# A Methodology for Assessing Automotive Supply Chain Security Based on Operational Mechanisms

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**Abstract.** As the automobile gradually moves towards intelligent and connected development, cooperation between companies in the automotive supply chain is getting closer and closer. Main automakers choosing different suppliers will have different impacts on the security and stability of the supply chains. Therefore, this article constructs evaluation index system for the automotive supply chain, which assesses the relative safety and stability of companies in the automotive supply chain from seven aspects: R&D capacity, Production capacity, Service capacity, Management capacity, Procurement capacity, Delivery capacity and Control capacity. Based on this, the article quantifies expert opinions on company evaluation using Double Hierarchy Hesitant Fuzzy Linguistic (DHHFL) implementation, calculates the importance of various evaluation indicators through entropy method, and finally achieves safety evaluation of each company. The multi-dimensional analysis of the safety state of automobile manufacturing enterprises provides decision-making suggestions for supply chain management.

**Keywords:** Supply Chain Security · Safety assessment methodology · DHHFL

## 1 Introduction

The automotive industry is an "integrated" industry of large collaboration and manufacturing, and a complete and powerful automobile supply chain is one of the basic characteristics of an automotive power. The automotive supply chain is centered around the automotive manufacturing companies. The focal company establishes collaborative behavior with suppliers based on product supply-demand, forming a dynamic system of mutual interest and alliance. Currently, the rapid development of intelligent connected vehicles, the fast iteration of product components, and the integration of modern technology have resulted in an increase in risk factors within the automotive supply chain. For example, factors such as the international trade situation, the global chip crisis, and the monopolization of critical technologies.

Many scholars have studied the safety assessment of automobile supply chain. X Tong [1] conducted an analysis of evaluation indicators from the perspectives of prevention, mitigation, and recovery of security incidents. However, the extraction was mainly


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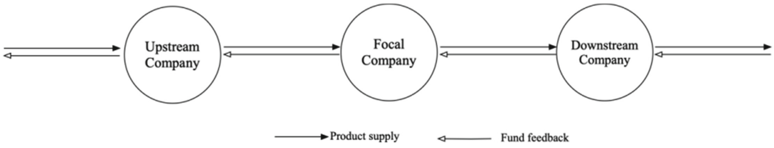


**Fig. 1.** Supply Chain Meta-Model

for transport security and terrorism-related security incidents. Lu G [2] proposed that supply chain security refers to a state where the supply chain remains intact, and the operational status, brand reputation, and financial activities of companies is unaffected. Gopal, G [3] based on the multi criteria decision-making method, achieves quantitative evaluation of supply chain indicators through the principle component analysis and Fuzzy method. Most of the foreign research on supply chain security revolves around factors such as national politics, illegal activities, or violations, which may not align well with the reality of the Chinese supply chain environment.

Domestic researchers, such as Tian Siyu [4] used the improved SCOR model and the "people, material, environment, management" four elements of comprehensive risk management as risk identification principles to identify risk factors in the supply chain. In domestic research, scholars have mainly focused on identifying indicators for specific aspects of supply chain security. This study proposes a hierarchical approach to identify safety evaluation indicators specifically tailored to the structure of the automotive supply chain. Building upon the operational mechanisms of the supply chain, this method ensures comprehensive indicator identification. It combines a dual-layer fuzzy hesitant linguistic term set and entropy method to achieve security assessment.

## 2 Design of Automobile Supply Chain Security Evaluation System

### 2.1 Analysis of Automotive Supply Chain Structure

The supply chain is a cooperative dynamic network centered around the focal company, connecting various entities based on product supply and demand. It encompasses all members ranging from suppliers of the focal company's suppliers to customers of the focal company's customers [5].

In the supply chain, the focal company collaborates with upstream suppliers to acquire the target products based on the product demands of downstream customers (Fig. 1). Additionally, the focal company obtains funds during the product delivery process (Fig. 2). In the automotive supply chain, the focal company refers to the original equipment manufacturer (OEM) that procures automotive product materials from upstream suppliers. The OEM engages in research, development, and manufacturing activities for complete vehicles, and delivers the automotive products to downstream customers, including automotive dealerships, mobility service companies, or end-users.

### 2.2 Identify Security Evaluation Index

Supply chain security refers to the state in which companies maintain the potential negative risks in the whole process of product development and manufacturing within a

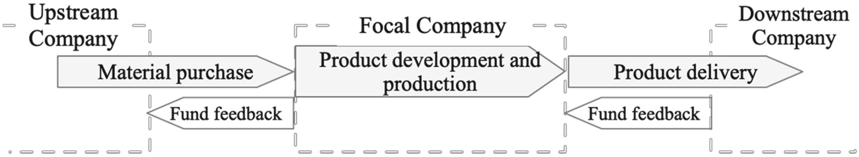


**Fig. 2.** The operational mechanism of the automotive supply chain

controllable range, and companies continuously obtain funds to meet their own development. Based on this, supply chain security can be assessed by identifying evaluation indicators from two aspects: internal product research and manufacturing activities within company (Fig. 3), and product supply and demand between companies (Fig. 4).

Internal product research and manufacturing activities encompass all the activities involved in the evolution of products from conceptual requirements to mass production. Identify evaluation index that can represent the performance of each activity.

- In the process of product planning and design, the OEM collects product demand information, analyzes product requirements, and designs product features and layout. This process characterizes company's research and development (R&D) capacity.
- In the process of product trial production and mass production, automobile products are manufactured through complex processes such as material procurement, sophisticated processing, integration, and manufacturing using production equipment. This process characterizes the production capacity of company.
- In the whole process of product development and manufacturing, Automotive products continue to iterate, requiring multiple testing procedures to ensure alignment with target requirements. This process characterizes the service capacity of company.
- The OEM strategically plans and controls activities and resources to achieve market objectives. This process characterizes the management capacity of company.

The security status between companies refers to the financial feedback obtained through product transactions, which enables the accumulation of funds to meet the development needs of company.

- The OEM first develops a list of components and software systems required for the entire vehicle and purchases the required materials from the supplier. This process characterizes the procurement capacity of company.

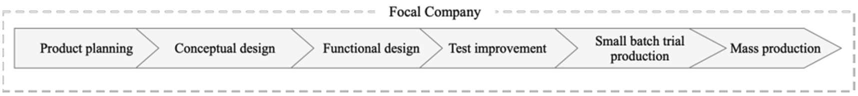


**Fig. 3.** Product development and manufacturing process within company

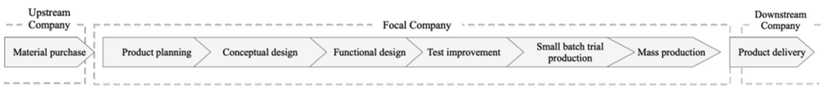


**Fig. 4.** Product Collaboration Process between Companies

**Table 1.** Evaluation index table based on supply chain operation mechanism.

| Elements of supply chain structure | Structural Element Activity Performance | Evaluation indicators for characterizing activities |
|---|---|---|
| Node Company Internal | Product Development | R & D capacity |
| | Product production | Production capacity |
| | Testing services | Service capacity |
| | Resource regulation | Management capacity |
| Node Company Collaboration | Material purchase | Procurement capacity |
| | Produce product transactions | Delivery capacity |
| | Market competition activities | Control capacity |

- The main engine factory obtains finished products through the product development and the manufacturing process and delivers them to the demand side for financial feedback. This process characterizes the delivery capacity of company.
- In the supply and demand relationship of products, the impact of market position and technological exclusivity of companies leads to the capacity of companies to occupy more market share. This process characterizes the control capacity of company.

Based on the analysis of supply chain operation mechanism mentioned above, identify evaluation index that can characterize various activities (Table 1).

### 2.3 Construction Security Evaluation Index System

The automobile Supply Chain Security Evaluation Index System, represents the activities of node companies as primary indicators, and utilizing attribute characteristics that evaluate the effectiveness of these activities as secondary indicators. Forming a hierarchical evaluation indicator system that is directed towards activities and attributes (Table 2). Identifying potential risk factors within various attribute features as index parameters, which can be matched against historical data of company.

## 3 Standardization of Security Evaluation Index System

### 3.1 Steps for Company Security Assessment

The experts evaluated the capabilities of each company respectively and quantified the evaluation opinions to obtain the evaluation scores by using the DHHFL and Defuzzification operations. By using the entropy method to calculate the entropy and the weights of each capability. The weights and corresponding evaluation scores are comprehensively calculated to achieve the safety assessment of company.

In the Double Hierarchy Hesitant Fuzzy Set (DHFLTS), the first layer $S = \{S_t | t = -\tau, \ldots, -1, 0, 1, \ldots, \tau\}$ represents the evaluation viewpoints of experts; The second layer $O = \{O_k | k = -\varsigma, \ldots, -1, 0, 1, \ldots, \varsigma\}$ indicates the strong level of expert support

**Table 2.** Index System for Safety Assessment of Automobile Supply Chain.

| Level1 valuation index | Level2 evaluation index | Index parameters |
|---|---|---|
| Research and development (R&D) capacity (C1) | R&D behavior quality ($C1_1$) | Development cycle and R&D investment, proportion of R&D personnel |
| | Quality of R&D achievements ($C1_2$) | Number of invention patents, number of software monographs and number of academic papers |
| Production capacity (C2) | Quality of production behavior ($C2_1$) | Capacity utilization rate, growth rate of finished products, and proportion of product quality assurance personnel |
| | Production equipment quality ($C2_2$) | Production equipment turnover rate, procurement period, and source |
| Service capacity (C3) | Importance of detecting behavior ($C3_1$) | Whether third-party testing services and certification are provided |
| Management capacity (C4) | Company size ($C4_1$) | Total assets and total number of employees of company |
| Procurement capacity (C5) | Material avail capacity ($C5_1$) | Material supply status, material source, safety stock level |
| Delivery capacity (C6) | Quality of finished products ($C6_1$) | Product yield rate, end-to-end pass-through rate, and system certification |
| | Quality of delivery behavior ($C6_2$) | Supply cycle and proportion of product quality control personnel |
| Control capacity (C7) | Social status ($C7_1$) | Market share and whether it is a Fortune 500 enterprise |
| | Product scarcity degree ($C7_2$) | Is the product exclusively supplied |

for this viewpoint. The first and second term sets are two completely independent sets of terms, which can be understood as supplementary descriptions of each language term in the first term set [6].

Step1: Using the double hierarchy hesitant fuzzy elements $h_{S_o}(x_i) = \{S_{\varphi_l<O_{\phi_l}>}(x_i)|S_{\varphi_l<O_{\phi_l}>} \in S_o; l = 1, 2, \ldots, L; \phi_l = -\tau, \ldots, -1, 0, 1, \ldots, \tau; \varphi_l = -\varsigma, \ldots, -1, 0, 1, \ldots, \varsigma\}$ to represent expert evaluation opinions, a fuzzy language matrix H is formed. Among them, L is the number of the double hierarchy hesitant fuzzy terms.

Step2: The DHHFL element $h_{S_o}(x_i)$ is a discrete representation of a series of expert evaluation opinions, which is transformed into a continuous expression form using a function (1) to obtain the corresponding membership degree $\gamma_l$ of the fuzzy language element and achieve the quantification of expert evaluation opinions.

$$f : [-\tau, \tau] \times [-\varsigma, \varsigma] \rightarrow [0, 1]$$

$$F\left(S_{\varphi_l<O_{\phi_l}>}\right) = f(\phi_l, \varphi_l) = \begin{cases} \frac{\varphi_l + (\tau + \phi_l)\varsigma}{2\tau\varsigma} = \gamma_l, -\tau + 1 \leq \phi_l \leq \tau \\ \frac{\phi_l}{2\tau\varsigma} = \gamma_l, \phi_l = -\tau \end{cases} \quad (1)$$

Step3: Use formula (2) to calculate the comprehensive expected value of the membership degree $\gamma_l$ corresponding to expert evaluation opinions, forming the expected matrix X.

$$E\left(h_{S_o}\right) = \frac{1}{L}\sum_{l=1}^{L} F\left(S_{\varphi_l<O_{\phi_l}>}\right) \quad (2)$$

Convert the comprehensive expected values $x_{ij}$ in the expected matrix X into evaluation scores $g_{ij}$ using formula (3).

$$g_{ij} = round(E\left(h_{S_o}\right) \times 100) \quad (3)$$

Step4: The more concentrated the evaluation opinions of experts on a certain competency indicator, the more valuable the information carried by the competency indicator. Conversely, the lower the value of the competency indicator. Using the entropy method to calculate the entropy of each capacity index under expert evaluation, reflecting the weight of the indicator [7].

- Firstly, standardize the expected value matrix X using the power coefficient method ( formula (4)). Obtain the standard fuzzy value matrix.

$$Y_{ij} = \frac{x_{ij} - x_{min(i)}}{x_{max(i)} - x_{min(i)}}\alpha + (1 - \alpha) \quad (4)$$

Among them, the efficacy coefficient $\alpha \in (0, 1)$ is generally taken as 0.9.

- Calculate the entropy value $e_i$ of the capability $C_i$ index for each element $Y_{ij}$ in the standard fuzzy value matrix using formula (5).

$$e_i = \frac{1}{(lnm)\sum_{j=1}^{m} Y_{ij}}[\left(ln\sum_{j=1}^{m} Y_{ij}\right)\sum_{j=1}^{m} Y_{ij} - \sum_{j=1}^{m} Y_{ij}lnY_{ij}] \quad (5)$$

- Use formula (6) to calculate the weight $w_i$ corresponding to the capability index $C_i$ based on its entropy value $e_j$.

$$w_i = \frac{1 - e_i}{\sum_{i=1}^{n}(1 - e_i)} \quad (6)$$

Step 5: By comprehensively calculating the evaluation scores of each company and the weight of evaluation indicators, the comprehensive scores $G_j$ of each company are obtained, achieving a comparison of company safety evaluations, and providing auxiliary decision-making for supplier selection and management.

$$G_j = \sum_{i=1}^{n} g_{ij} \times w_i \tag{7}$$

### 3.2 Examples of Company Security Assessment

In this study, four host factories were selected as safety assessment objects, and historical production data of the four host factories were obtained. Supply chain management experts were invited to refer to the historical data of the companies and evaluate their capabilities. Using a Double Hierarchy Hesitant Fuzzy set to represent experts' evaluation opinions, a fuzzy language matrix H is formed (Table 3).

Use formula (2) to calculate the comprehensive expected value of the membership degree $\gamma_l$ corresponding to expert evaluation opinions, form the expected matrix X, and achieve the quantification of expert evaluation (Table 4).

Based on the evaluation opinions of experts, the entropy method is used to calculate the weights of each safety evaluation index, indicating the importance of the index to the safety status (Table 5).

According to the results shown in Table 5, production and delivery capacities demonstrate sustainable stability and have a relatively significant impact on the safety of companies. Formula (7) was used to comprehensively calculate the security score of each enterprise (Table 6).

The overall indicator scoring and weight calculation determine the safety rating of the companies, $A_1 > A_4 > A_3 > A_2$. Company $A_1$ has the highest overall rating, while although company $A_4$ has a relatively even distribution of capacities, it is at a disadvantage in terms of delivery capacity. Choosing $A_4$ among the four suppliers would be most advantageous for the safety and stability of the OEM's supply chain. Additionally, suppliers

**Table 3.** Fuzzy Language Matrix.

| $C_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $C_1$ | $\{S_{1<O_2>}, S_{2<O_2>}\}$ | $\{S_{1<O_3>}, S_{2<O_0>}\}$ | $\{S_{2<O_{-2}>}, S_{2<O_2>}\}$ | $\{S_{2<O_0>}\}$ |
| $C_2$ | $\{S_{1<O_1>}, S_{2<O_0>}\}$ | $\{S_{1<O_{-1}>}, S_{2<O_{-1}>}\}$ | $\{S_{1<O_2>}\}$ | $\{S_{1<O_0>}, S_{2<O_{-2}>}\}$ |
| $C_3$ | $\{S_{0<O_0>}, S_{1<O_3>}\}$ | $\{S_{1<O_0>}\}$ | $\{S_{0<O_2>}, S_{1<O_2>}\}$ | $\{S_{1<O_1>}\}$ |
| $C_4$ | $\{S_{2<O_1>}\}$ | $\{S_{1<O_0>}, S_{2<O_{-1}>}\}$ | $\{S_{1<O_0>}, S_{2<O_0>}\}$ | $\{S_{2<O_0>}, S_{2<O_3>}\}$ |
| $C_5$ | $\{S_{2<O_1>}, S_{3<O_0>}\}$ | $\{S_{1<O_0>}, S_{2<O_0>}\}$ | $\{S_{2<O_{-2}>}, S_{3<O_{-2}>}\}$ | $\{S_{1<O_1>}, S_{2<O_2>}\}$ |
| $C_6$ | $\{S_{1<O_1>}, S_{2<O_2>}\}$ | $\{S_{0<O_0>}\}$ | $\{S_{0<O_{-2}>}, S_{1<O_1>}\}$ | $\{S_{0<O_0>}, S_{1<O_3>}\}$ |
| $C_7$ | $\{S_{0<O_2>}\}$ | $\{S_{1<O_{-2}>}, S_{1<O_{-1}>}\}$ | $\{S_{0<O_3>}, S_{1<O_0>}\}$ | $\{S_{2<O_{-3}>}\}$ |

**Table 4.** Expectation Matrix.

| $C_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $C_1$ | 0.8056 | 0.7666 | 0.8333 | 0.7222 |
| $C_2$ | 0.8056 | 0.7666 | 0.8333 | 0.7222 |
| $C_3$ | 0.6364 | 0.6667 | 0.6389 | 0.7222 |
| $C_4$ | 0.8889 | 0.7381 | 0.75 | 0.9167 |
| $C_5$ | 0.9286 | 0.75 | 0.8611 | 0.7963 |
| $C_6$ | 0.7963 | 0.5 | 0.5657 | 0.6364 |
| $C_7$ | 0.6111 | 0.5833 | 0.6 | 0.6667 |

**Table 5.** Weight Table of Safety Assessment Indicators.

| $C_i$ | $w_i$ |
|---|---|
| $C_1$ | 0.1051 |
| $C_2$ | 0.23 |
| $C_3$ | 0.1296 |
| $C_4$ | 0.1489 |
| $C_5$ | 0.1223 |
| $C_6$ | 0.1267 |
| $C_7$ | 0.1374 |

**Table 6.** Company Security Score Sheet.

| $A_j$ | $G_j$ |
|---|---|
| $A_1$ | 76.2261 |
| $A_2$ | 67.3292 |
| $A_3$ | 70.7033 |
| $A_4$ | 74.5228 |

can enhance their own capability levels based on the evaluation results, strengthen their market competitiveness, and ensure sustainable operational status.

## 4 Conclusion

This study presents a methodology for assessing the safety of automotive supply chains, which includes the identification of safety evaluation indexes, the construction of a hierarchical index system, and methods for calculating evaluation scores. Based on this methodology, companies propose an evaluation indicator system that aligns with their own safety requirements and quantifies the safety state of the company through a hierarchical approach. This methodology provides decision support for supplier management, ensuring the resilience of the supply chain, and improving the effectiveness of digital management in companies.

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