Research on Quantitative Risk Assessment Method of Packaged Cargoes Carried By Ship Based on Online Dynamic Big Data Fusion Technology

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Abstract: In this paper, a quantitative risk assessment method of packaged cargoes carried by ship based on online dynamic big data fusion technology was researched. In recent years, major accidents such as oil spill, fire, explosion and ship loss occurred frequently in shipborne cargo transportation. Due to the lack of real-time dynamic risk analysis, both early warning and emergency handling of those accidents are extremely difficult. In this paper, a risk transmission model was built, which based on the flow chain for cargo transportation. A system including the analysis of cargo transportation risk and quantitative assessment model based on real-time dynamic big data fusion technology was built. Finally, a scientific quantitative assessment method was formed. And a container ship passing through Shenzhen waters was taken as an example in order to verify the practicality of the method. In this way, it can realize the quantitative assessment of risk (especially the risk of dangerous packaged cargoes) in the waterage. What’s more, according to the assessment results, it can analyze the high-risk factors and high-risk parts in the process of waterage, and then realize the informationalized and modernized intelligent supervision in a whole process and all round way, which will effectively improve the level of accident prevention in China.

1. Introduction
In recent years, major accidents such as oil spill, fire, explosion and ship loss frequently occurred in shipborne cargo transportation. The reasons for those accidents vary. For instance, the accidents of ship loss are caused by overweight containers [1], false reporting of dangerous cargoes [2] and improper packing [3]; the accidents of oil spill are caused by collision and grounding of ships. Due to the lack of dynamic real-time analysis, both early warning and emergency handling of those accidents are extremely difficult. How to use advanced scientific and technological methods to ensure the safety of packaged cargoes and strengthen the safety supervision of packaged cargoes has become an urgent problem.

This paper analyzes the transportation risk of packaged cargoes and builds a quantitative assessment method for packaged cargoes on the basis of dynamic real-time big data fusion technology. And this model can realize the quantitative risk assessment of packaged cargoes (especially the risk of dangerous packaged cargoes) in the water age. According to the evaluation results, it can analyze the high-risk factors and high-risk links during the transportation of packaged cargoes, so as to realize the informationalized and modernized intelligent supervision in a whole process and all round way. What’s
more, it can also trace the dangerous sources, track the whole transportation process of dangerous cargoes and control risks. Ultimately, this method can effectively improve the level of accident prevention in China.

1.1. Risk transmission model based on the flow chain

The cargo transportation is not a single independent shipping process, but a chain process with interlocking multiple links. Among those links, once one has risks and cannot be controlled in time, the risks will be continuously transmitted to the next link. And actually, the eventual accident is always caused by the accumulation of risks in different links. In this way, this process is a risk flow chain on the path. For example, the chain of container exportation must go through various operations, such as production, storage, cargo packaging, packing, land transportation, shipping and water transport. However, water transport, as the last link, is the most vulnerable to risk accidents. If the risk factors of each operation accumulate step by step, the accumulative effect will eventually lead to the occurrence of accidents. So if risk management is only carried out at the last link, it is difficult to control the risks.

The transmission model covers all the flow chains[5] of shipborne cargo transportation, from the consignor to the destination port of cargo transportation. The risk of flow chain comes from its internal links and external environment. The risk transmission model based on the flow chain is shown in Figure 1.

![Figure 1. Risk Transmission Model Based on the Flow Chain in Packaged Cargo Transportation](image)

1.2. Risk transmission analysis based on the flow chain

As for the process of packaged cargo transportation, the risks mainly include four aspects: the risk of the cargoes themselves, the risk of cargo packaging, the risk of the container and the risk of the ship where the container is located. In addition, the flow chain of cargo transportation from the factory to the final terminal is also the process of risk accumulation. (1) the risk of ship[6]

① According to the condition of safe navigation

The condition of ship includes two aspects: one is the physical condition, which consists of ship size, hull, main engine, equipment material, structure and function, etc.; all of which cannot be changed by
ship staffs. The other is technically variable conditions, including ship loading conditions, ship safeguard and ship maintenance.

② According to the requirement of seaworthiness
A ship is deemed to be suitable for navigation or towing when the following five aspects are considered: a) ship shape, structure, strength, water density and other elements; b) personnel; c) equipment and devices: GPS, navigation maneuver equipment (main engine, steering gear, anchor gear), communication equipment, mooring and cargo lift equipment; d) safety facilities and cargo requirements; e) material and spare parts. According to statistics of relevant departments, about 27% of maritime accidents are caused by unseaworthiness. In the chapter 4 of Maritime Traffic Safety Law of the People's Republic of China, it is stipulated that if the ship is in a condition unsuitable for navigation or towing, the competent authority shall have the right to forbid it from leaving the harbour or order it to suspend its voyage, change its route or cease its operations.

③ According to the key items of PSC inspection and the main defects statistics of the ship during the inspection
According to the requirement of the SOLAS Convention and related regulations, PSC inspection has two major points: the competence of crews and the technical condition of ship. The key points of inspection concerning ship conditions are as follows: hull condition, structural strength, load line marking, fire rescue equipment, anti-fouling equipment, auxiliary equipment, electrical equipment, alarm equipment, navigation aids, radio equipment, mooring equipment, main engines, auxiliary equipment, rudder cargo and cargo-handling appliance, etc.

(2) the risk of cargoes
When the containers are transported, if the package and the box are intact, the mark is correct and clear, and the requirements of stowage isolation and binding are also met, then it is safe. However, sealing is required after packing. If there are some problems in the process of cargo transportation, such as packing breakage or improper management, it will lead to many safety problems in the container transportation, which will lead to various accidents. The safety risks of container transportation mainly include three aspects:

① Cargo risk
Since the cargoes themselves are dangerous, they should be packaged abiding by the relevant rules. And under normal circumstances, as long as the cargoes are packaged in conformity with the relevant rules of IMDG, the problems are less likely to happen. Nevertheless, if the dangerous cargoes are not packaged, or if the packaging does not meet the requirements, there's a high likelihood of problems during transportation. In addition, dangerous cargoes prohibited by waterway transportation may also be mixed in ordinary cargoes, to which should also be paid attention.

② Container risk
Used as dangerous cargoes carriers, containers load industrial waste from time to time. There is serious pollution inside. Therefore, before loading dangerous cargoes, in order to ensure the safety, containers should be thoroughly cleaned. Although containers themselves are strong and well-sealed, and can withstand a certain pressure, thus isolating dangerous cargoes, once the container is damaged or not tightly sealed, the container may enter the water or lead to the leakage of dangerous cargoes. That will result in serious pollution accidents, especially when the cargoes are spontaneously ignited cargoes, corrosive cargoes or poisonous cargoes.

③ Management risk of dangerous cargo containers
Improper stowage and isolation as well as false reporting are the most prominent problems in the management of dangerous cargo containers. In stowage, the suitable container location should be determined strictly according to the specific requirements of IMDG-Code for stowage and isolation of dangerous cargo containers. In addition, it is liable to cause potential security flaws by concealing and false-reporting dangerous cargo containers because in this case, the personnel and supervision departments will treat dangerous containers as ordinary ones. Then the shipping conditions are difficult to meet the specified requirements and the potential safety hazards are caused. What’s more, padding of
dangerous cargoes in containers, unreliable binding, ambiguous marking and even discrepancy between marking and actual packing are also common problems in container management.

(3) The risk of wharf
In the process of loading and unloading, the wharf must meet the safety requirements of cargo handling, and the wharf for dangerous cargo transportation should have the corresponding qualification. In addition, there may be risks of improper loading, unloading and stowage of cargoes at wharf.

(4) Risk of institution and personnel involved in the transportation chain
The risk analysis of each link in the container transportation chain is as follows:
① Consignor(shipper) risk
The consignor (especially the consignor of dangerous cargoes) should provide the contractual cargoes and the documents required for consignment. He also needs to properly pack the goods, mark and label the dangerous goods, and truthfully inform the official name, nature of the dangerous goods as well as the preventive measures to be taken.

The main reasons for the shipper's false report and concealment may be as follows: a) The shipper is tempted by huge profits. The ocean freight for dangerous cargoes is about 30% higher than ordinary cargoes; b) The shipper isn’t familiar with the cargoes and does not know that the consigned cargoes are dangerous; c) The understanding and assessment of consigned dangerous cargoes are insufficient; d) Some cargoes are restricted by some countries or shipping companies for various considerations. In this case, buyers can only sign sales contracts with the consignor in private, and the shipper completes the transportation by changing the name of the cargoes, providing false information or not providing transport documents for dangerous cargoes. e) Restrictions on the transportation of dangerous chemicals by a certain route also increase the risk of false reporting to a certain extent. f) Packing inspectors fail to fulfill their duties at the container packing site, which results in the quality of dangerous cargo containers not meeting the standard requirements, thus causing potential accidents. At the same time, packing inspectors also have the risk of false reporting. Packing inspectors play an important role in ensuring the safety of container transportation for dangerous cargoes.

② The risk of cargo agent
The shipper entrusts the cargo agent to carry out dangerous cargoes’ declaration and booking services. If the consignor did inform the cargo agent that those are dangerous cargoes, the cargo agent may also deliberately report them as ordinary cargoes. The cargoes false-reported by the cargo agent are easy to conceal and difficult to find. The reasons are as follows: a) The market of cargo agent is mixed, there are small-scale, poor credit, and low-risk cargo agencies; b) In order to avoid related transportation, surcharges and other related expenses, the cargo agent doesn’t declare dangerous cargoes deliberately; c) Consignors and cargo agents lack of knowledge of dangerous cargoes as well as knowledge of international rules of dangerous cargo transportation; d) The declarer has no declaration qualifications and does not understand the risks of cargoes.

③ The risk of shipping agency
Lack of strict management and careful examination of the cargoes may also result in transport risks. Some shipping companies refuse to carry dangerous cargoes, which leads to the lack of regular transport channels for dangerous cargoes on some sea route. And to a certain extent, that also causes that false reporting can’t be stopped despite repeated bans.

④ The risk of land transport enterprise
The consignor or the cargo agent entrusts a qualified trailer company to pick up empty containers at the yard, pack the cargoes in a factory or warehouse, transport the cargoes by land and ship them at the wharf. The risk factors in those steps are: a) if the trailer company uses trailers for non-dangerous cargoes to consign dangerous cargoes, or if in order to avoid supervision, the trail company loads dangerous cargoes in a trailer at the time of loading, and then replaces the head of the trailer with that of the trailer for non-dangerous goods and ship those dangerous cargoes as the ordinary cargoes, there will be a great risk. b) To carry dangerous cargoes requires the trailer driver to be qualified. If the trailer driver is not qualified to transport dangerous cargoes, that is to say, he/she does not understand the risks of dangerous cargoes.
cargoes’ transportation, it may also result in the risk in the process of container loading, transportation or other links.

⑤ The risk of ship owner (carrier)
   a) The risks caused by lack of qualifications. Some ineligible private bosses have docked their ships to companies qualified to transport dangerous cargoes. In this way, they can obtain the qualification to transport dangerous cargoes. These private shipowners pay a certain fee to the shipping company every year to make sure their ships are qualified to transport dangerous cargoes. Under these circumstances, the shipper and the carrier may collude to conceal the truth.
   b) Carrier's negligence in receiving cargoes. When the shipper does not provide the correct shipping name and the carrier is not familiar with the cargoes, incompatible cargoes may be mistakenly packed in the same container, which causes inappropriate stowage and isolation. What’s more, after shipment, the carrier may treat them as ordinary cargoes without special ventilation and observation of humidity. All of the above may eventually lead to accidents.
   c) The carrier’s lack of knowledge related to dangerous cargoes. Or he may reduce or completely disregard the isolation and stowage requirements in order to carry as many containers or cargoes as possible.

1.3. Characteristics of the risks in packaged cargoes transportation

Characteristics of the risks in packaged cargoes transportation are as follows.

(1) The risks of packaged cargoes are continuously transmitted and accumulated in the course of transportation, and the maritime transport area supervised by maritime authorities is the most dangerous part because of the accumulation of risks, which is the most difficult link to control.

(2) Sources of risk data involve multiple management departments, and the data is difficult to fuse.

(3) The risk factors are complex and the comprehensive risk value is difficult to quantify.

(4) Information risk may affect the operation of the whole logistics chain. Because the data information used for risk assessment includes almost all the information of the whole flow chain, the risk management and analysis are more challenging than the tangible loss.

2. Implementation process of quantitative risk assessment

2.1. Implementation design of data fusion

Data fusion is a multi-level process of multi-source data at certain grades, and each level represents different degrees of information abstraction. The process includes information detection, association, correlation, estimation and merging. Based on the feature level fusion method in multi-sensor data fusion method, this paper uses the neural network to synthesize and process the feature information extracted from the original information of each information source. The data fusion process uses artificial intelligence inference method for analysis and reasoning, and uses neural network as the method of target feature recognition. The framework of online dynamic big data fusion technology for packaged cargoes is shown in Figure 2.

2.2. Research on quantitative risk assessment method

(1) Hierarchical structure model of risk influencing factors

Firstly, establish an index system of risk assessment for packaged cargoes. Secondly, build a hierarchical model based on the index system.

Target level A is "the risk value of packaged cargoes", and in criterion level B, four index modules are established, namely "ship-fitness", "cargo-fitness", "port-fitness" and "personnel-fitness". The index modules of index level C are established under the each four index module of criterion level. Among them, "shipping company performance", "crew", "related personnel in the logistics chain" and "related personnel performance in the logistics chain" have established their sub-modules respectively. The risk assessment index system of packaged cargoes and the hierarchical structure model of risk influencing factors are shown in Figure 4.
Analytic Hierarchy Process (AHP) is used to determine the weight of index. By comparing the evaluation indices in the same level, the most important judgment matrix can be obtained, which can determine the importance order of those factors.

(2) Determination method of index weight relation
This study compares the relative importance of the same level indices by experts' scoring. $S_{ij}$ indicates the importance of the evaluation index $S_i$ relative to the evaluation index $S_j$. The range of values is 1-9 (see Figure 3). A pairwise comparison matrix between the evaluation indices is established (see Equation (1)). Compute the eigen vectors of pairwise comparison matrix for each level index. After normalization, the weight vector can be obtained $\omega = (\omega_1, \omega_2, \ldots, \omega_n)$ and $\omega_n$ is the corresponding weight of evaluation index n. The final weight results of each index calculated in this study are shown in Table 1.
Figure 3. Proportional Scale of Index’s Relative Importance

\[
B = \begin{bmatrix}
    b_{11} & b_{12} & \cdots & b_{1n} \\
    b_{21} & b_{22} & \cdots & b_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    b_{n1} & b_{n2} & \cdots & b_{nn}
\end{bmatrix}
\]  

(1)

Table 1. Weight calculation results of each index

| First level index | Second level index | Third level index | Weight \( \omega_i \) |
|-------------------|--------------------|-------------------|-----------------------|
| **Cargo-fitness (\( \omega_1 = 0.322 \))** | Name of cargoes | / | 0.0596 |
| | Type of cargoes | / | 0.0984 |
| | Packaging of cargoes | / | 0.0366 |
| | Container weigh | / | 0.0196 |
| | Safety of container | / | 0.1392 |
| | State of cargoes | / | 0.0316 |
| | Stowage or lashing of cargoes | / | 0.2348 |
| **Port-fitness (\( \omega_2 = 0.0926 \))** | Standardized assessment of safety in production | / | 0.5054 |
| | Number of accidents at the wharf | / | 0.1949 |
| | Wharf credit | / | 0.1245 |
| | Number of administrative penalties involving danger prevention | / | 0.1224 |
| | Number of defects in danger prevention inspection | / | 0.0528 |
| **Ship-fitness (\( \omega_3 = 0.446 \))** | Number of accidents of ship | / | 0.0323 |
| | Ship type | / | 0.0338 |
| | Ship age | / | 0.029 |
| | Focus tracking ship or not | / | 0.405 |
| | Ship detention | / | 0.026 |
| | Number of defect records based on FSC inspection | / | 0.0897 |
Figure 4. Risk Assessment Index System for Packaged Cargoes and Hierarchical Model of Risk Influencing Factors

(3) Consistency test
If the random consistency ratio CR is less than 0.1, the consistency test is passed. The CR values of each level in this study are shown in Table 2. The CR values of each level meet the need of the consistency test.
Table 2. CR value of each level

| N | target level | criterion level | index level |
|---|--------------|-----------------|-------------|
|   | risk of packaged cargoes | cargo-fitness | personal-fitness |
|   |   | port-fitness | ship-fitness |
|   |   |   | cre |
|   |   |   | performance of related unit in logistics chain |
|   |   |   | related personnel in logistics chain |
|   |   |   | performance of shipping company |
| CR | 0.0439 | 0.0971 | 0.0912 | 0 | 0.088 | 0 | 0.0162 | 0.0956 | 0.0963 |

(4) Determination of the evaluation index’s membership

Based on the relevant research results, this study establishes a one-to-one correspondence between the specific evaluation criteria of indices and the degree of risk, and builds the membership function of indices. According to the corresponding evaluation criteria, the risk can be divided into five levels: extremely high, high, general, low and extremely low. The continuous quantification method of fuzzy membership function is constructed. In this study, large Cauchy distribution and logarithmic function are used as membership functions:

\[
f(x) = \begin{cases} 
(1 + \alpha(x - \beta)^2)^{-1}, & 1 \leq x \leq 3 \\
\alpha \ln x + b, & 3 \leq x \leq 5 
\end{cases}
\]  

(2)

\(\alpha, \beta, a, b\) are undetermined constants

When the risk is extremely high, the degree of membership is 1, when the risk is general, the degree of membership is 0.8, and when the risk is very low, the degree of membership is 0.01. That is, \(f(5) = 1, f(3) = 0.8, f(1) = 0.01\). So the calculation results are \(\alpha = 1.1086, \beta = 0.8942, a = 0.3915, b = 0.3699\).

Then the membership function of the evaluation indices determined in this study is:

\[
f(x) = \begin{cases} 
(1 + \alpha(x - \beta)^2)^{-1}, & 1 \leq x \leq 3 \\
0.3915 \ln x + 0.3699, & 3 \leq x \leq 5 
\end{cases}
\]  

(3)

Based on the requirements of international conventions related to packaged cargoes and the practical experiences of junior managers, the author has studied and formulated the evaluation criteria for each assessment factor. The evaluation level can be determined by referring to that evaluation criteria.

(5) The model of multi-level fuzzy comprehensive evaluation[10]

The FCE (Fuzzy Comprehensive Evaluation) judgment matrix is generated by using the indices of each factor of the analytic hierarchy model as the evaluation index. The FCE judgment matrix is used to calculate the cargoes’ known information obtained by the big data support system, then obtain the comprehensive evaluation result of the cargo transportation risk. The results of comprehensive evaluation are shown in Table 3.

Table 3. The results of comprehensive evaluation

| Evaluation target | Comprehensive evaluation score |
|-------------------|--------------------------------|
| Risk assessment of shipborne packaged cargoes | \(H = \sum_{i=1}^{n} S_i w_i\) |

In this formula: \(H\) is the score of solid bulk cargo transportation risk, \(1 < H \leq 5\); \(S_i\) is the score of each index, \(1 < S_i \leq 5\); \(W_i\) is the comprehensive weight of each index; \(n\) is the number of the index. In the final calculation result, if \(4 \leq H \leq 5\), the transportation risk is extremely high; if \(3 \leq H < 4\), the transportation risk is high; if \(2 \leq H < 3\), the transportation risk is general; if \(H < 2\), the transportation risk is low.
3. Case study
This method can be applied to the dynamic supervision of packaged cargoes by maritime department, port supervision department, customs, inspection and quarantine department and other regulatory authorities. And it can also be applied to the selection of the target containers in the open-package inspection. The author verifies the practicability of the method through the following examples of open-package inspection. The object of this assessment is a Singaporean container ship passing through Shenzhen waters. The ship departs from Shanghai Port and is berthed by Yantian Port. The final destination is the Port of Tanjung Pelepas in Malaysia.

(1) Assessment factors
- Name of cargoes: Hydrogen Cyanamide; State of cargoes: liquid state; Stowage or lashing of cargoes: the binding plan is unreasonable (the cargoes need temperature control, which is not considered by the binding plan); Type of cargoes: 6.1 and the packaging is III (according to IMDG rules); Container weight: 61880t; Type of containers: container for dangerous cargoes; Safety of container: container inspection report with incomplete content; Packaging of cargoes: barrel; Standardized assessment of safe production at the wharf: Level 3; Credit of the docked wharf: Non-concealment; Number of defects in danger prevention inspection: more than three times; Ship type: container ship; Ship age: 15 years; Focus tracking ship or not: no; Number of administrative penalties involving danger prevention: more than three times; Crew certificate: with certificate; The cargo agent has two cases of concealment. The rest of the data is missing and the risk takes the intermediate value.

(2) The verification results
Bringing the assessment factors mentioned above into the risk assessment model proposed in this paper, then the results can be worked out:

| Target of the assessment | Comprehensive evaluation score |
|--------------------------|--------------------------------|
| Risk of ship-fitness     | H₁=2.57                        |
| Risk of cargo-fitness    | H₂=3.70                        |
| Risk of port-fitness     | H₃=3.48                        |
| Risk of personnel-fitness| H₄=2.90                        |
| Comprehensive assessment results | H=3.06                     |

Therefore, according to the comprehensive assessment results, the risk of the packaged cargoes is high (H=3.06), which should be checked as the target box. In addition, in the process of cargo transportation, the risk of cargo fitness (H₂ = 3.70) and port fitness (H₁ = 3.48) is high, so the cargoes and the port should be the key link of supervision and inspection. In the actual transportation process, the ship has a leakage accident in Shenzhen sea area, which is consistent with the assessment results of this model.

4. Conclusion
(1) This study puts forward a risk assessment index system for packaged cargoes based on ship-fitness, cargo-fitness, port-fitness, personnel-fitness. According to the requirements of relevant international conventions and combined with the practical experience of junior managers, the evaluation criteria of each assessment factor are formulated.

(2) This study constructs risk transmission model based on the flow chain for packaged cargoes, and a system including the analysis of cargo transportation risk and quantitative assessment model based on real-time dynamic big data fusion technology.

(3) In this study, a quantitative risk assessment method for packaged cargoes based on online dynamic big data fusion technology is proposed, and its practicability is verified by an example of a container ship passing by Shenzhen waters. This method can be applied to the dynamic supervision of packaged cargoes by maritime department, port supervision department, customs, inspection and quarantine.
department and other regulatory authorities. And it can also be applied to the selection of the target containers in the open-package inspection.

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