Research on Supply Chain Risk Evaluation in Machinery Manufacturing Industry

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Abstract: Under the development of global economy, supply chains are facing more and more risks. The supply chain risks encountered in the machinery manufacturing industry will affect the normal operation of the supply chain, which in turn affects the profitability and development of enterprises. To guarantee the smooth implementation of the supply chain in the machinery manufacturing industry, it is necessary to carry out the risk evaluation of the supply chain. This paper studies the supply chain risk evaluation based on the machinery manufacturing industry, identifies the internal and external risks, and evaluates the risks by using entropy weight method, hierarchical analysis method and material element model. The purpose of this paper is to provide theoretical methods and countermeasures to support the risk evaluation of the supply chain in the machinery manufacturing industry, and to promote the smooth development of the supply chain in China's machinery manufacturing industry.

Keywords: Manufacturing; Supply Chain; Hierarchical Analysis; Risk Evaluation

1. Introduction

Along with the progress of society, the development of machinery manufacturing industry [1] has also entered a new stage. Machinery manufacturing industry not only plays a key role in promoting scientific and technological progress, but also occupies an important position in the development of the national economy. In recent years, under the support of various national manufacturing policies, infrastructure investment has been increasing, and the domestic machinery manufacturing industry is also growing steadily, but there is still the problem of supply chain risk.

Machinery manufacturing enterprises will encounter a variety of risks in the procurement, manufacturing, transportation and other links, such as insufficient supply capacity of suppliers will lead to the enterprise to manufacture not enough products, affecting the profitability of the enterprise; improper choice of distribution routes will lead to delayed delivery of the enterprise, affecting the enterprise's credibility; the sales link to the customer to bring a bad experience, resulting in the loss of customers. Most enterprises face the problem of supply chain risk, and risk evaluation can provide suggestions for risk response. Therefore, it is necessary to carry out supply chain risk evaluation for machinery manufacturing enterprises.

2. Categories and Identification of Supply Chain Risks in Machinery Manufacturing

Supply chain risks are usually categorized into external and internal risks [2], with external risks including national policies, market demand, socio-economic environment, natural disasters and so on. Internal risks include research and development risks, procurement risks, production risks, transportation risks, etc. encountered in the supply chain operation.

In order to identify supply chain risks more objectively, the flowchart method can be used for identification.

2.1 Research and Development Risks

Based on the summary of previous literature and the R&D flowchart, as in Figure 1, the risk elements of the R&D process are categorized into: R&D solution feasibility risk and R&D testing standardization risk.

2.1.1 R & D program is not feasible will lead to supply chain risk

In the development of R & D program must consider the market demand for new mechanical products and the financial capacity of enterprises, if the lack of feasibility considerations, it will affect the development process of mechanical products, which in turn causes supply chain risks.

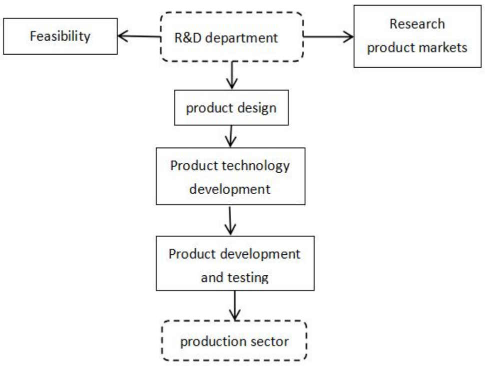

Figure 1. Flow Chart of Mechanical Product Development

2.1.2 Risks arising from insufficient standardization of research and development testing

The testing of mechanical products requires high standards and specialization. Failure to meet the testing requirements will affect the results of the test, which will in turn affect the production and sales of the entire supply chain, bringing risks to the entire supply chain.

2.2 Procurement Risk

Based on the summary of the previous literature and the procurement flow chart, as in Figure 2, the risk elements in the procurement process are categorized into: the risk of excessive purchase price, the risk of quality problems of the purchased parts, and the risk of delayed delivery by the suppliers.

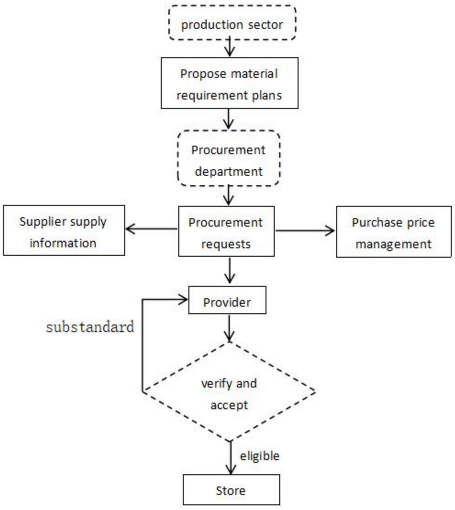

Figure 2. Flow Chart of Procurement of Machinery Products

2.2.1 Excessive procurement price leads to supply chain risk

In the procurement process, if the price of raw materials negotiated with the upstream suppliers is not appropriate, resulting in the procurement of too high a price, it will make the number of funds invested by the enterprise become more, and the cost of procurement will rise, which will lead to the occurrence of supply chain risk.

2.2.2 Quality problems in purchased parts can lead to supply chain risks

When the quality of the purchased parts provided by the supplier has problems, it will affect the next step of the manufacturing process of the enterprise, resulting in slower progress of the enterprise's manufacturing, which will lead to the occurrence of supply chain risk.

2.2.3 Delayed delivery by suppliers leads to supply chain risks

When the supplier delays the delivery time specified in the agreement, it will lead to a delay in the completion of the mechanical products, affecting the cooperation with downstream customers and having a bad impact on the sales of the products, thus leading to supply chain risks.

2.3 Production Risk

Based on the summary of previous literature and the production flow chart, as in Figure 3,the risk elements of the production process are categorized into: production plan development risk, production cost uncertainty risk, and product inventory mismanagement risk.

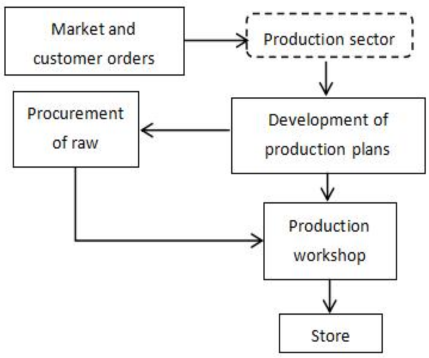

Figure 3. Flow Chart for the Production of Mechanical Products

2.3.1 Risks arising from unscientific production planning

The production plan of mechanical products is generally based on the customer's order demand and the number of past sales, if the production plan is unreasonable it will affect the production of products, which may result in product backlog or production interruption, affecting the operation of the supply chain.

2.3.2 Risks caused by uncertainty in production costs

Uncertainty exists in the production process of mechanical products, including changes in order demand, staff salaries, irregularity of equipment maintenance, etc. These uncertainties will affect the control of production costs and cause supply chain risks to occur.

2.3.3 Risks caused by improper inventory management

Mechanical products have high requirements for the storage environment, requiring a large inventory space and keep the environment relatively dry, humid air will corrode the steel, and thus cannot guarantee that 100% of the product can be put into use, resulting in supply chain risks.

2.4 Distribution Risk

Based on the summary of previous literature and the distribution flow chart, as in Figure 4, the risk elements of the distribution process are categorized into: distribution method selection risk and distribution product damage risk.

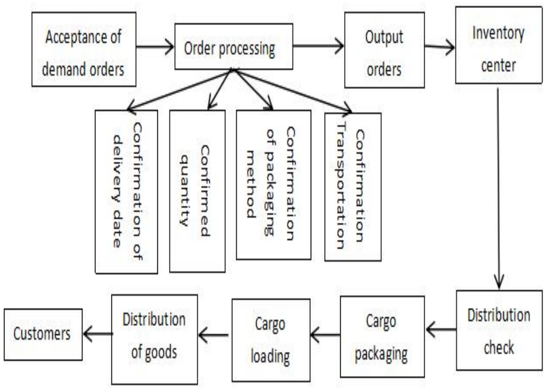

Figure 4. Flow Chart of Machinery Product Distribution

2.4.1 Risks caused by inappropriate choice of distribution method

The supply chain of the machinery manufacturing industry involves cross-region, if there is an improper choice of distribution methods may lead to products cannot be delivered in time or product distribution costs rise, affecting the supply chain logistics operations and sales of machinery products.

2.4.2 Risks caused by damage to distributed products

If an accident is encountered during the transportation of a product, it can cause damage to the product, thus affecting the sales of the product and creating a risk to the overall supply chain.

2.5 Sales Risk

Based on the summary of previous literature and the sales process map, as in Figure 5, the risk elements of the sales process are categorized into: the risk of insufficient diversity of sales models and the risk of losing key customers.

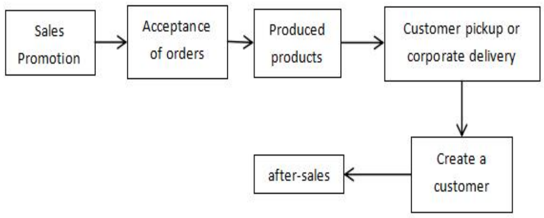

Figure 5. Flow Chart of Machinery Product Sales

2.5.1 Risks caused by insufficient diversity of sales models

If you insist on the traditional sales model, and today's emerging e-commerce and Internet model is out of line, it will lead to a decline in the number of sales, affecting the profitability of the enterprise, resulting in the occurrence of supply chain risks.

2.5.2 Risks caused by the loss of key customers

Orders for machinery products are on the large side, so if the relationship with key customers is not handled well, giving customers a bad experience and causing them to lose customers, it will affect the stability of sales, which will in turn jeopardize the balance of the supply chain.

3. Supply Chain Risk Evaluation in Machinery Manufacturing

3.1 Establishment of Evaluation Index System

Through the analysis of the above preliminary identification of risk indicators, it is found that they all meet the standards, so the risk evaluation index system of mechanical product supply chain is obtained [3], in which there are 6 primary indicators and 16 secondary indicators, and the specific system structure is shown in Table 1.

The evaluation of mechanical products supply chain risk is more complex, can use entropy weight method [4] and hierarchical analysis method [5] to determine the combination of weights [6] to ensure the objectivity of the weights, the use of material element can be topological model of the research method[7], based on the results of the questionnaire survey and analysis, the calculation of the evaluation of each level of the relative weight of the different indicators between the different indicators and determine the level of the risk level.

Table 1. Mechanical Products Supply Chain Risk Evaluation Index System

Project name	Level 1 indicators	Level 2 indicators
Mechanical products supply chain risk evaluation index system	External risk	natural disaster
		industrial policy
		Changes in market demand
		economic environment
	R&D risk	Feasibility of R&D programs
		R&D testing normality
	Procurement risk	Excessive procurement prices
		Procurement quality issues
		Delayed delivery by vendors
	Production risk	Production planning
		Uncertainty in production costs
		Inadequate management of product inventory
	Distribution risk	Distribution Options
		Distribution of damaged products
	Sales risk	Insufficient diversity of sales models
		Loss of key customers

3.2 Hierarchical Analysis

AHP is a combination of qualitative and quantitative decision analysis method commonly used in solving complex problems, through the decomposition of complex problems into various constituent factors and according to their dominant relationship to form a hierarchical structure, in order to determine the weights of the indicators through the comparison of the two, so as to assist in decision-making [8].

Hierarchical analysis includes the following steps:

3.2.1 Establishment of evaluation hierarchy

The hierarchical structure used for assigning the weights of the indicators in this paper is the evaluation index system of the supply chain risk of mechanical products established in the above.

3.2.2 Construction of judgment matrix

In the judgment matrix construction process, based on the 1-9 proportionality scale method, the expert selects the scale value from which the elements are compared and scored, and the judgment matrix is constructed.

Take the element c_n as an example, Let the next level of subordinate elements be $c_1, c_2, \cdots$, c_n, and construct the judgment matrix:

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} = C(c_{ij}) \quad (1)$$

The 1-9 scale method used in this paper is shown in Table 2 for the specific judgment scales and descriptions.

3.2.3 Weight calculation

Hierarchical analysis uses the basic idea of root of features and is calculated as:

$$Cw_i = \lambda_{\max} \mathrm{W} \quad (2)$$

The steps for solving λ_{max} and W for the judgment matrix are as follows:

(i) Multiply the row elements of the judgment matrix and find its nth square root:

$$M_i = \left(\prod_{j=1}^{n} c_{ij} \right)^{1/n}, i = 1,2,\cdots,n \quad (3)$$

(ii)Normalize the row vectors of C:

$$w_i = M_i \Big/ \sum_{j=1}^{n} M_j, i = 1,2,\cdots,n \quad (4)$$

The required eigenvector is:

$$W = (w_1, w_2, \cdots, w_n)^T \quad (5)$$

(iii) Calculate the maximum eigenvalue of the judgment matrix:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Cw)_i}{w_i} \quad (6)$$

Table 2. Scale of 9 Levels of Evaluation and Its Description

Scale value	Hidden meaning	Clarification
1	Equal importance	The elements c_i and c_j are equally important when compared to each other
3	Slightly important	The element c_i is slightly more important than c_j.
5	General importance	The elements c_i and c_j are compared, with the former being generally more important than the latter.
7	High priority	The elements c_i and c_j are compared, with the former being more strongly important than the latter.
9	Very important	The elements c_i and c_j are compared, with the former being more important than the latter.
2, 4, 6, 8		The middle value of the above adjacency judgment
From the bottom	Inverse comparison	The importance of element c_i with respect to c_j is c_{ij} and the importance of element c_j with respect to c_i is $1/c_{ij}$

3.2.4 Consistency test

(i) Seek consistency indicators:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (7)$$

(ii) Consistency ratio:

$$CR = \frac{CI}{RI} \quad (8)$$

RI denotes the sample mean and when *CR*<0.1, the judgment matrix passes the consistency test,The sample means are shown in Table 3.

Table 3 Means of the RI Sample for the Consistency Indicator

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

3.3 Entropy Weight Method

The entropy and weight method is a mathematical method for calculating a composite indicator based on a comprehensive consideration of the amount of information provided by each factor. Its main principle is to calculate the entropy and weight of an indicator by obtaining the score of the indicator and normalizing the score data [9].

3.3.1 Constructing judgment matrices and normalization

The judgment matrix constructed by m evaluation experts on the evaluation system consisting of n indicators is:

$$X = (x_{ij})_{\min} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, (i = 1,2,\cdots,m, j = 1,2,\cdots,n) \quad (9)$$

Normalization is performed and obtained:

$$Y_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \quad (10)$$

(when the indicator is a negative indicator)

$$Y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (11)$$

(when the indicator is positive)

3.3.2 Calculate the information entropy value and indicator weights

The characteristic weight of the *i* th evaluation of the *j* th indicator is:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}} \quad (12)$$

The information entropy of the *j* th indicator is:

$$E_j = -\ln(m)^{-1}\sum_{i=1}^{m} p_{ij}\ln p_{ij} \quad (13)$$

The weight of the *j* th indicator is:

$$\theta_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j} \quad (14)$$

3.4 Portfolio Empowerment

In order to better respond to the evaluation of supply chain risk of mechanical products, the composite normalization method can be used for the combination of weights. The composite weight is denoted as W_T, and its calculation formula is:

$$W_T = \mu\theta_j + (1-\mu)w_i \quad (15)$$

3.5 Topological Modeling of Object Elements

Object element is an ordered triad composed of "things, features, and quantitative values", and the basic principle of the Object Evaluation Method lies in the use of object elements to describe the research object. Through the construction of topological sets and correlation functions to quantify the development of the research object, the method can effectively expand the boundary between classical and fuzzy sets [10].

The specific steps are as follows:

(i) Determination of the classical domain of supply chain risk:

$$R_{0j}=(N_{0j},C,V_{0j})=\begin{pmatrix} N_{0j} & c_1 & v_{0j1} \\ & c_2 & v_{0j2} \\ & \cdots & \cdots \\ & c_n & v_{0jn} \end{pmatrix}=\begin{pmatrix} N_{0j} & c_1 & (a_{0j1},b_{0j1}) \\ & c_2 & (a_{0j2},b_{0j2}) \\ & \cdots & \cdots \\ & c_n & (a_{0jn},b_{0jn}) \end{pmatrix} \quad (16)$$

(ii) Determination of Supply Chain Risk Sectors:

$$R_p=(p\ ,C,V_p)=\begin{pmatrix} p & c_1 & v_{p1} \\ & c_2 & v_{p2} \\ & \cdots & \cdots \\ & c_n & v_{pn} \end{pmatrix}=\begin{pmatrix} p & c_1 & (a_{p1},b_{p1}) \\ & c_2 & (a_{p2},b_{p2}) \\ & \cdots & \cdots \\ & c_n & (a_{pn},b_{pn}) \end{pmatrix} \quad (17)$$

(iii) Determination of object elements to be evaluated:

$$R_{0i}=(p_{0i},C,V)=\begin{bmatrix} p_{0i} & c_1 & v_{i1} \\ & c_2 & v_{i2} \\ & \cdots & \cdots \\ & c_n & v_{in} \end{bmatrix},(i=1,2,\cdots,n) \quad (18)$$

(iv) Calculation of correlation

$$K_j(V_i)=\begin{cases} \dfrac{-\rho(V_i,V_{ij})}{\left|V_{ij}\right|}, V_i\in V_{ij} \\ \dfrac{\rho(V_i,V_{ji})}{\rho(V_i,V_{pi})-\rho(V_i,V_{ji})}, V_i\notin V_{ij} \end{cases} \quad (19)$$

After obtaining the individual indicator correlation function through the above formula, a sequential recursive approach is used to calculate the comprehensive indicator correlation, which is calculated as follows:

$$K_j(p_i)=\sum\nolimits_{i=1}^{n}\omega_i K_j(V_i) \quad (20)$$

The results of the evaluation of the matrix to be evaluated were determined as shown in Table 4.

(v) Determination of evaluation ratings

According to the principle of maximum affiliation, the specific assessment level of the assessment object can be determined based on the comprehensive relevance [11]. Let assessment *m* be the object *N* rank, and let:

$$j^*=\frac{\sum_{j=1}^{m} j\overline{K_j}(N)}{\sum_{j=1}^{m}\overline{K_j}(N)} \quad (21)$$

Table 4 Description of Correlation Values

Relatedness	Analysis of evaluation results	Evaluation rating determination
$0<K_j(p_i)<1$	Evaluation results determined to meet level *j* criteria	Analyze and compare the correlation values of different grades, follow the principle of maximum affiliation, and determine the set of grades corresponding to the largest comprehensive correlation value as the evaluation grade of the object element to be evaluated.
$-1<K_j(p_i)<0$	The criteria for level *j* are judged not to be met, but can be converted to that level, and the greater the value of the quantity, the easier it is to do so.	
$K_j(p_i)<-1$	Determine that the substance element to be evaluated does not meet the requirements of level *j* and is not eligible for transformation.	

$\overline{K}(N)$ is the result of the integrated correlation normalization process, calculated as follows:

$$\overline{K}(N)=\frac{K_j(N)-\min K_j(N)}{\max K_j(N)-\min K_j(N)} \quad (22)$$

Where j^* is the bias characteristic value of the evaluation results sought in the evaluation model, based on the degree of bias of j^* in the two neighboring grades can determine the comprehensive evaluation results.

3.6 Classification

Considering the objectivity of the results of the evaluation of the risk of the mechanical products supply chain, this paper combines the relevant literature and the realism of the selection of specific indicators under the evaluation system to take 5 levels of division, divided into V = {no risk, lower risk, medium risk, higher risk, high risk} five, the score is set to full 5 points, that is, the indicator of the risk of the smaller the more convergence of the 0 points, and vice versa, convergence of the 5 points.

4. Conclusions

To summarize, the supply chain of machinery manufacturing enterprises encounters different risks in the process of operation, such as procurement risk, production risk and distribution risk. However, by identifying the risks, the supply chain risk evaluation model can be established, and the efficiency of the supply chain can be improved by suggesting countermeasures against the risks.

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