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# Supply Chain Risk Assessment and Control of Port Enterprises: Qingdao port as case study

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ABSTRACT

China's reform has led to rapid port enterprise development and improved major coastal port throughput capacity and loading efficiency. Modern port enterprises are important nodes in global supply chain integration and have begun to function as integrated logistics service centers. Qingdao port was used to evaluate enterprise supply chain risk. An improved AHP method was used to propose measures to strengthen port enterprise supply chain risk management. Port service process risk, operational risk, port relationship process risk, and external environment-associated risk are too high in this supply chain. To strengthen supply chain risk control, improved port service efficiency, enhanced port operational ability, strengthened membership management, and improved supply chain risk prevention mechanisms are required.



## 1. Introduction

As the point of intersection of shipping and traffic, modern ports play an increasingly important role in the modern comprehensive logistics system. With the acceleration of economic globalization, the intensity of international trade is increasing; the interpretation of modern logistics has been extended, and international logistics has gradually become a trend in modern logistics development. As the port is the node of import and export for cargo distribution and transportation, its development is not only directly related to the development of the port economy, but also related to the operations and competitiveness of a country's foreign trade. According to data disclosed by the National Bureau of Statistics, cargo throughput in China's major coastal ports reached 7,695,570 thousand tons by the end of 2014, representing an increase of 5.69%. Cargo exports reached 3,346,530 thousand tons (a 7.27% increase), while cargo imports reached 4,439,040 thousand tons (a 4.52% increase). Quay length was extended to 778,579 meters (a 4.58% increase), and total berths to 5923 (an 2.81% increase).

The deepening of China's reform has led to the rapid development of port enterprises, and improvement in major coastal port throughput

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capacity and loading efficiency. Under global economic integration, the port is no longer considered a solitary node; instead, its competitive position is more dependent on its role in the supply chain (Carbone and Martino, 2003; Song and Panayides, 2007). Therefore, modern port enterprises have become an important node in the global integrated supply chain, and their role has changed from transportation or distribution center to an integrated logistics service center.

In this situation, the strengthening of the port supply chain through horizontal and vertical integration has become an objective of China's major port enterprises. However, compared with developed countries, China's port enterprises are relatively underdeveloped in terms of management concepts and methods, and experience many supply chain development problems. For example, compared with the manufacturing supply chain, the port enterprise supply chain represents a service supply chain; its uncertainty and integration is more difficult, and supply chain risk management is more complex. Given this background, strengthening of port enterprise supply chain risk management research is of important theoretical value and practical significance.

## 2. Literature Review

The studies on supply chain risk in foreign countries mainly focus on three aspects: supply chain risk identification, supply chain risk assessment, and supply chain risk prevention and control.

In supply chain risk identification research, scholars have identified risk factors from different perspectives. Some scholars considered the supply and demand perspective (Hallikas et al., 2002; Johnson, 2001; Sharma and Bhat, 2012), and divided supply chain risk into demand and supply risk. Some scholars pointed to risk factor identification based on supply chain structure (Ghadge et al., 2012; Musa, 2012), and divided supply chain risk into capital risk, information flow risk, and logistics risk. Mandal (2011) noticed that supply chain risk mainly originates from supply chain demand uncertainty and imperfect supply chain organization.

In the study of supply chain risk assessment, some scholars used the analytical hierarchy process (AHP) (Jaberidoost et al., 2015; Radivojević and Gajović, 2014), the fuzzy comprehensive evaluation method (Aqlan and Lam, 2015), and other mainstream risk assessment methods. Some scholars adopted relatively novel evaluation methods, for example, Bogataj and Bogataj (2007) used frequency and net present value analysis methods to evaluate the cost-associated risk factors. Klibi and Martel (2012) evaluated supply chain network risk using Monte Carlo simulation; they indicated that the combination of scenario analysis and Monte Carlo simulation can better evaluate the risk fluctuations associated with supply chain network demand.

In supply chain risk prevention and control research, some scholars focused on internal supply chain risk control (Agrawal and Seshadri, 2000; Finkelstein and Esaulova, 2006; Jiang et al., 2006; Kuo et al., 2006; Kvam et al., 2006), starting with the reasons for risk occurrence, to analyze the relationship between risk factors and comprehensive risk expression. Some scholars studied risk control from the whole supply chain perspective (Bertsimas and Thiele, 2004; Huang et al., 2007; Savaskan et al., 2004; Xu et al., 2007), and considered the supply chain as an adaptive system. The focus of the research was risk integration, that is, to define all risk factors as elements of comprehensive risk. Some scholars studied risk control from the respective of establishing risk prevention mechanisms and improving risk management (Heckmann et al., 2015; Lavastre et al., 2012; Oehmen et al., 2009).

Domestic research on supply chain risk is mainly concentrated on two aspects, namely, the identification of supply chain risk and supply chain risk assessment.

In supply chain risk identification research, some scholars analyzed risk factors from the internal and external supply chain perspectives (Fu et al., 2012; Hu, 2008), and divided supply chain risk into two categories, namely, endogenous risk and exogenous risk; however, Xu et al. (2013) paid more attention to internal supply chain risk. In addition, some scholars focused on researching supply chain risk factor identification (Chen, 2012; Jing and Liu, 2014; Suo, 2011). Jing and Liu (2014) believed that there are currently four general types of supply chain risk identification models: the Supply Chain Operations Reference Model (SCOR), Fault Tree Analysis Model (FTA), Scenario Analysis Model (ASM), and other identification models (expert advice, financial statements, and others).

In supply chain risk assessment research, many scholars used grey evaluation (Zhang and Chen, 2011; Feng, 2010; Liu and Ma, 2011; Li and Cheong, 2008), while some scholars used neural network evaluation (Hou, 2013; Wang, 2010). In addition to the mainstream methods, some scholars adopted new methods to evaluate supply chain risk; for example, Zhong (2012) analyzed the applicability of the variable weight extension matter-element model to supply chain risk assessment; Xu and Tian (2004) and Yan et al. (2013) put forward a loss function to evaluate supply chain risk; Shu et al. (2014) evaluated supply chain risk through a support vector machine algorithm; Zheng (2015) described the mutual relationship between risk factors and risk, as well as among risk events, using Bayesian figures.

The above literature review indicates that, for this specific case and industry, domestic and foreign supply chain risk research is concentrated on the manufacturing industry and manufacturing enterprises. Further, foreign and domestic supply chain risk research is not only undertaken from an economic perspective but also from a management perspective. There is room for further exploration, since theoretical research on the port enterprise service supply chain is limited. The risk model is the method that is mainly used in supply chain risk identification research and expert investigation; it resulted from two former methods, and is confused with poor systemic gradation. Commonly used research methods include the AHP, the fuzzy comprehensive evaluation method, and matter-element theory. However, these three methods have some limitations in supply chain risk assessment, such as poor operability and low efficiency.

Based on the above analysis, this study develops the port enterprise SCOR risk model, by combining the SCOR model with the characteristics of port enterprise supply chains, to protect the scientific, systemic gradation of the port enterprise supply chain risk model. Then, we introduce a fuzzy mathematics method to deal with the fuzzy evaluation of the target level value of port enterprise supply chain risk assessment, and establish a fuzzy AHP method to render the quantitative indexes dimensionless, so as to improve the AHP method and increase evaluation efficiency.

## 3. Port Enterprise Supply Chains

The port enterprise supply chain has common supply chain features: it comprises the upstream and downstream enterprises of the network structure, namely, the integration of information flow, logistics, and capital flow. At the same time, it has the specific characteristic of port enterprises, namely, it is a service supply chain with the port enterprise at its core. Based on the above analysis, the following port enterprise supply chain definition is proposed: a service network structure composed of upstream and downstream enterprises to add value through customs and services, with the port enterprise as the core and modern information technology as the means.

### 3.1. *Differentiating Enterprise Supply Chains from Manufacturing Supply Chains*

Port enterprise supply chains differ from manufacturing supply chains, as is summarized in Table 1.

**Table 1**

Comparison between port enterprise and manufacturing supply chains

| Aspects | Detail Differences | Manufacturing supply chain |
|---|---|---|
| Control core | Service supply chain, integration of port service, taking the port enterprise as the core, port services for designing, planning, implementation and improvement | Product supply chain, integration of product, taking the manufacture enterprise as the core, upstream and downstream enterprises' optimization of producing, planning, sales and logistics. |
| Organization members | Relatively complex, organization members are port enterprises, other port (which may be competitors or partners), suppliers, transporters, wholesalers and consumers | Relatively simple, organization members are core enterprises, suppliers, distributors, retailers, logistics providers and consumers. |
| Control objects | Capital flow, information flow, service flow and logistics | Capital flow, information flow and logistics |
| Time response pattern | Instantaneity of supply and demand perception | Lags of supply and demand perception |
| Engagement of all parties | The supply and delivery of services are simultaneous, the parties need to cooperate closely | Modular combination of chain, the parties only need to complete the relevant tasks |

Table 1 indicates that key differences between port enterprise and manufacturing supply chains are in the control core, the member organizations, control objects, time response pattern, and engagement of all parties.

With respect to the control core, the port enterprise supply chain is a service supply chain with the port enterprise at its core, while the manufacturing supply chain is a product supply chain with the manufacturing enterprise at its core. Intangible services always connect port supply chains, and value addition can be achieved through service delivery. The manufacturing supply chain is connected through products, and value addition can be achieved by the transformation of raw materials into products. The port supply chain provides intangible services that, different from tangible products, cannot be stored. Such chains differ significantly in value creation and value addition from manufacturing supply chains. A manufacturing enterprise achieves value addition through products, while a port enterprise adds value through services, rendering the port supply chain more complicated.

Considering member organizations, the port enterprise supply chain comprises the port enterprise, other ports (which may be competitors or partners), suppliers, transporters, wholesalers, and consumers. The port enterprise is critically dependent on geographical location, because the port is the center of port produce and services. However, manufacturing enterprises differ, and some large manufacturing enterprises have production centers throughout the country. Because of its dependence on geographical location, the port enterprise has the strengthening of cooperation with other ports as one of its goals. For port enterprises, other ports are both competitors and cooperators. This results in more complex member relationship structures, more coordination difficulties, worse supply chain stability, and more uncertainty and risk for port enterprise supply chains. In terms of control objects, the modes of operation of port enterprise and manufacturing supply chains are shown in Figure 1.

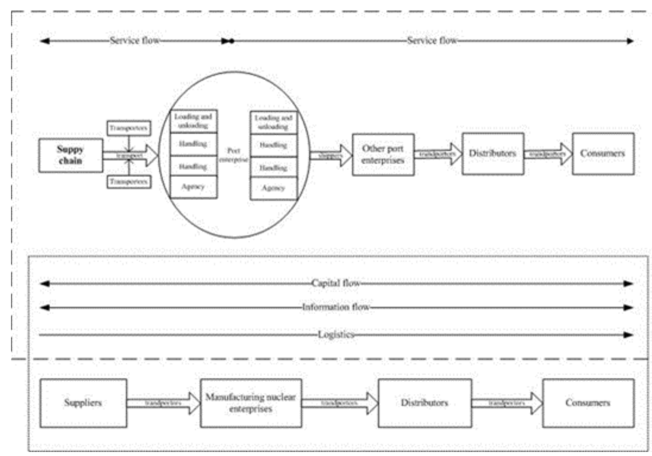



**Fig. 1.** Comparison of the modes of operation of port enterprise and manufacturing supply chains

Figure 1 indicates that the control objects of manufacturing supply chains mainly comprise information flow, logistics, and capital flow. In addition, port enterprise supply chains include service flow. In the latter supply chain, the port enterprise is not only the core enterprise, but also at the core of service flow. Its services extend to upstream and downstream supply chains: on the one hand, the process of "suppliers—port" always involves "loading and unloading," "handling" and "warehousing" at port enterprises, in addition to the logistics functions provided by logistics service providers; on the other hand, the port enterprise service involves "distribution" and "handling," which extends to downstream enterprises. It can be seen that the port enterprise will include logistics in its supply chain. However, manufacturing enterprises will outsource logistics, the non-core service, to logistics service providers.

In terms of time response pattern, the port enterprise does not have its own tangible inventory, since services do not have a physical form and cannot be stored. While there are delays in product demand adjustment and feedback, service demand is constantly changing. These demand fluctuations complicate decision making in port service chains with full demand response. It also leads to port supply chains' increased uncertainty, increased requirements for flexibility and customization, and increased supply chain risk.

Considering the engagement of all parties, the supply and delivery of port enterprise supply chain services are simultaneous, and parties need to cooperate closely, which is difficult to coordinate. In manufacturing supply chains, members only need to complete their respective tasks, which are relatively less difficult.

The above discussion indicates that the port enterprise supply chain is more complicated, uncertain, and unstable than the manufacturing supply chain. Some of the common risks in manufacturing supply chains may not constitute risks in the port enterprise supply chain. The latter have unique characteristics and is more difficult to manage.

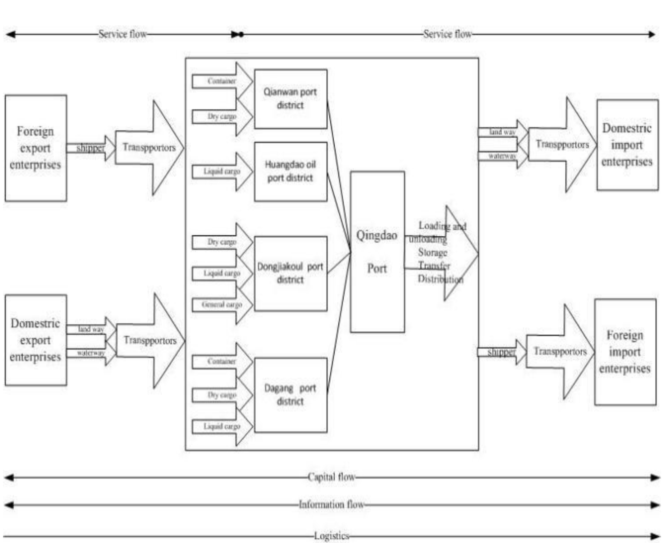
### 3.2. *Port Enterprise Supply Chain Risk*

The key to identifying port enterprise supply chain risk is finding the causal factors of uncertainty. In this study, we divide these factors into external and internal factors.

With respect to the influence of external factors, a port enterprise (as a country's "bridgehead" of import and export trade) impacts both international trade and the domestic macroeconomic situation. From the economic perspective, both global and domestic economic decline will affect a country's import and export trade; exchange rate risk, caused by exchange rate fluctuations, will also result in turmoil for the port enterprise supply chain. From the political perspective, the port enterprise is sensitive to aspects of the foreign political environment that increase its supply chain risk, such as the adverse effect of wars on oil prices, transport routes, expected economic growth, and consumer confidence. Further, export tax rebates and subsidy policy changes will affect the industry and enterprise's import and export trade, and may disrupt downstream port enterprises.

With respect to internal factors, uncertainty in members' development and overall supply chain operational mechanisms were identified as concerns. Uncertainty about members' development may result in unrest from the accumulation of port enterprise operational risks (including profitability, solvency, operational ability, development ability, and management level), the decline of suppliers and distributors' ability to control nodes, and changes in logistics efficiency. Supply chain stability and operational efficiency will greatly be influenced by operational imperfections of the supply chain organizational mechanism, as well as the interest distribution, cost sharing, and information sharing mechanisms.

In conclusion, when identifying port enterprise supply chain risk, we should combine the characteristics of port enterprise supply chain patterns, and consider the influences of internal and external factors.




## 4. Qingdao Port Group Supply Chain Risk Identification and the Construction of an Evaluation Model

### 4.1. *Qingdao Port Group supply chain analysis*

Qingdao Port Group is an ocean port enterprise with a service supply chain. The supply chain model is shown in Figure 2.

**Fig. 2.** Qingdao Port Group supply chain model

Figure 2 indicates that the Qingdao Port Group supply chain, compared to an enterprise supply chain, includes not only capital flow, information flow, and logistics, but also service flow. In addition, as a port enterprise, Qingdao Port Group represents the accounting node of the entire logistics chain. Similar to an iron ore business, its supply chain operations model includes "foreign mine—delivery through logistics business (ocean shipping company)—goods arrive at Qingdao Port—Qingdao Port Group arranges entry according to the goods' attributes, loading and unloading, storage, transfer, and distribution—goods are transported to the import enterprise through logistics service providers (iron and steel enterprise or iron ore trading company)."

### 4.2. *SCOR Model-Based Supply Chain Risk Identification for Qingdao Port Group*

As shown in Figure 3, the SCOR model divides the supply chain into five parts: planning, procurement, manufacturing, distribution, and return.

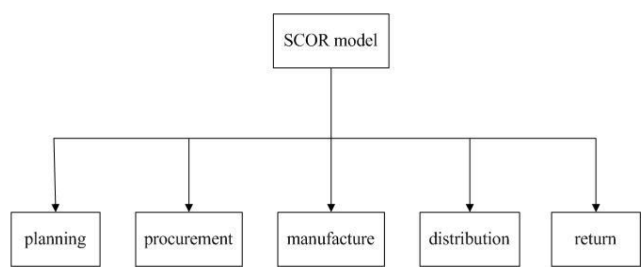



**Fig. 3.** SCOR model construction

The SCOR model is the first industry-wide standard supply chain operations reference model, but is more focused on manufacturing supply chain operations. The Qingdao Port Group supply chain is a service supply chain, with the Qingdao Port Group at its core. Its supply chain does not have "procurement" and "manufacturing" modules. Instead, a "port service" module is proposed, based on the earlier port enterprise supply chain analysis.

Further, supply chain operations risk is included in the hierarchical structure of the risk management model, but external risk is not. As a port enterprise, the operations and development of the Qingdao Port Group is closely related to the import and export trade. Therefore, it has both external environment-associated and operational risks. In addition, the SCOR model has the weakness of neglecting the capital flow risk analysis. "Three streams" in any class of problems will affect the healthy and stable operation of the entire supply chain. Therefore, capital flow risk is needed to guarantee the totality of the port enterprise supply chain. This paper only analyzes nuclear enterprise financial risks.

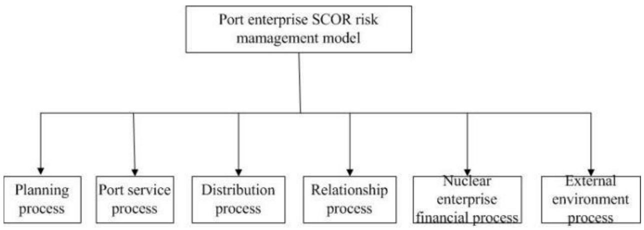



**Fig. 4.** Port enterprise SCOR risk management model

This paper combines the SCOR model with the results of domestic port enterprise supply chain risk research, and divides the Qingdao port group SCOR risk management model into six modules according to the characteristics of port enterprise supply chain operations. These include: planning process risk, port service process risk, distribution process risk, relationship process risk, nuclear enterprise financial risk, and external environment-associated risk, as shown in Figure 4.

#### 4.2.1. *Planning Process Risk*

Scientific and reasonable planning is directly related to the achievement of goals. The more complete the plan, the easier it is to follow the established direction with less uncertainty and achieve the goal. The port enterprise planning process should include two parts, as follows: internal planning process risk and supply chain planning process risk. The Qingdao Port Group example illustrates that internal plans include a strategic plan, berth plan, ship plan, handling plan, storage plan, transfer plan, and distribution plan. Supply chain plans mainly include a strategic plan and a risk prevention plan.

#### 4.2.2. *Port Service Process Risk*

At present, the Qingdao Port Group has four main services: loading and unloading, storage, transfer, and distribution. Port service process risk is related to the port service and distribution facilities, such as the rationality of port berth allocation, the operational efficiency of production (ship, crane and container, etc.), and the efficiency and responsivity of handling, storage, transfer, and distribution. As the core of the port supply chain, the port enterprise's service process risk is directly related to the operation of the entire supply chain. If this port service process experiences significant risk, breakdown of the entire port enterprise supply chain is likely.

#### 4.2.3. *Distribution Process Risk*

Distribution process risk constitutes one of the main logistics-associated supply chain risks of Qingdao Port Group. This includes transportation route selection risk, transportation equipment selection risk, logistics selection risk, port departure and entry risk, delivery risk, customs clearance risk, and goods defect risk. Among them, the first three risks will affect logistics cost control of the supply chain, while the last one is related to logistics quality. Others will affect logistics efficiency.

#### 4.2.4. *Relationship Process Risk*

Following completion of production by manufacturing enterprises, products are manufactured and can be delivered to consumers directly or through distributors. Port enterprise supply chain service changes follow logistics process changes. Most goods in the port enterprise supply chain are raw materials (dry cargo such as iron ore, or liquid cargo such as petroleum); an enterprise rather than the ultimate consumers represent the most downstream entity in the chain. The port enterprise supply chain is shorter than the manufacturing supply chain. The fifth SCOR model process is called "return." However, the port enterprise supply chain does not produce tangible products, and its services cannot be stored; it delivers a service that is non-refundable. "Return" for a port enterprise is always associated with the loss of supply chain members. The main risks are "the improvement of the member coordination mechanism, interest distribution mechanism, responsibility sharing and exit mechanism, and member information asymmetry."

#### 4.2.5. *Nuclear Enterprise Financial risk*

In the port enterprise supply chain, flows include not only information, logistics, and service flows, but also the core supply chain's capital flow. The core enterprise's capital flow risk is a financial risk that will affect the operational risk of the entire supply chain. Nuclear enterprise financial risks mainly include profit risk, debt risk, operational risk, development risk, and cash flow risk.

#### 4.2.6. *External Environment-Associated Risk*

External environment-associated risk mainly includes economic risk, political risk, and natural environment-associated risk. Economic risk is caused by domestic and international macroeconomic operations, exchange rate fluctuations, and international trade. Political risk refers to factors such as wars that lead to increased costs, and even to breakdown of the supply chain. Natural environment-associated risk is mainly manifested by the impact of natural disasters on port enterprises' production, and is related to the location of port enterprises and the choice of transportation routes.

### 4.3. *Construction of the SCOR-based Qingdao Port Group Supply Chain Risk Evaluation Model*

This paper divided the Qingdao Port Group's supply chain risk into six modules, namely: planning process risk, port service process risk, distribution process risk, relationship process risk, nuclear enterprise financial risk, and external environment-associated risk. According to scientific, systematic, significance, and operability principles, we constructed a supply chain risk evaluation index system for Qingdao Port Group by combining domestic and foreign research results, as shown in Table 2.

**Table 2**

Qingdao Port Group supply chain risk evaluation index system

| First class indicators | Second class indicators | Index explanation |
|---|---|---|
| Planning process risk (R1) | The improvement of the enterprise strategic plan<br>The improvement of berth plan<br>The improvement of ship plan<br>The improvement of handling<br>The improvement of storage | The more perfect, the lower the risk |

| | | |
|---|---|---|
| | The improvement of transfer | |
| | The improvement of distribution | |
| | The improvement of supply chain strategic plan | |
| | The improvement of supply chain risk prevention | |
| Port service process risk (R2) | The rationality of berth allocation | The more reasonable, the lower the risk |
| | The operation efficiency of production | |
| | Handling efficiency and the degree of response | The higher the efficiency, the more sensitive response, the lower the risk |
| | Storage efficiency and the degree of response | |
| | Transfer efficiency and the degree of response | |
| | Distribution efficiency and the degree of response | |
| Distribution process risk (R3) | The rationality of transport route selection | The more reasonable, the lower the risk |
| | The rationality of transport machine selection | |
| | The rationality of logistics selection | |
| | The timeliness of port departure and entry | The more timely, the lower the risk |
| | The punctuality of delivery goods | More on time, the lower the risk |
| | Port customs clearance efficiency | The higher the efficiency, the lower the risk |
| | Goods defect condition | The less defect of goods, the lower the risk |
| Relationship process risk (R4) | The improvement of member coordination mechanism | The more perfect, the lower the risk |
| | The improvement of member interest distribution mechanism | |
| | The improvement of member responsibility sharing mechanism | |
| | The improvement of member exit mechanism | |
| | Member information asymmetry | The more serious asymmetry, the higher the risk |
| Nuclear enterprise financial risk (R5) | Profit risk | Show as "return on equity" |
| | Debt risk | Show as "current ratio" |
| | Operation risk | Show as "operating cycle" |
| | Development risk | Show as "net profit growth rate" |
| | Cash flow risk | Show as "operating cash index" |
| External environment risk (R6) | Domestic and international macroeconomic operation risk | Assessment of GDP growth |
| | Exchange rate risk | Assessment of the appreciation of RMB |
| | International trade risk | Assessment of import and export trade |
| | Natural environment risk | Assessment of the probability of core business affected by natural disasters |
| | Wars risk | Assessment of the probability of core business affected by wars |

From Table 2, according to the RBS (Risk Breakdown Structure), this paper divided the supply chain risk of Qingdao Port Group into 37 specific indicators across 6 categories, namely: planning process risk (R1) with 9 specific indicators; port service process risk (R2) with 6 specific indicators; distribution process risk (R3) with 7 specific indicators; relationship process risk (R4) with 5 specific indicators; nuclear enterprise financial risk (R5) with 5 specific indicators; and external environment-associated risk (R6) with 5 specific indicators. In addition to the 5 specific quantitative indicators of nuclear enterprise financial risk, the remaining 32 specific indicators of risk are qualitative indicators.

## 5. Qingdao Port Group Supply Chain Risk Assessment Based on the SCOR–FAHP model

### 5.1. *The Improved AHP*

The concept of AHP improvement: in the calculation of the index weight, we still use the traditional AHP. Through expert investigation, we constructed the main criterion layer index and the pairwise comparison matrix of the sub-criterion layer index, calculated the eigenvalue of the maximum by the root value method, calculated the index weight, and then did a consistency check. The main improvement was to the calculation of the scheme layer index weight. In the traditional AHP, it is assumed that the number of scheme layers is $m$ and the number of sub-criterion layers is $n$; the comparison matrix of the scheme layer is $n \times [m \times (m-1)/2]$, according to the arrangement combination principle. In this paper, for example, the number of sub-criterion layers is 37, and the number of scheme selection layers (including the horizontal comparison port enterprise) is 4. In conclusion, the pairwise comparison matrix number of the scheme layer is 2664. Further, each matrix requires a consistency check, which results in low evaluation efficiency and poor operability. Therefore, this paper introduces the fuzzy mathematics principle and quantifies the specific characterization of the underlying index. For the qualitative index, experts in the relevant research and practice field (supply chain management experts in college and supply chain senior management personnel in enterprises) were invited to mark and summarize the average index weight. The calculation formula is:

The score of a qualitative index = average (expert grading).

We rendered the quantitative indexes dimensionless by using fuzzy mathematics analysis. The treatment principle is:

For the indexes where the maximum is sought, the process model is:

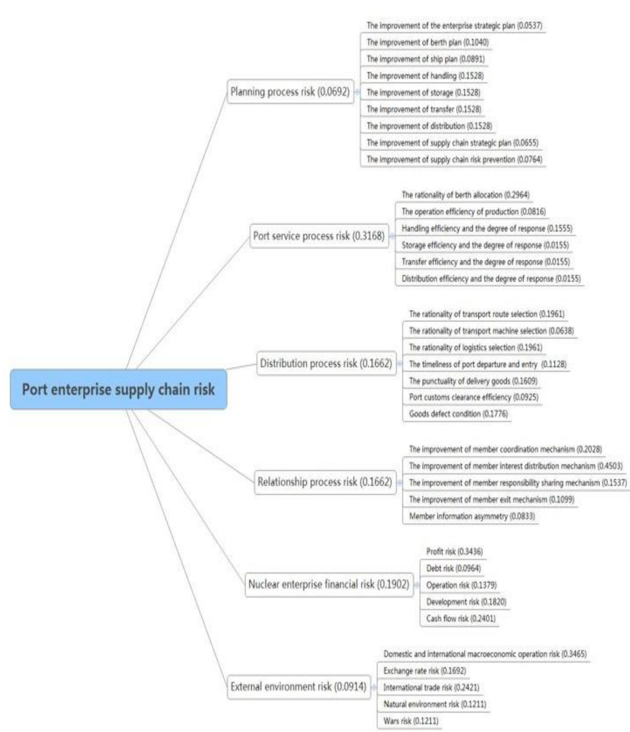
$$O_j = \frac{X_j - minX_i}{maxX_i - minX_i} \times 100$$

For the indexes where the minimum is sought, the process model is:

$$O_j = \frac{maxX_i - X_j}{maxX_i - minX_i} \times 100$$

In the formulas above, $max\, X_i$ refers to the industry maximum, while $min\, X_i$ indicates the industry minimum.

All the port enterprise evaluation scores can be obtained by calculating the product of specific indicators' score and the comprehensive weight, and summarizing them.



5.2. *Qingdao Port Group Supply Chain Risk Assessment*

For this survey, 168 questionnaires were distributed by e-mail to key domestic university teachers and graduate students, as well as to port enterprise management personnel in the domestic market. The response included 132 valid questionnaires, with 78 (59.09%) and 54 (40.91%) of the questionnaires from college staff and enterprise management personnel, respectively.

Figure 5 summarizes the index weights, calculated according to the above results.

**Fig. 5.** Summary of the port enterprise supply chain model index weights

Figure 5 indicates, based on the weight of the main criterion layer, that the index weights of risks R1 to R6 are 0.0692, 0.3168, 0.1662, 0.1662, 0.1902, and 0.0914, respectively. The first and last risks are relatively lower. The index weight is different from others in the sub-criterion layer, which embodies the principle of primary and secondary risks.

The Qingdao Port Group supply chain dimension scores are shown in Table 3.

**Table 3**

The summary of Qingdao Port Group supply chain risk scores

| First class indicators code | Second class indicators score | The highest score theoretically |
|---|---|---|
| R1(5.0883) | R11(0.2601) | R1(6.9200) |
| | R12(0.5614) | |
| | R13 (0.4624) | |
| | R14 (0.7402) | |
| | R15 (0.7613) | |
| | R16 (0.7825) | |
| | R17 (0.7825) | |
| | R18 (0.3626) | |
| | R19(0.3754) | |
| R2(24.4053) | R21(7.4181) | R2(31.6800) |
| | R22(1.9130) | |
| | R23(3.5469) | |
| | R24(3.7932) | |
| | R25(3.8425) | |
| | R26(3.8917) | |
| R3(12.5191) | R31(2.2488) | R3(16.6200) |
| | R32(0.7741) | |
| | R33(2.5422) | |
| | R34(1.4623) | |
| | R35(2.0056) | |
| | R36(1.1838) | |
| | R37(2.3023) | |
| R4(12.3328) | R41(2.6290) | R4(16.6200) |
| | R42(5.3885) | |
| | R43(1.9159) | |
| | R44(1.3334) | |
| | R45(1.0660) | |
| R5(10.4515) | R51(6.2621) | R5(19.0200) |
| | R52(1.3229) | |
| | R53(0.0000) | |
| | R54(2.4349) | |
| | R55(0.4316) | |
| R6(5.6720) | R61(1.9002) | R6(9.1400) |
| | R62(1.0052) | |
| | R63(1.4383) | |
| | R64(0.5534) | |
| | R65(0.7748) | |

5.3. *Results and Discussion*

To increase the comparability between the supply chain risk indicators of the Qingdao Port Group, the following changes were made: the index comparable score = index summary score / index theory highest score × 100. According to the principle above, the “comparability” treatment was applied to the Qingdao Port Group supply chain risk indicators (a perfect score is 100; the higher the score, the lower the risk). The results indicate the following:

In terms of planning process risk, which has the highest score of 6.9200, Qingdao Port Group’s actual score is 5.0883. Figure 6 shows the score for each dimension.

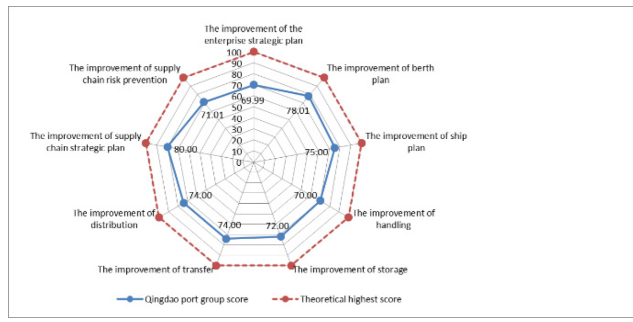



**Fig. 6.** Qingdao Port Group supply chain planning process risk scores

From Figure 6, it is clear that the scores are concentrated between 70 and 80. The highest score is 80, corresponding to “improvement of the supply chain strategic plan.” The two lowest scores are for “improvement of the enterprise strategic plan” and “improvement of the handling plan.”

For port service process risk, which has the highest score of 31.6800, the Qingdao Port Group’s actual score is 24.4053. Figure 7 shows the score for each dimension. From Figure 7, it is clear that the scores are in relative equilibrium. The highest score is 79, corresponding to “the rationality of berth allocation” and “distribution efficiency and the degree of response.” The lowest score is 72, with higher risk, corresponding to “handling efficiency and the degree of response.”

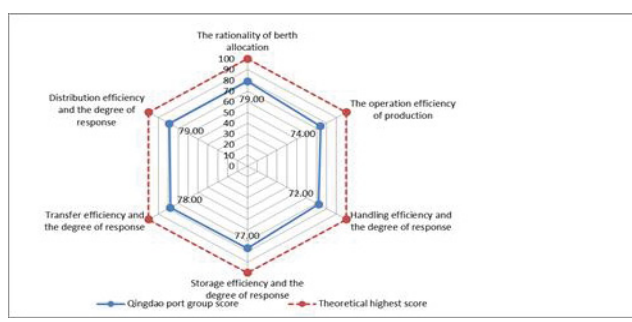



**Fig. 7.** Qingdao Port Group supply chain service process risk scores

For port distribution process risk, with the highest score of 16.6200, Qingdao Port Group’s actual score is 12.5191. Figure 8 shows the score for each dimension.

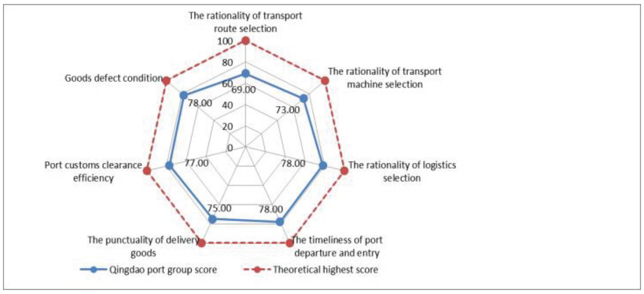



**Fig. 8.** Qingdao Port Group supply chain distribution process risk score

According to Figure 8, the highest score of 78 is assigned to "goods defect condition," "the timelessness of port departure and entry," and "the rationality of logistics selection." The lowest score of 69 in the higher risk category is assigned to "the rationality of transport route selection."

For port relationship process risk, with the highest score of 16.6200, Qingdao Port Group's actual score is 16.3328. Figure 9 shows the score for each dimension.

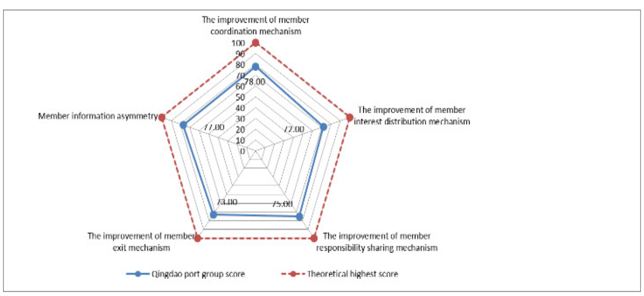



**Fig. 9.** Qingdao Port Group supply chain port relationship process risk score

From Figure 9, it can be seen that Qingdao Port Group's member coordination mechanism is relatively perfect in terms of supply chain relationship process risk—the same as for member information asymmetry. These indicators have higher scores, namely, 78 and 77, respectively. For port nuclear enterprise financial risk, which has the highest score of 19.0200, Qingdao Port Group's actual score is 10.4515. Figure 10 shows the score for each dimension.

Compared with all domestic listed companies in port, the Qingdao Port Group has a low profit risk, with a high risk for debt and development, and the highest risk for operations and cash flow.

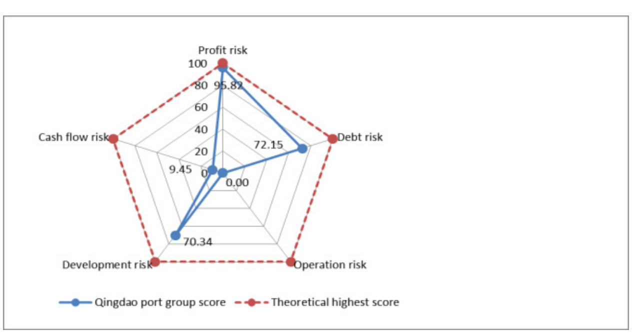



**Fig. 10.** Qingdao Port Group supply chain nuclear enterprise financial risk score

For external environment-associated risk, which has the highest score of 9.1400, the Qingdao Port Group's actual score is 5.6720. Figure 11 shows the score for each dimension.

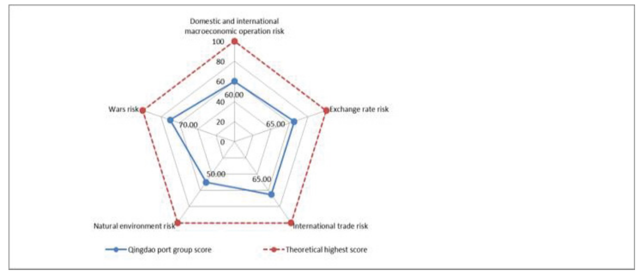



**Fig. 11.** Qingdao Port Group supply chain external environment-associated risk score

From Figure 11, it can be seen that some factors have adverse effects and increase Qingdao Port Group's supply chain macroeconomic operational risk. The factors include the macroeconomic decline, the appreciation of RMB, and slow foreign trade growth. In terms of natural disaster risk, consider that Qingdao Port Group is located in the north of China, at high latitude, and is an ice harbor. The port operations may be vulnerable to aspects such as cold. Therefore, it has a high natural disaster risk. For war-related risk, it should be noted that Qingdao Port Group is China's largest oil and iron ore terminal. Wars have a significant effect on crude oil imports, leading to an increased risk for the Qingdao Port Group. Figure 12 indicates that port service process risk, distribution process risk, and planning process risk are relatively low. Other risks are high, especially nuclear enterprise financial risk and external environment-associated risk. It requires Qingdao Port Group to draw a clear distinction between primary and secondary aspects in the process of strengthening supply chain risk control, and to focus on nuclear enterprise financial risk, external environment-associated risk, relationship process risk, and planning process risk. Figure 12 shows Qingdao Port Group supply chain risk dimension scores.

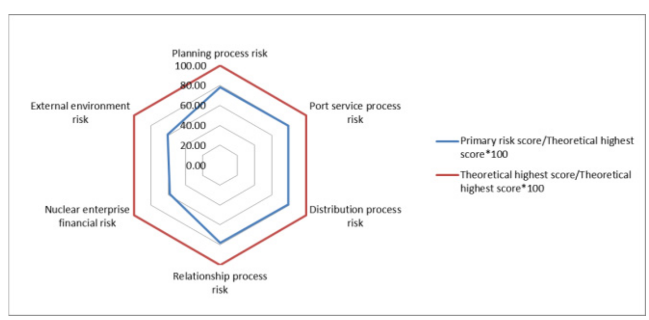



**Fig. 12.** Qingdao Port Group supply chain risk dimension scores

## 6. Countermeasures to Strengthen Qingdao Port Group's Supply Chain Risk Control

### 6.1. *Improve Supply Chain Strategic Plan and Reduce Planning Process Risk*

Risk assessment results indicate that improvement of Qingdao Port Group's supply chain strategic plan would lead to a reduction in the entire supply chain's planning process risk. Therefore, it is recommended that Qingdao Port Group's supply chain strategic plan is seen as key to risk prevention, and that a supply chain integration strategy is developed and combined with other strategies to support supply chain integration and reduce Qingdao Port Group's planning process risk.

### 6.2. *Increase Port Loading and Unloading Efficiency and Decrease Service Process Risk*

At present, Qingdao Port Group's supply chain service process risk is mainly concentrated in loading and unloading risk. The port loading and unloading processes should be optimized to prevent the risk associated with loading and unloading inefficiencies. To improve port service efficiency, Qingdao Port Group should transform from a traditional port firm to modern a logistics operation, and divide the functional areas into four port districts (Qianwan, Huangdao, Dongjiakou, and Dagang) in a rational way. Low-cost and high-efficiency organizational processes should be developed, and a modern comprehensive logistics service system should gradually be established. Qingdao Port Group should exploit China's policy-related opportunities for the development of "marine powers," "one belt and one road," and the "China and South Korea free trade area" with its scientific layout of sea-rail and sea-road intermodal transportation. The logistics resources of the whole port district and economic hinterland should be integrated, and the industry chains' upstream and downstream of the port should be extended.

### 6.3. *Select Rational Transport Routes and Equipment, and Control Distribution Process Risk*

The study's results indicate that Qingdao Port Group has a high distribution process risk on account of its low scores for "the rationality of transport route selection" and "the rationality of transport equipment." Control of Qingdao Port Group's distribution process risk can be strengthened by risk prevention and risk mitigation. Qingdao port's transport route and equipment selection assessment mechanisms should be developed according to the characteristics of ocean and port transport, and rational transport routes and equipment should be selected based on the principles of cost and time optimization, in order to reduce the risks associated with logistics costs and distribution processes.

### 6.4. *Strengthen Supply Chain Member Relationship Management, and Control Relationship Process Risk*

Study results indicate that the delay of the supply chain interest distribution mechanism, member exit mechanism, and member responsibility sharing mechanism leads to higher risks for supply chain interest distribution, member exit, and member responsibility sharing for Qingdao Port Group. The main alleviation methods are risk mitigation and risk transfer. In terms of risk mitigation, we should understand profit distribution risk, which is the core supply chain relationship process risk, and clarify members′ supply chain responsibilities, rights, and interests to ensure the symmetry of rights and obligations, so as to achieve the balance of benefits, risks, and contributions. In terms of risk transfer, supply chain contract management should be strengthened by designing and improving cooperation contracts. The external environment faced by the port enterprise supply chain is dynamic, with the flexibility to facilitate signing of a dynamic contract and establishing a long-term cooperative relationship.

### 6.5. *Establish a Supply Chain Risk Compensation Mechanism, and Pre-caution Financial Risk*

The study results indicate that Qingdao Port Group has a high debt risk and development risk and, specifically, high operational and cash flow risks. Qingdao Port Group can pre-caution financial risk through risk retention and risk prevention, so as to decrease financial loss, prevent capital chain breakdown, and pre-caution enterprise financial risk. For risk retention, supply chain development funds and risk compensation funds should be established to increase enterprise development funds and risk compensation funds and prevent capital chain breakdown. For risk prevention, Qingdao Port Group should promote the construction of a modern comprehensive port logistics system so as to strengthen the port's operational ability and improve freight turnover efficiency.

### 6.6. *Establish a Supply Chain Emergency Management Mechanism, and Pre-caution External Environment-Associated Risk*

Study results indicate that Qingdao Port Group faces a high macroeconomic operational risk and natural disaster risk. To mitigate risk and prevent destruction of the development of Qingdao Port Group's supply chain from unpredictable events, a supply chain emergency management mechanism should be established, and a contingency plan and emergency safeguard mechanism should be developed for force majeure events such as those associated with wars and the natural environment. Further, a supply chain management mechanism should be established for the port enterprise core; strategic cooperators should be engaged to improve the ability of upstream and downstream supply chain enterprises to deal with sudden incidents and to prevent supply chain breakdown as a result of these factors.

## 6. Conclusion

Under global economic integration, modern port enterprise becomes an important mechanism for global supply chain integration, and its role changes from transportation or distribution center to an integrated logistics service center. Given this background, it is of great theoretical and practical significance to strengthen research on supply chain assessment and port enterprise control. Considering Qingdao port as case study, and using an improved AHP method, the enterprise supply chain risk was evaluated with the aim of addressing existing enterprise supply chain risk problems; measures were put forward to strengthen the control and management of port enterprise supply chain risk.

Based on the results of this study, we draw the following conclusions：

1. The main concerns for the Qingdao Port Group are high port service process risk, port operation risk, port relationship process risk, and external environment-associated risk.

2. In order to strengthen supply chain risk control, the Qingdao Port Group must improve port service efficiency, enhance port operations management, and improve the supply chain risk prevention mechanism.

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