th criterion to the j-th criterion on the decision-making objective is denoted by a_{ij}. The comparison information generates a data matrix A, called the pairwise comparison matrix. The values on the diagonal of the matrix are all equal to 1, because it is the comparison between the factor itself and itself.

Table 3: Comparison of the Influence of Elements.

index	A_1	A_2	……	A_n
A_1	a_{11}	a_{12}	……	a_{1n}
A_2	a_{21}	a_{22}	……	a_{2n}
……	……	……	……	……
A_n	a_{n1}	an2	……	a_{nn}

The definitions and properties of pairwise comparison matrices are as follows:

Definition 1: A matrix is called a positive reciprocal matrix if it $A=(a_{ij})_{n\times m}$ satisfies certain conditions $a_{ij}>0$, $a_{ji}=1/a_{ij}$ (i, j=1, 2, … n).

Definition 2: If a positive reciprocal matrix A satisfies the condition $a_{ij}*a_{jk}=a_{ik}$ (i, j, k=1,2,…n), it is called a consistent matrix.

Definition 3: If the maximum characteristic root of a positive reciprocal matrix $\lambda\geq n$, it is a consistent matrix if and only $\lambda=n$.

Based on the above definition and matrix-related theorems, the consistent matrix A has the following characteristics: If the largest characteristic root of A is λ_{max}, and the corresponding characteristic vector is $\omega=(\omega_1, \omega_2, \ldots \omega_n)^T$, then $a_{ij}=\omega_i/\omega_j$, ω_i can represent the weight of the factor A_i. Therefore, by finding the characteristic vector corresponding to the maximum eigenvalue of the comparison matrix, the weights of different criteria can be obtained; normalizing the weights makes them more convenient to use.

Similarly, under a certain criterion, the weight and ranking of each alternative can be obtained by using a pairwise comparison matrix.

2) Matrix consistency test

It should be noted that the constructed pairwise comparison matrix may not necessarily satisfy consistency, so a matrix consistency check is required to ensure the scientific nature of the weight analysis. According to Definition 3, the maximum characteristic root of an n-order positive reciprocal matrix A is λ, $\lambda\geq n$, and A is a consistent matrix only when $\lambda=n$. Since λ continuously depends on a_{ij}, the more λ is greater than n, the more inconsistent A is. Therefore, the magnitude of λ-n can be used to measure the degree of inconsistency of A. Let the consistency ratio be CR, and its calculation is shown in equation (1).

$$CR=CI/RI \tag{1}$$

The consistency index, which called CI of the finger matrix is calculated as shown in equation (2):

$$CI=(\lambda-n)/(n-1) \quad (2)$$

For the random consistency index RI, its calculation process is as follows: randomly construct 500 pairwise comparison matrices to A_1, A_2, …, A_{500}, obtain the consistency index C_1, C_2, … C_{500}. The formula for calculating RI is shown in equation (3):

$$RI=(C_1+C_2+\cdots+C_{500})/500 \quad (3)$$

The values of the random consistency index are shown in Table 4 below:

Table 4: Random Consistency Index Value

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Generally, when the matrix consistency ratio is within an acceptable range, it is considered that the degree of inconsistency of the matrix is within an acceptable range, and its normalized eigenvector can be used as the weight vector. In addition, pairwise comparisons of elements are often subjective. To make the pairwise comparison matrix more scientific, methods such as questionnaire surveys or hiring multiple experts to score and take the average can be used.

3.2.3. The overall hierarchy ranking and testing.

The process of determining the relative importance of all factors in a certain level to the overall objective by calculating their ranking weights is called the overall ranking of the hierarchy. The overall ranking of the hierarchy also requires a consistency check.

1) Calculate the weight of each scheme under the decision-making objective

The decision-making basis for target Z includes m factors such as A_1, A_2...A_m, and the weight values of each factor on target Z are a_1, a_2...a_m in turn; there are n alternatives in total, such as B_1, B_2...B_n, and the weight value of alternative B_j under factor A_i is b_{ji}; the weight value of alternative B_j under target Z is b_j, and the calculation equation is shown in (4):

$$b_j=a_1b_{j1}+a_2b_{j2}+\ldots+a_mb_{jm} \ (i=1, 2, \ldots m; j=1, 2, \ldots n) \quad (4)$$

2) Consistency test of overall ranking

Let the A consistency index of the hierarchical single ranking of the factors in the Bupper layer be CI_i, and the random consistency index be RI_i, then the consistency ratio of the overall hierarchical ranking is shown in equation (5):

$$CR=(a_1CI_1+a_2CI_2+\cdots+a_mCI_m)/ (a_1RI_1+a_2 RI_2+\cdots+a_mRI_m) \quad (5)$$

If CR<0.1, it was believed that the overall ranking of levels had passed the consistency test.

3.3. Application Examples

A clothing sales e-commerce company is looking to select a long-term logistics service provider, with options including three third-party courier companies: SF Express, STO Express, and ZTO Express. The company considers various factors when making its selection, including the cost-effectiveness, speed, and reliability of logistics services. Please assist the company in selecting an appropriate partner.

The above case is a typical multi-scheme comparison problem, which can be solved by applying AHP to implement a hierarchical analysis and decision-making that combines qualitative and quantitative analysis. The specific steps are as follows:

Step 1: Draw AHP diagram

The AHP diagram includes: the target layer Z, the criteria layer A, represented by A_1, A_2, A_3, A_4, and A_5, which indicate five influencing factors such as economic efficiency, speed, punctuality, reliability, and safety; and the scheme layer B, represented by B_1, B_2, and B_3, which indicate three alternative enterprises such as SF Express, STO Express, and ZTO Express. The AHP diagram is shown in Figure 1.

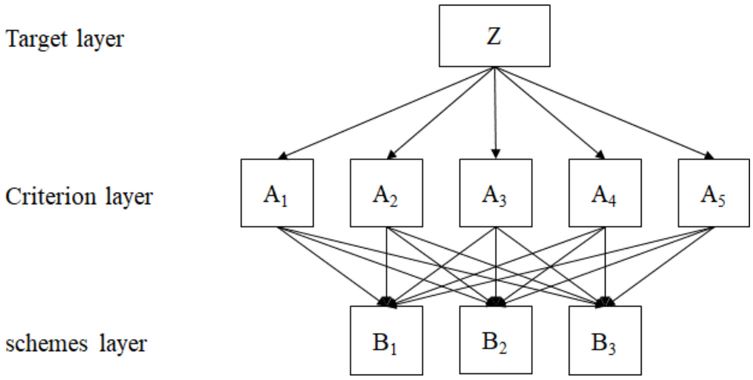

Figure 1: Analytic Hierarchy Process Diagram

Step 2: Calculate the single-level weights and rankings.

In this stage, it need to construct a pairwise comparison matrix for each influencing factor in the criteria layer, determine the impact weights of each factor on the final objective, and conduct a test.

Firstly, the relative importance of the criteria layer factors is compared pairwise, as shown in Table 5. The pairwise comparison matrix A is as follows:

Table 5: Pair Comparison Table of Criterion Layer

Z	A1	A2	A3	A4	A5
A1	1	1/2	4	3	3
A2	2	1	7	5	5
A3	1/4	1/7	1	1/2	1/3
A4	1/3	1/5	2	1	1
A5	1/3	1/5	3	1	1

Secondly, calculate the maximum characteristic root of matrix A and its corresponding eigenvector, which are λ_{max}=5.073 and ω_{ai}= {0.263, 0.475, 0.055, 0.099, 0.110}, respectively.

Next, calculate the consistency ratio. The matrix consistency index CI= (5.073-5)/ (5-1) =0.018. Looking up the random consistency index RI for a 5-order matrix, it is 1.12. Therefore: the random consistency ratio CR=0.018/1.12=0.016<0.1.

In conclusion, the pairwise comparison matrix A has passed the consistency check.

Step 3: Construct pairwise comparison matrices for each criterion and conduct tests.

In this stage, it need to construct pairwise comparison matrices for each criterion, determine the weight of each scheme under each criterion, and conduct tests. Since there are 5 influencing factors in the decision-making criteria layer and 3 alternative schemes in the lower layer, we need to conduct pairwise comparisons for the schemes under each influencing factor, calculate the weights, and determine the superiority and inferiority. Therefore, in this example, we need to construct 5 three-level pairwise comparison matrices as follows:

$$B_1=\begin{bmatrix}1 & 3 & 4\\ 1/3 & 1 & 3\\ 1/4 & 1/3 & 1\end{bmatrix}\quad B_2=\begin{bmatrix}1 & 5 & 7\\ 1/5 & 1 & 3\\ 1/7 & 1/3 & 1\end{bmatrix}\quad B_3=\begin{bmatrix}1 & 1/4 & 1/6\\ 4 & 1 & 1/2\\ 6 & 2 & 1\end{bmatrix}$$

$$B_4=\begin{bmatrix}1 & 1 & 4\\ 1 & 1 & 3\\ 1/4 & 1/3 & 1\end{bmatrix}\quad B_5=\begin{bmatrix}1 & 1/2 & 1/2\\ 2 & 1 & 2\\ 2 & 1/2 & 1\end{bmatrix}$$

Next, calculate the largest eigenvalue of the matrix λ_{b1}, …$\lambda_{b5}$and the corresponding eigenvector ω_{b1}, …ω_{b5}, and normalize the vector.

Finally, calculate the consistency index CI_{b1},…CI_{b5}, check the random consistency index of the third-order matrix, calculate the consistency ratio of each matrix CR_{b1},…CR_{b5}, and perform consistency testing.

The relevant settlement results are shown in the table 6:

Table 6: Summary of scheme layer weights

project	factorA_1	factorA_2	factorA_3	factorA_4	factorA_5
The weight of factor A_i is a_i	0.263	0.475	0.055	0.099	0.110
The weight of scheme 1 is b_{1i}	0.608	0.724	0.089	0.458	0.198
The weight of scheme 2 is b_{2i}	0.272	0.193	0.324	0.416	0.490
The weight of scheme 3 is b_{3i}	0.120	0.083	0.587	0.126	0.312
The largest eigenvalue of matrix B_i	3.074	3.066	3.009	3.009	3.054
Consistency index of matrix B_i	0.037	0.033	0.005	0.005	0.027
Random consistency index of matrix B_i	0.58	0.58	0.58	0.58	0.58
Consistency ratio of matrix B_i	0.064	0.057	0.008	0.008	0.046

In summary, the pairwise comparison matrices have passed the consistency check, and the weights of each scheme under different influencing factors have been obtained.

Step 4: Calculate the total ranking of the scheme and implement consistency testing.

Calculate the weight of the scheme under the target Z according to equation (4):

$$b_1=a_1b_{11}+a_2b_{12}+a_3b_{13}+a_4b_{14}+a_5b_{15}$$

$$=0.608*0.263+0.724*0.475+0.089*0.055+0.458*0.099+0.198*0.110=0.58$$

Similarly, it can be obtained $b_2=0.28$； $b_3=0.15$.

In summary, under the decision-making objective Z, the weight of the B-level plan is

$$\omega_{bj}=\{0.576,0.276,0.156\}.$$

It should be noted that the results of the overall ranking of the hierarchy also require consistency testing. According to equation (5), the consistency index of the overall ranking is calculated as follows:

$$CR=(a_1CI_1+a_2CI_2+\cdots+a_mCI_m)/(a_1RI_1+a_2RI_2+\cdots+a_mRI_m)$$

$$=(0.263*0.037+0.475*0.033+0.055*0.005+0.099*0.005+0.110*0.027)/0.58$$

$$=0.05<0.1$$

Therefore, the overall ranking of the scheme level has passed the consistency test. B_1indicating that SF Express is the optimal logistics partner for the enterprise.

4. Conclusions

Enterprises in the supply chain can concentrate their advantageous resources and leverage their core competitiveness to achieve a win-win cooperation. Therefore, enterprises should attach importance to the construction and management of partnerships. The evaluation and selection of partners by enterprises are influenced by various factors such as market environment, their own development status, and future development strategies. It is necessary to carefully determine the evaluation index system for partners and reasonably determine the evaluation and selection methods. AHP is a typical method that combines qualitative and quantitative analysis, with clear steps and easy to grasp. To some extent, it overcomes the strong subjectivity of qualitative analysis and can be combined with expert scoring methods, fuzzy comprehensive evaluation, linear algebra matrix properties, and other knowledge points to form a coherent and comprehensive knowledge system.

When learning and applying AHP, the following points should be noted: first, understanding the basic idea of AHP; second, mastering the implementation steps of the method; third, selecting evaluation indicators reasonably; fourth, constructing a reasonable pairwise comparison matrix and mastering the calculation methods of the characteristic roots and characteristic vectors of the pairwise comparison matrix, and being able to test the consistency of the matrix; fifth, mastering the calculation method of the overall hierarchical sorting and being able to conduct overall consistency testing.

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