Vulnerability Evaluation of Port Logistics System Under Public Health Emergencies

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Abstract: It is the goal that evaluating scientifically port logistics system vulnerability level under public health emergencies, exploring the influencing factors of brittleness and improving the production operation and management efficiency of port logistics system. According to the production practice of port logistics system and vulnerability theory, a vulnerability evaluation index system of port logistics system under public health emergencies is established in five aspects, including external risk disturbance, human resource management level, infrastructure level, operation and management level, and intelligence level. The combinatorial weights are obtained by combinatorial empowerment method of game theory, and it is used to process data that evidence theory improved by conflict correction process and mass function with normal cloud model. The vulnerability of Dalian port logistics system is analyzed empirically, and the result is better effectiveness.

1. INTRODUCTION

With normalizing the prevention and control of COVID-19, research of the mechanism of the impact of public health emergencies, especially COVID-19, on the operation and management of port logistics systems is gradually increasing. Xu1 used data from major Chinese ports to construct a model to investigate the influence of macroeconomics, epidemic and government on port operations, and the results showed that all three have a strong influence. Tai2 took Shanghai port as an example to build a system dynamics model that studied the impact of different epidemic states on the port, and the study showed that the epidemic had a greater impact on passenger transportation, while the risk of overseas epidemic and cargo stranding should be borne in mind. Most researchers analyzed the influencing factors of the epidemic on the port and shipping industry from the perspective of macro industry, and did not explore the problems existing in the production and management process of port logistics system under public health emergencies and their solutions.

Vulnerability is a property that characterizes the internal and external influence of the system, while the system also exhibits different vulnerabilities under different perturbations. Currently, vulnerability research has developed from a single discipline to multi-disciplinary as well as coupled systems. In the field of port and navigation, vulnerability is mainly studied in the vulnerability of maritime network and port and navigation system assessment. In terms of maritime network vulnerability, Li3 recognized the uncertainty of influencing factors of maritime transport nodes to construct an improved catastrophe model based on factor analysis and make an empirical evaluation of the key nodes of sea lanes in China. Zhang4 analyzed the topological structure characteristics of the container shipping network by the complex network theory, and simulated the variation conditions of the characteristic parameters of the container shipping network under the two modes of port random failure and deliberate attack. In terms of port and navigation system assessment, HSIEH5 examined the vulnerability of port failures from an interdependency perspective, and evaluated port vulnerability, four international commercial ports in Taiwan were employed as empirical cases, through semi-quantitatively systematic methods, including fuzzy cognitive maps and sensitivity model, while geographic information systems are used to clarify the spatial-functional interdependency. Cao5 proposed a fast reaction-based port vulnerability assessment framework which allows the quantification of ex-post port vulnerability and applied to the case of the 2015 Tianjin Port explosion, one day and four months after the explosion, in two assessment periods. In the existing research on the port system and its vulnerability assessment, the vulnerability theory has not been introduced into the application of the evaluation of the port logistics system under similar public health emergencies. By studying the vulnerability of port logistics system and its anti-vulnerability strategy under public health emergencies, it has certain reference value for the research on the production operation and management optimization of port logistics system at the present stage.

Combined with the background of COVID-19, this paper puts forward a brand new index system of port logistics system, enriching the evaluation research of port logistics system. Meanwhile, aiming at the index system,
a method based on game theory for combination weighting and evidence theory for qualitative index evaluation is proposed, which provides a certain reference for the qualitative evaluation research of port and navigation. Finally, an empirical analysis of Dalian Port is carried out to explore the anti-vulnerability strategy of Dalian Port logistics system under public health emergencies.

2. Vulnerability evaluation indicator system

The Regulations on Emergency Response to Public Health Emergencies states that a public health emergency is a kind of events that occur suddenly and cause or may cause serious damage to public health, including major infectious disease epidemic, mass unexplained disease, major food and occupational poisoning and other events that seriously affect public health. The port logistics system is a complex system, which is both a link in the supply chain and a node in the logistics chain, and its internal composition consists of multiple subjects that does its own job and collaborates with each other to complete the service of changing the displacement of goods at the port, mainly including the Health and Welfare Commission, the port office, border inspection, customs, the Maritime Bureau, port enterprises, shipping companies and cargo owners, with each of the multiple subjects.

2.1 Overview of the vulnerability theory of port logistics system under public health emergencies

Public health emergencies are characterized by diversity of causes, wide spread, complexity of hazards, continuous generation of new events and frequent occurrence of events, which are difficult to predict in port logistics systems. Vulnerability theory takes into account the internal and external conditions of the system and their interactions to analyze the impact elements of the system in a more comprehensive manner. The main elements of vulnerability include exposure, which is the set of characteristics outside the system, sensitivity and adaptability, which are the sets of characteristics inside the system. It is systematically identified the vulnerability-causing factors and provided scientific suggestions for the prevention and management of public health emergencies by analyzing vulnerability of port logistics system under public health emergencies.

Combining the vulnerability theory and the practice of port, this paper summarizes the definition of port logistics system vulnerability under public health emergencies as follows: "the probability of the port logistics system being subjected to external perturbation, the degree of adverse impact when subjected to external perturbation, and the ability to recover from the adverse impact to normal operation under public health emergencies". There is a recursive relationship between the three characteristics of vulnerability of port logistics systems under public health emergencies. The first characteristic of vulnerability is the exposure reflecting the disturbance of public health emergency outside the system, the second is sensitivity reflecting the impact of public health emergency disturbance into the system, and the third is adaptability reflecting the ability to overcome the disturbance of public health emergencies. The analysis framework of the recursive evolution of vulnerability is shown in Figure.1.

Figure.1 Framework for analysis of the sequential evolution of port logistics system vulnerability under public health emergencies

2.2 Vulnerability evaluation index system of port logistics system

Established in the above theories, this paper establishes a vulnerability evaluation index system for port logistics systems under public health emergencies as shown in Table.1. It is based on the study and policies of port logistics and public health emergencies, the operation and management practices of port logistics systems, and consultation with port research experts and relevant practitioners.

Table.1 Vulnerability evaluation index system of port logistics system under public health emergencies

<table>
<thead>
<tr>
<th>Vulnerability characteristics</th>
<th>Criterion layer</th>
<th>Specific indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Disturbance of external risk (B1)</td>
<td>Regional volume of imports and exports (C1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of arriving ships (C2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Governmental stringency index (C3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cumulative number of confirmed cases (C4)</td>
</tr>
</tbody>
</table>
3.2 Steps of vulnerability evaluation

Suppose that \( \theta \), called frame of identification, is a finite set, which contains \( N \) elements, and \( \mathcal{A} \), called proposition, is subset of \( \emptyset \), which contains all subsets of \( \emptyset \) and has 2\( N \) elements, is a power set of \( \emptyset \). Mass function (or called BPD function) is a mapping relation which is expressed as below:

\[
m: \mathcal{O} \to [0, 1], \quad A \mapsto m(A)
\]

Thereinto, \( m(A) \), called evidence value, indicates the degree to which the evidence supports the proposition \( A \). In particular, \( m(\emptyset) = 0 \) and \( \sum_{A \subseteq \emptyset} m(A) = 1 \).

In the evidence theory, it is the core and difficult point that constructs a appropriate mass function, which realizes the reconversion between quantitative data and qualitative language. Cloud model, especially normal cloud model, fits the mass function, where the specific constructed process shown in Figure.2.

![Figure 2: Constructed process of mass function based on normal cloud model](image)

The results of the traditional evidence theory are contrary to the intuitive judgment and need to be further modified. It is introduced that a conflict correction algorithm based on the conflict coefficient, Jousselme distance and Pignistic probabilistic distance. The specific process is shown in Figure.3.

![Figure 3: Process of evidence conflict correction algorithm](image)

2.3 Weight calculation of indicators

There are generally two methods of obtaining indicator weights, including subjective and objective weighting methods. In order to take into account the characteristics of both, this paper uses the combination weighting method based on game theory, with the goal of Nash equilibrium. In order to take into account the characteristics of both, this paper uses the combination weighting method based on game theory, with the goal of Nash equilibrium. Combined with Indicator data situation, the subjective weights are obtained by Delphi method and processed by cloud model, and the objective weights are obtained by CRITIC assignment method.

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### 3. Evaluation methodology based on improved evidence theory

Most of the indicators are qualitative indicators in this paper, which need to be quantified by using Delphi method, but there are differences and even conflicts in expert evaluation results, which need to be combined by using reasonable and effective methods. Evidence theory is a kind of inferential decision-making method based on uncertainty evidence, which can effectively eliminate the conflict among the evidence and neutralize the subjectivity and ambiguity of the evaluation process, so this paper proposes a vulnerability evaluation method of port logistics system based on evidence theory.

#### 3.1 Improved evidence theory

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The second is calculating weights of indicators. Experts are invited to score the degree of importance of indicators, where the weight rubric levels and the range of assigned values are shown in Table.2. Subjective weight values are obtained by cloud model, objective weight values are obtained by CRITIC method, and finally combined weight values are obtained by game theory.

The third is scoring and calculating of evaluated value of indicators. Experts are invited to score the indicators with minimum and maximum scoring values, where the evaluating rubric levels and scoring ranges are shown in Table.2, and the value-estimating matrix is obtained. According to the processes in Figure.1 and Figure.2, improved matrix of evidence is obtained after transformation of mass function and correction of conflicts. Finally, the matrixes of evidence of comprehensive indexes are calculated by weighted calculation.

The forth is analysis of evaluation results. According to the principle of maximum affiliation, it is the maximum evidence value is used as the result of each indicator and the comprehensive evaluation, and further discussed with practice.

Table 2 Reference standard of evaluation and cloud scale

In conclusion, it is suggested to improve the epidemic warning by big data technology and the level of automated production and operation efficiency. Meanwhile, capacity of risk pro-warning is insufficient. The evaluation results of C19 and C21, which reflect the capability of risk pre-warning is "lower level". On the one hand, economic demand and policy control led to the decline of production and operation efficiency. Meanwhile, capacity of risk pro-warning is insufficient. The evaluation results of C19 and C21, which reflect the capability of risk pre-warning by big data technology and the level of automated construction, are both "lower level". It indicates that Dalian Port still has deficiencies in big data technology, especially in the risk pro-warning of epidemic. Meanwhile, the automation degree of terminals in each port area is not high, while the dependence on manual labor is large. In a word, it reflects that the intelligent construction of Dalian Port logistics system still needs to be improved.

In conclusion, it is suggested to improve the epidemic prevention and control mechanism, the management of
human resources, and the application of intelligent technology in Dalian Port logistics system.

4. Conclusion

It can help prevent and reduce its impact that analyzing the vulnerability of port logistics system under public health emergencies and exploring anti-vulnerability strategies. However, the index system cannot cover all the practical connotations of port logistics system production and management due to the limitation of index selection. Meanwhile, as the COVID-19 continues and the prevention and control gradually tends to normalize, the connotation of port logistics system vulnerability will be also changing, so the actual operation and management mechanism of port logistics system and the links or cargo types that are more affected by the epidemic should be further studied, and the vulnerability indicators of the port logistics system should be further improved in the context of normalized prevention and control.

References