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Risk evaluation of automobile green supply chain under dual carbon target

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Abstract: *Under the dual-carbon target, the importance of the automotive supply chain is becoming increasingly prominent. As a key link to promote the green transformation of the automotive industry, the supply chain is not only related to the cost control and operational efficiency of enterprises, but also the core driving force to achieve energy conservation and emission reduction and promote sustainable development. However, the automobile green supply chain involves many parties, and the stability of the supply chain is affected by the potential risks of each link. Based on literature research, this paper identifies 3 first-level evaluation indicators and 16 second-level evaluation indicators of automotive green supply chain, and establishes a risk evaluation index system by using analytic hierarchy process. In view of the high risk factors in the results, improvement suggestions are put forward, so as to effectively prevent and control risks. This paper aims to provide theoretical methods and strategy support for the risk management of automotive green supply chain, and promote the sustainable development of China's automotive green supply chain.*

Keywords: *automobile green supply chain; Risk assessment; Analytic hierarchy process*

1. Introduction

On September 22, 2021, the Guiding Opinions of the CPC Central Committee and The State Council on the Work of Carbon Peaking and carbon Neutrality were released, establishing a strategic blueprint, policy framework and implementation guarantee for achieving this goal. The annual emission of pollutants from motor vehicles in China reaches 50 million tons, highlighting the severe air pollution and bringing opportunities for the innovation of the automotive green supply chain. Facing the urgent tasks and transformation opportunities of environmental protection, it is necessary to increase the efforts of clean production and green manufacturing, research and development of cutting-edge technologies, attach importance to environmentally friendly development, and jointly build a sustainable future [1]. In February 2021, The State Council issued the Guiding Opinions on Accelerating the Establishment and Improvement of a Green, low-carbon and Circular Development economic System, which clearly points out that a green, low-carbon and circular development economic system needs to be established and improved [2]. Automobile green supply chain involves many parties. The development of automobile green supply chain is faced with many risks from external factors, internal factors or intermediate factors. Many scholars have studied the risks of automobile green supply chain. Wu Chunyou and others pointed out that for different industries and enterprises, the path to build and implement green supply chain management is different. Each enterprise shall adopt corresponding strategies according to its actual situation, aiming to achieve the dual goals of environmental protection and economic benefits simultaneously [3]. On the basis of in-depth research on green supply chain management in the automotive industry, Wang Zhihong et al. used analytic hierarchy process to build a set of risk assessment system for automotive green supply chain. Subsequently, they used the fuzzy comprehensive evaluation method to evaluate the risks in the system in order to implement effective risk prevention and control measures [4]. Ding Weidong et al. proposed a method combining reliability evaluation matrix and fuzzy analysis to conduct a comprehensive and systematic assessment of risk factors, and put forward risk prevention strategies accordingly. Some scholars have pointed out that there are significant threats and challenges in the operation of the green supply chain model [5]. Fu Xingfang et al. believe that green supply chain management has become a new strategy for the sustainable survival of various industries, and its core concept is to fully consider environmental factors, implement circular production management, and make full use of network technology as the basic means to achieve green supply chain management [6].

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Throughout the existing literature, it can be found that the research on green supply chain risk management has achieved relatively rich theoretical and empirical results, but there are still some areas that need further research. First, the standard and method of supply chain risk identification urgently need to be established and improved. Under the background of dual carbon and the current research status of automotive green supply chain, it is particularly important to identify and evaluate the risks of automotive green supply chain. Therefore, this paper uses analytic hierarchy process to analyze the risk of automobile green supply chain, comprehensively evaluates the risk indicators of automobile green supply chain, and obtains the high risk indicators affecting automobile green supply chain.

The above scholars made an in-depth analysis of the obtained results and proposed strategies to avoid and reduce risks, aiming to provide a solid scientific basis for accelerating the safe implementation of the green supply chain, so as to ensure that the measures taken can effectively prevent potential risks [7].

2. Construction of analytic hierarchy process evaluation model

2.1 Introduction to Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision aid tool that integrates qualitative and quantitative analysis. It was proposed by Thomas Setti in the 1970s to solve complex decision problems. With its practicality and efficiency, it is widely used worldwide, covering the fields of economy, management, military, transportation and so on. In the study of social and economic management, AHP provides an efficient modeling approach in the face of complex systems and their difficult to quantify and subjective factors. In this method, the decision problem is regarded as a system, the optimization criteria are refined into criterion layer, and then decomposed into sub-criterion layer, the performance of alternative schemes on each sub-criterion is evaluated, and the optimal decision scheme is determined through hierarchical analysis [8].

2.2 Principles for selecting risk assessment indicators

The risk assessment of automobile green supply chain depends on a set of perfect risk evaluation index system. In building this system, we must adhere to the following core principles:

(1) Scientific principle: It focuses on the close combination of theory and practice. In the process of establishing the risk assessment index system, it must be firmly established on the basis of scientific theory to ensure that the logical structure of the system is strict and rational. In addition, it is necessary to provide objective and accurate data support, and strive to minimize the interference of subjective factors to ensure the accuracy of evaluation results [9].

(2) Operability principle: It requires quantitative processing of qualitative indicators through scientific mathematical conversion means, while quantitative indicators must be able to directly and clearly reflect the changing status and trend of risks. This approach helps us to grasp and evaluate the actual situation of risk more accurately, so as to improve the pertinence and effectiveness of risk management.

(3) Integrity principle: In the risk management system, each subsystem is closely linked to form a logical and unified whole. Therefore, after the establishment of the indicator system, we need to carefully examine these indicators to ensure that they can fully and accurately reflect the evaluation objectives, so as to ensure the integrity and systematism of the indicator system.

(4) The principle of hierarchy: the risk management system can be further subdivided into multiple sub-systems, which show a clear hierarchical structure. When constructing an indicator system, we must ensure that there is no causal relationship between indicators in the same hierarchy and that they remain independent of each other. Doing so helps us to shed more light on the hierarchical and structural features of risk management.

2.3 Establishment of hierarchical analysis model

With reference to the risk indicators mentioned in relevant literature and combined with the characteristics of the automotive green supply chain, the risk factors of the green automobile supply chain are comprehensively summarized and analyzed from the perspectives of 16 indicators including external risk, internal risk and intermediate risk as follows:

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Based on the above analysis, this paper aims to evaluate the risks of automotive green supply chain [10], and the three first-level indicators identified are: B1 external risk and B2 internal risk. B3 Intermediate risk. Next, the secondary indicators are classified as follows: external risks include natural risks (B11), policy risks (B12), economic risks (B13), social risks (B14) and market risks (B15); Internal risks include green R&D risk (B21), green procurement risk (B22), green production risk (B23), green logistics risk (B24), green marketing risk (B25), green recovery risk (B26) and financial risk (B27). Intermediate risks include cooperation risk (B31), supplier risk (B32), distributor risk (B33) and information risk (B34). Based on the above three clearly defined aspects and 16 specific impact indicators, we have built a scientific and reasonable green automobile supply chain risk assessment index system. For details, please refer to Table 1.

Table 1: Green automobile supply chain risk index evaluation system

Target layer	Criterion layer	Index level
Green automobile supply chain risk assessment system A	External risk B1	Natural risk B11
		Policy risk B12
		Economic risk B13
		Social risk B14
		Market risk B15
	Internal risk B2	Green R&D risk B21
		Green procurement risk B22
		Green production risk B23
		Green logistics risk B24
		Green marketing Risk B25
		Green recycling risk B26
		Financial risk B27
	Intermediate risk B3	Cooperation risk B31
		Supplier risk B32
		Distributor risk B33
		Information risk B34

3. Analytic hierarchy process evaluation model

3.1 Construct judgment matrix

In order to compare the importance of different criteria in supplier evaluation and understand the specific performance of risk at each indicator level under a certain criterion, we need to qualitatively describe the advantages and disadvantages of these factors and organize these descriptions into a judgment matrix. However, the evaluation of elements in a judgment matrix is often both difficult and subjective. In order to reduce subjectivity as much as possible and improve the objectivity of the evaluation, we can use the way of sending questionnaires to several experts. The specific approach is to build a pair of comparison matrix, by comparing the factors in the same level one by one, to build a judgment matrix. Then, we calculate the weight of each factor to analyze the importance of the factors at the next level to the factors at the previous level. When calculating the weight value, it is necessary to use the importance scale as the basis, and these scales constitute the measurement criteria of the judgment matrix [11], as shown in Table 2.

Table 2: Scale table

Factor i and factor j	Quantized value
Equally important	1
Slightly important	3
Stronger importance	5
Strongly important	7
vital	9
The median of two adjacent judgments	2,4,6,8

Suppose that the target layer is A, the criterion layer is B, and the sub-criterion layer is C, and the judgment matrix of each factor can be listed as follows

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$$A=\begin{pmatrix} 1 & 0.25 & 2 \\ 4 & 1 & 4 \\ 0.5 & 0.25 & 1 \end{pmatrix} \quad B1=\begin{pmatrix} 1 & 0.25 & 0.2 & 0.33 & 0.25 \\ 4 & 1 & 0.33 & 0.5 & 0.25 \\ 5 & 3 & 1 & 4 & 3 \\ 3 & 2 & 0.25 & 1 & 0.5 \\ 4 & 4 & 0.33 & 2 & 1 \end{pmatrix}$$

$$B2=\begin{pmatrix} 1 & 3 & 0.33 & 2 & 0.5 & 4 & 0.2 \\ 0.2 & 1 & 0.2 & 0.5 & 0.25 & 2 & 0.14 \\ 3 & 5 & 1 & 4 & 2 & 6 & 0.33 \\ 0.5 & 2 & 0.25 & 1 & 0.33 & 3 & 0.25 \\ 2 & 4 & 0.25 & 3 & 1 & 5 & 0.33 \\ 0.25 & 0.5 & 0.17 & 0.33 & 0.2 & 1 & 0.14 \\ 5 & 7 & 3 & 4 & 3 & 7 & 1 \end{pmatrix} \quad B3=\begin{pmatrix} 1 & 0.33 & 3 & 0.25 \\ 3 & 1 & 4 & 0.33 \\ 0.33 & 0.25 & 1 & 0.2 \\ 4 & 3 & 5 & 1 \end{pmatrix}$$

3.2 Calculate the weight of each factor

① The standard judgment matrix is obtained by the integration of column vectors [12].

$$A=\begin{pmatrix} 0.18 & 0.17 & 0.29 \\ 0.73 & 0.67 & 0.57 \\ 0.18 & 0.17 & 0.14 \end{pmatrix} \quad B1=\begin{pmatrix} 0.06 & 0.02 & 0.09 & 0.04 & 0.05 \\ 0.24 & 0.10 & 0.16 & 0.06 & 0.05 \\ 0.29 & 0.29 & 0.47 & 0.51 & 0.6 \\ 0.18 & 0.20 & 0.19 & 0.13 & 0.1 \\ 0.24 & 0.39 & 0.16 & 0.26 & 0.2 \end{pmatrix}$$

$$B2=\begin{pmatrix} 0.08 & 0.13 & 0.06 & 0.13 & 0.07 & 0.14 & 0.08 \\ 0.03 & 0.04 & 0.04 & 0.03 & 0.03 & 0.07 & 0.06 \\ 0.25 & 0.22 & 0.18 & 0.27 & 0.27 & 0.21 & 0.14 \\ 0.04 & 0.09 & 0.06 & 0.07 & 0.05 & 0.11 & 0.10 \\ 0.17 & 0.18 & 0.09 & 0.2 & 0.14 & 0.18 & 0.14 \\ 0.02 & 0.02 & 0.03 & 0.02 & 0.03 & 0.04 & 0.06 \\ 0.41 & 0.31 & 0.55 & 0.27 & 0.41 & 0.25 & 0.42 \end{pmatrix} \quad B3=\begin{pmatrix} 0.12 & 0.07 & 0.23 & 0.14 \\ 0.36 & 0.22 & 0.31 & 0.19 \\ 0.04 & 0.05 & 0.08 & 0.11 \\ 0.48 & 0.66 & 0.38 & 0.56 \end{pmatrix}$$

② The line sum is normalized, and the resulting value is W.

$$A(w)=\begin{pmatrix} 0.21 \\ 0.66 \\ 0.16 \end{pmatrix} \quad B1(w)=\begin{pmatrix} 0.05 \\ 0.12 \\ 0.43 \\ 0.16 \\ 0.25 \end{pmatrix} \quad B2(w)=\begin{pmatrix} 0.1 \\ 0.04 \\ 0.22 \\ 0.07 \\ 0.16 \\ 0.03 \\ 0.37 \end{pmatrix} \quad B3(w)=\begin{pmatrix} 0.14 \\ 0.27 \\ 0.07 \\ 0.52 \end{pmatrix}$$

③ Calculate the feature root and get

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AW= $\begin{pmatrix} 1 & 0.25 & 2 \\ 4 & 1 & 4 \\ 0.5 & 0.25 & 1 \end{pmatrix}\begin{pmatrix} 0.21 \\ 0.66 \\ 0.16 \end{pmatrix} = \begin{pmatrix} 0.695 \\ 2.14 \\ 0.43 \end{pmatrix}$ In a similar way, B1W= $\begin{pmatrix} 0.28 \\ 0.62 \\ 2.45 \\ 0.80 \\ 1.41 \end{pmatrix}$ B2W= $\begin{pmatrix} 0.71 \\ 0.30 \\ 1.62 \\ 0.49 \\ 1.11 \\ 0.22 \\ 2.78 \end{pmatrix}$ B3W= $\begin{pmatrix} 0.57 \\ 1.14 \\ 0.29 \\ 2.24 \end{pmatrix}$

④ Calculate the maximum eigenvalue

$$\lambda max= \sum_{i=1}^{n} \frac{[AW]i}{nWi}$$

A(λ_{max})=3.08 In a similar way,B1(λ_{max})=5.42 B2(λ_{max})=7.25,B3(λ_{max})=4.18

3.3 Performing a consistency check

①Calculate the consistency index CI(CI= $\frac{\lambda_{max} - 1}{n-1}$)

A(CI)=0.04,B1(CI)= 0.105, B2(CI)=0.04,B3(CI)=0.06

②Calculate the consistency ratioCR(CR= $\frac{CI}{RI}$),RI Refers to the freedom index, the revised value RI is shown in the table 3.

Table 3: Revised RI data table

Dimension (m)	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.96	1.12	1.24	1.32	1.41	1.45

Table 4 is obtained by synthesizing the above data: the closer CR is to 0, the higher the consistency of the judgment matrix. According to Table 4, it can be judged that the CR values of matrix A, B1, B2 and B3 are all less than 0.1, which is basically consistent.

Table 4: Values of each matrix

	Matrix A	Matrix B1	Matrix B2	Matrix B3
λ_{max}	3.08	5.42	7.25	4.18
CI	0.04	0.105	0.04	0.06
CR	0.07	0.094	0.03	0.07

3.4 Result Analysis

The weight calculation results are shown in Table 5. Through the analysis of the calculated weight values of indicators at all levels, it can be clearly observed that the proportion of internal risk in the criterion layer is the largest, which highlights the core position of internal risk in the automotive green supply chain risk system. After that, the ranking of criterion layer weight is: internal risk, intermediate risk and external risk. Further refined to the index level, the external risk covers five specific indicators, and the weight of these indicators is also different. The weights are economic risk B13, market risk B15, social risk B14, policy risk B12 and natural risk B11. There are seven internal risks, of which financial risk B32 has the greatest weight, followed by production risk B23, and recovery risk B31 has the least weight. Among intermediate risks, the weight of information risk B36 is more important than that of

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distributor B35, and the weight of supplier risk B34 is more important than that of cooperation risk B33.

Table 5: Risk evaluation weight system of automotive green supply chain

Criterion layer	weight	Index level	weight
External risks(B1)	0.21	Natural Risk(B11)	0.05
		Policy Risk (B12)	0.12
		Economic Risk(B13)	0.43
		Social Risk (B14)	0.16
		Market Risk (B15)	0.25
Internal Risk (B2)	0.66	R&d Risk (B21)	0.10
		Procurement Risk (B22)	0.04
		Production Risk(B23)	0.22
		Logistics Risk (B24)	0.07
		Marketing Risk (B25)	0.16
		Recovery Risk (B31)	0.03
		Financial Risk (B32)	0.37
Intermediate risk (B3)	0.43	Cooperation Risk(B33)	0.14
		Supplier Risk (B34)	0.27
		Distributor Risk (B35)	0.07
		Information Risk (B36)	0.52

4. Conclusions and Suggestions

4.1 Conclusion

In the risk assessment of automotive green supply chain studied in this paper, internal risks account for the largest proportion, accounting for 0.66, followed by intermediate risks, accounting for 0.43, and then external risks, accounting for 0.21. Among the three risk levels, the internal risk needs the attention of all stakeholders in the automotive supply chain, and the financial risk and production risk are the highest among the internal risks. Recycling risks and procurement risks are minimal. Financial risk is the most important of internal risks

All stakeholders of the green automobile supply chain should pay attention to it. Protect financial security, avoid risks, and affect the normal operation of the green car supply chain. The weights of each intermediate risk index are information risk, supplier risk, cooperation risk and distributor risk from high to low. Information risk in today's society needs special attention, once the information is inaccurate or information leakage will cause a lot of unnecessary trouble, bring danger to the entire automobile supply chain, information risk also needs to be attached great importance. In the three perspectives studied in this paper, the external risk weight accounts for the smallest proportion, and economic risk and social risk account for the largest proportion of external risks through analytic hierarchy process, followed by policy risk and natural risk. When the external economic situation is relatively severe, the green automobile supply chain will also be affected by the external economy, and the heavy damage to the external economic risks will endanger the safe operation of the green automobile supply chain to a large extent, so it is necessary to do a good job in the automobile supply chain emergency protection mechanism and measures.

4.2 Suggestions

4.2.1 Suggestions for External risk Optimization

In the context of dual-carbon, the green automobile supply chain is facing many risks from the economy, society, policy, and nature. In order to effectively deal with these risks, the following are some specific measures.

The company implements financial risk response measures. First, the green automobile supply chain should improve cost control and efficiency. Second, it should establish diversified financing channels. Third, it should strengthen market risk prediction and response. The company implements social risk response measures. First, the green automobile supply chain should strengthen the health and safety of employees. Second, it should establish a harmonious supply chain partnership. Third, it should strengthen social communication and information disclosure. The company implements policy risk response measures. First, the green automobile supply chain should pay close attention to policy developments. Second, it should ensure compliance management. Third, it should actively participate in policy formulation. The company implements natural risk response measures. First, the green automobile supply chain should strengthen environmental monitoring and early warning. Second, it should make emergency plans. Third, it should improve supply chain resilience. To sum up, the green automobile supply chain should comprehensively consider economic, social, policy, and natural risks in the context of dual-carbon, and take corresponding countermeasures to reduce risks. The implementation of these measures will help promote the sustainable development of the green vehicle supply chain.

4.2.2 Suggestions for internal risk optimization

The company implements financial risk response measures. First, the company should establish diversified financing channels. Second, the company should strengthen cost control. Third, the company should establish a financial risk early warning mechanism. Fourth, the company should improve the capital structure. The company implements production risk response measures. First, the company should adopt advanced green production technology. Second, the company should focus on quality management and control. Third, the company should carry out supply chain coordination, establish close cooperative relations with suppliers, and jointly deal with production risks. Fourth, the company should formulate emergency plans to prevent and respond to possible production risks. The company implements marketing risk response measures. First, the company should strengthen the research and forecast of market trends. Second, the company should establish the concept of green marketing. Third, the company should develop diversified marketing channels. Fourth, the company should strengthen customer relationship management to improve customer satisfaction and loyalty. The company implements development risk response measures. First, the company should increase investment in research and development to improve research and development capabilities and levels. Second, the company should establish technical cooperation relations with universities and scientific research institutions to carry out technical exchanges and cooperative research and development. Third, the company should strengthen the awareness of intellectual property protection and improve the intellectual property protection system.

4.2.3 Suggestions for intermediate risk optimization

The company implements information risk response measures. First, the company should enhance information sharing. Second, the company should improve its data analysis capabilities. Third, the company should establish an early warning mechanism and a risk early warning model to forecast and warn of possible risks based on historical data and real-time information, allowing for proactive measures to prevent them. The company implements supplier risk response measures. First, the company should rigorously select suppliers. In addition to considering price, quality, and other factors, it should also focus on their environmental protection capabilities, carbon emission reduction measures, and sustainable development abilities, ensuring that suppliers meet the requirements of a green supply chain. Second, the company should establish a supplier evaluation system. Third, the company should strengthen cooperation with suppliers. The company implements cooperative risk response measures. First, the company should define the objectives of cooperation. Second, the company should strengthen communication and coordination. Third, the company should establish a risk-sharing mechanism. The company implements distributor risk response measures. First, the company should strengthen distributor training. Second, the company should establish a distributor evaluation system. Third, the company should optimize distribution channels.

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