

Identification of Supply Chain Disruption Risks and Strategies in the Electric Vehicle Industry Based on Fuzzy Analytic Hierarchy Process (FAHP)

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Abstract. In recent years, the electric vehicle industry has witnessed unprecedented development opportunities. However, with rapid technological iterations and fluctuating market demands, the vulnerability and complexity of the electric vehicle supply chain have significantly increased the potential risk of supply chain disruptions. Against this backdrop, this study adopts the Fuzzy Analytic Hierarchy Process (FAHP) to systematically analyze the risks of supply chain disruptions in the electric vehicle industry. By constructing a judgment matrix through industry data surveys and expert scoring, and conducting consistency checks, the weights of various risk factors are determined. The study finds that technological quality risk, demand forecast deviation, and logistics disruption are the primary factors affecting the stability of the electric vehicle supply chain. Additionally, although the probability is relatively low, the potential destructiveness of exogenous risks is equally undeniable. Accordingly, the study will propose targeted management strategies to enhance the resilience of the new energy vehicle supply chain at both the enterprise and industry levels in response to these risks.

Keywords: Supply Chain; FAHP; EV Industry.

1. Introduction

The new energy vehicle (NEV) industry, as one of the modern high-tech industries, is becoming a crucial direction for the development of the global automotive industry. In recent years, driven by macroeconomic conditions and policy incentives, the new energy vehicle market has witnessed unprecedented growth opportunities. Global automobile manufacturers are increasing their investments in the NEV sector, developing new technologies, expanding production capacity.

With the transition of electric vehicles into the mainstream consumer market, the industrial supply chain landscape is undergoing significant changes. Compared to the traditional automotive industry, the rapid iteration of technology and constant changes in market demand have significantly increased the vulnerability and complexity of the EV supply chain, thereby elevating the potential risk of supply chain disruptions. Against this backdrop, this paper aims to systematically study the risks of supply chain disruptions in the NEV industry, identify and assess internal and external risk factors, and propose targeted management strategies.

In recent years, supply chain risk management has increasingly become a crucial point in the field of supply chain management. Especially following the global pandemic, supply chain risks have garnered significant attention. According to current literature, the supply chain risk management process comprises three main components: risk identification, risk assessment, and risk control. For risk assessment, scholars commonly use methods such as the Analytic Hierarchy Process (AHP), Bayesian Network (BN) techniques, and fuzzy evaluation methods to pursue objective and accurate risk quantification. For instance, Mohamed et al. combined the neutral AHP and TOPSIS techniques to address information uncertainty, fuzziness, and inconsistency, resulting in more accurate and objective quantification of supply chain risks [1]. However, there is still no universally accepted and clear definition of supply chain disruption risk in risk assessment. This paper adopts the relatively comprehensive and reasonable definition proposed by Guo Xi et al., which defines supply chain disruption risk as the sudden occurrence of unexpected events leading to significant deviations in

supply quantity, customer demand, cost, or quality from the predetermined management objectives of the supply chain [2].

Simultaneously, there are also differences in the classification methods used by the academic community regarding supply chain disruption risks. From the supply chain process perspective, some scholars classify it into supply disruption, production disruption, and demand disruption. From the impact perspective, common classification methods divide supply chain disruptions into two types: one with a relatively high occurrence probability, short duration, low impact, and easy to prevent and control; and another with a low occurrence probability, long duration, high impact, and difficult to prevent and control [3]. These classification methods focus on different research content and methods; hence, this paper will adopt the internal-external cause analysis method to construct the theoretical framework based on the research theme.

In recent years, scholars have also conducted in-depth studies on supply chain risks and management strategies in the new energy vehicle industry. Song Yang et al. focused on the issue of anti-disruption strategies for supplier inventory management in the NEV supply chain under uncertain environments [4]. Yang Yang et al. introduced the SCOR model to identify risks from the basic stages of the supply chain and constructed a corresponding risk evaluation index system [5]. Huang Yongshan identified various factors leading to supply chain disruptions by examining cases of temporary production stoppages in Chinese NEV enterprises due to supply chain disruptions [6].

However, there is still a lack of systematic frameworks, qualitative and quantitative handling of various risk factors, and identification of risk characteristics for the entire industry supply chain in the context of supply chain disruption risks in the NEV industry. Addressing these gaps, this study innovatively adopts the fuzzy Analytic Hierarchy Process (AHP) based on the characteristics of the NEV supply chain. It establishes a hierarchical model including the goal layer, general criteria layer, first-level sub-criteria layer, second-level sub-criteria layer, and solution layer. By constructing judgment matrices for elements at each level through expert scoring and industry trend surveys, conducting consistency tests, and ranking the weights of risk factors, the study finally proposes strategic recommendations based on the risk assessment.

2. Methodology

2.1. Introduction to Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

Research employs the Analytic Hierarchy Process (AHP) to evaluate the disruption risks within the electric vehicle (EV) supply chain. AHP is a decision analysis method that combines both qualitative and quantitative approaches. It breaks down complex decision problems into a hierarchical structure and systematically analyzes and makes decisions based on the relative importance judgments and consistency checks.

Disruption risks in the EV supply chain exhibit uncertainty and multi-objective characteristics. AHP is suitable and flexible for identifying such issues by integrating qualitative and quantitative factors, thereby providing a scientific basis for supply chain management processes. However, traditional AHP has certain limitations when addressing fuzziness and uncertainty, which may lead to unstable decision outcomes under such conditions.

To address these limitations, this study proposes an assessment method for EV supply chain risks based on the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). Fuzzy AHP extends traditional AHP by introducing fuzzy set theory, utilizing fuzzy membership functions to handle the ambiguity and uncertainty in judgments, thereby enhancing the stability and reliability of decision results. Scholars like Faisal Aqlan and Goran have combined this method with other analytical techniques in their empirical research on supply chains. This paper applies this model specifically to evaluate risk factors in the EV supply chain [7, 8].

2.2. The indicator system framework of EV industry supply chain

First, to achieve the hierarchical decomposition of the AHP model, this research thoroughly analyzes relevant literature and combines this with recent typical risk events in global EV supply chains. From the perspective of internal and external variables of the supply chain [9, 10], a comprehensive and systematic risk indicator system for the EV supply chain will be constructed.

The risk indicator system is divided into two major categories: external risks and internal risks. External risks include factors from the external environment of the supply chain, such as natural disasters, economic fluctuations, and political and social factors. Internal risks refer to risks that may arise within the supply chain stages and processes, encompassing four dimensions: supply risks, demand risks, logistics risks, and information risks. The specific indicator system framework is shown in the following framework diagram as shown in Figure 1.

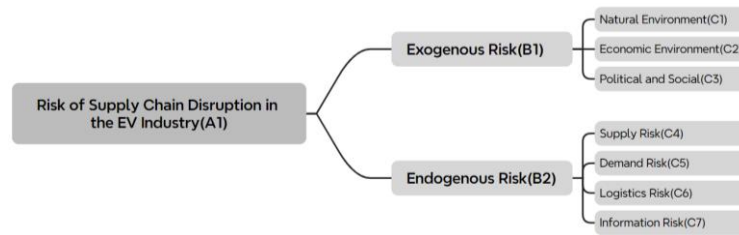


Figure 1. The indicator system framework of EV industry supply chain

From the supply risk dimension, this study mainly considers two aspects: supplier capacity inadequacies and technical quality risks. Supplier capacity inadequacies refer to the inability to meet EV production demands due to limitations in the supplier's production capacity, equipment failures, or raw material supply issues, causing supply chain disruptions over a certain period. Technical quality risks refer to the failure of the parts and technology provided by suppliers to meet the performance and safety requirements of EV production.

From the demand risk dimension, the focus is on two key aspects: demand forecast deviation and market competition risks. Demand forecast deviation risks refer to the risks of production shortages due to inaccurate predictions of future market demand. Market competition risks involve issues such as price wars and market share battles, particularly the challenge of competing with the traditional automotive market for market share, which affects the stability of the supply chain.

From the logistics risk dimension, the primary focus is on transportation disruption risks. Transportation disruption risks involve the risk of product transportation interruptions or delays due to unforeseen or uncontrollable factors during the logistics process, directly impacting delivery times, costs, and quality.

Table 1. Sub-criteria Branch Details Table

C: Sub-criteriaI	C: Sub-criteriaII
Natural Environment (C1)	Natural Disasters
Economic Environment (C2)	Economic Fluctuations
Political and Social (C3)	Policy Orientation
Supply Risk (C4)	Supplier Capacity Insufficiency
	Technical Quality Risk
Demand Risk (C5)	Demand Forecast Deviation
	Market Competition
Logistics Risk (C6)	Transportation Interruption
	Information Delay
Information Risk (C7)	Information Asymmetry

The information risk dimension is divided into information delay and information asymmetry risks. Information delay risks refer to the untimely transmission of information between upstream and downstream enterprises, leading to delayed production adjustments and inaccurate inventory

management. Information asymmetry risks refer to the incomplete exchange of information between supply chain stages, resulting in erroneous decisions in Table 1.

2.3. Fuzzy Analytic Hierarchy Process (FAHP) Application

In this study, the construction of the judgment matrix combines industry data surveys and expert scoring methods. Through extensive industry data collection, various data related to EV supply chain disruption risks are gathered, including the probability of risk factors such as market demand fluctuations, supplier capacity, and logistics situations in recent years. Combined with expert analysis in the EV supply chain industry, the importance of each indicator is scored [11]. The scoring method uses the fuzzy AHP scale to compare the importance of each indicator pairwise, with specific scale values provided in Table 2. If element i is judged to be a_{ij} times more important than element j , then element j is judged to be $1/a_{ij}$ times more important than element i .

Table 2. Fuzzy Hierarchical Analysis Scale and Meaning

Scale number	Meaning
1	Factor i has the same importance as factor j .
3	Factor i has slightly more importance than factor j .
5	Factor i has significantly more importance than factor j .
7	Factor i has strongly more importance than factor j .
9	Factor i has absolutely more importance than factor j .
2, 4, 6, 8	Intermediate values between adjacent judgments.

The indicators' weights are calculated using the arithmetic mean method for the matrices at each level: A-B, B-C1, and C2-C2. The calculation formula is as follows equation (1):

$$w_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{k=1}^n a_{kj}}, \quad (i = 1, 2, \dots, n) \quad (1)$$

For the initial judgment matrix of the first sub-criterion level (C1) to the overall criterion level (B), normalization is performed to obtain the single-layer weight W .

Table 3. Initial Judgment Matrix for B-C1 Layer

Sub-criteria	C1	C2	C3	C4	C5	C6	C7
C1	1	1/3	1/5	1/7	1/7	1/7	1/5
C2	3	1	1	1/5	1/5	1/3	1/3
C3	5	1	1	1/5	1/3	1/3	1/3
C4	7	5	5	1	3	5	5
C5	7	5	3	1/3	1	1	3
C6	7	3	3	1/5	1	1	5
C7	5	3	3	1/5	1/3	1/5	1

Table 4. Normalized Judgment Matrix for B-C1 Layer

Sub-criteria	C1	C2	C3	C4	C5	C6	C7	W
C1	0.03	0.02	0.01	0.06	0.02	0.02	0.01	0.0253
C2	0.09	0.05	0.06	0.09	0.03	0.04	0.02	0.0553
C3	0.14	0.05	0.06	0.09	0.06	0.04	0.02	0.0666
C4	0.20	0.27	0.31	0.44	0.50	0.62	0.34	0.3829
C5	0.20	0.27	0.19	0.15	0.17	0.12	0.20	0.1853
C6	0.20	0.16	0.19	0.09	0.17	0.12	0.34	0.1806
C7	0.14	0.16	0.19	0.09	0.06	0.02	0.07	0.1039

Table 5. Matrix for A-B, C4-C*, C5-C*, C7-C* Layers

Criteria	Relative Weight
B1	0.25
B2	0.75
C41	0.17
C42	0.83
C51	0.75
C52	0.25
C71	0.5
C72	0.5

To verify the logical consistency in the construction of the judgment matrix, a consistency test is conducted on the original matrix and the generated weights in the equation (2) to (4).

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{(AW)_i}{W_i} \quad (2)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

The maximum eigenvalue λ_{\max} , consistency index CI , and consistency ratio CR are calculated. For the B-C1 matrix, the maximum eigenvalue is 7.65, the consistency index is 0.108, and the consistency ratio is $0.824 < 0.1$, indicating that the consistency test is passed. Other judgment matrices also pass the consistency test in the Table 2 to 5.

2.4. Result

To derive the final weights of each scheme relative to the highest level goal, the weight vectors of each layer are multiplied according to the hierarchical structure. The criterion level weight vector is W_1 , the first sub-criterion level weight vector is W_2 , and the second sub-criterion level weight matrix is W_3 . The final weight vector W can be expressed as the equation (5):

$$W = W_1 \times (W_2 \times W_3) \quad (5)$$

The resulting weight vector provides a comprehensive assessment of the relative importance of each risk factor within the EV supply chain, allowing for informed decision-making and risk management strategies (Table 5 and Table 6).

Table 6. Final Results of Fuzzy Analytic Hierarchy Process for Electric Vehicle Supply Chain Disruption Risks

Objective	B: Overall Criteria	C: Sub-criterial	C: Sub-criterialII	Weight	Sequence	
Risk of Supply Chain Disruption in the Electric Vehicle Industry	Exogenous Risk	Natural Environment	Natural Disasters	0.006	10	
		Economic Environment	Economic Fluctuations	0.014	9	
		Political and Socia	Policy Orientation	0.017	8	
	Endogenous Risk	Supply Risk	Supplier Capacity Insufficiency		0.048	4
			Technical Quality Risk		0.239	1
		Demand Risk	Demand Forecast Deviation		0.104	2
			Market Competition		0.035	7
		Logistics Risk	Transportation Interruption		0.135	3
			Information Delay		0.039	5
		Information Risk	Information Asymmetry		0.039	5

3. Conclusion

Based on the results of the Fuzzy Analytic Hierarchy Process (FAHP), this study identifies the following characteristics of supply chain disruption risks in the EV industry:

As a high-tech industry, the stability and continuity of the supply chain for electric vehicles are heavily reliant on technical quality. The rapid pace of technological iteration in electric vehicles imposes high demands on technical quality. Failure to meet these demands can directly impact product performance, leading to widespread product recalls and repairs, severely disrupting supply chain operations.

The EV market is highly influenced by policies, consumer preferences, and market trends etc., resulting in significant demand fluctuations. If there is a deviation in demand forecasting, it will lead to inventory overstock or shortages in the supply chain, causing production schedule adjustments, supplier delivery delays, and a series of other issues. Additionally, compared to traditional automotive manufacturing, NEV production involves more countries and regions in supply chain coordination. The smoothness of logistics directly affects the timely supply of raw materials and components, as well as the market launch of finished vehicles. Therefore, enhancing the resilience of the NEV supply chain relies heavily on both the demand and logistics aspects.

Although external factors have a relatively low probability of occurrence and thus a lower ranking in terms of weight, their potential impact cannot be ignored. Sudden environmental changes can greatly affect the stability of the supply chain, leading to prolonged disruptions. For instance, unexpected natural disasters or global economic fluctuations can severely disrupt the supply chain, resulting in long-term interruptions and recovery periods.

Based on the above characteristics, this study suggests two approaches to reduce the impact of risk factors on the entire supply chain: lowering the probability of risk occurrence and mitigating the potential impact of risks. In terms of technical quality control, the NEV supply chain should improve technological development and quality control mechanisms, employing advanced quality management tools and methods to ensure the stability and reliability of technical quality. NEV companies should rigorously evaluate and select suppliers, enhancing their technical capabilities and quality control standards. Comprehensive quality inspection and real-time quality monitoring should be implemented during the production process.

In terms of demand forecasting and logistics, every link in the NEV supply chain should enhance market data analysis capabilities, establish dynamic forecasting models and real-time monitoring systems, and swiftly respond to market changes by adjusting production and inventory strategies. Building a multi-channel, multi-path logistics system can reduce dependence on a single logistics channel and establish comprehensive logistics contingency plans. Finally, to address unexpected events, the NEV industry should improve emergency response plans, establish cooperation with government, industry organizations, and supply chain partners, ensuring a quick response and minimizing impact when external risks occur.

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