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A Study on the Assessment of Key Influencing Factors of Emergency Logistics System Reliability Based on DEMATEL-AISM Model

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Abstract: In order to identify the key influencing factors of emergency logistics system reliability, improve the reliability of emergency logistics system and ensure the smooth and efficient operation of emergency activities, Firstly, based on the connotation of the reliability of emergency logistics system, the factors impacting the reliability of emergency logistics system are organized and summarized, screened and analyzed, and the reliability assessment metrics system of emergency logistics system containing four primary indicators and seventeen secondary indicators is constructed. Secondly, the DEMATEL method was used to clarify the key influencing factors of the reliability of emergency logistics systems and the degree of interaction between each influencing factor, and use the AISM method to reveal the interaction relationships between factors. Finally, through the analysis of the model construction results, it is found that: the causal attributes of the factors determined by the DEMATEL method and the AISM method are consistent, and the hierarchy in which the factors are classified by the AISM method is significantly correlated with the causal degree of the factors obtained by the DEMATEL method. Combining the DEMATEL method and the AISM method, it was finally determined that the focus of the reliability improvement of the emergency logistics system should be placed on six key influencing factors: organizational coordination capability, rapid response capability, support of advanced technology, expert consultants, satisfiability of emergency supplies reserve, and flexibility of production system.

Keywords: emergency logistics; system reliability; decision laboratory method DEMATEL; adversarial explanatory structural model AISM

1. Introduction

The outbreak of the COVID-19 at the end of 2019 has brought serious impact on both the economy and the safety of people's lives in China. The sudden public health event has caused a serious impact on the emergency logistics system, revealing its own shortcomings and deficiencies, such as insufficient transportation capacity, insufficient rapid response capability, and inadequate supply of emergency materials. Based on this,

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the Party Central Committee emphasizes "to improve the national emergency management system and enhance the ability to deal with emergency events", so as to improve the reliability of the emergency logistics system.

The reliability of emergency logistics system is a kind of capability, that is, the ability to satisfy the needs for materials, logistics facilities and equipment, and personnel in emergency situations. However, due to the sudden and urgent nature of emergency logistics, during the implementation of logistics activities, the emergency logistics system is often affected by various internal and external factors, making its reliability difficult to control, which may lead to failure to meet the various needs in the emergency situation and cause irreparable losses. Thus, it is necessary to evaluate the critical influencing factors that impact the reliability of emergency logistics systems, so as to propose targeted countermeasures to enhance system reliability.

2. Overview of research on the reliability of emergency logistics system

Scholars at home and abroad have done a lot of research on the reliability of emergency logistics systems. Foreign scholars Thomas[1](2002) first introduced reliability theory into the study of supply chain and developed a supply chain reliability evaluation method for emergency logistics system based on reliability interference theory. Wang Jinfeng et al[2](2011) constructed a comprehensive evaluation model to assess the reliability of emergency logistics system for coal mine floods, which uses functions and comprehensive correlation to measure the interactions among indicators to better assess the reliability of the whole system. Wang Qingrong et al[3](2014) used the virtual emergency logistics collaborative system as the research object, and used a combination of fuzzy theory and dynamic Bayesian network to analyze its reliability. Zhu Changfeng[4](2014) used Holonic system modeling technique to construct a virtual emergency logistics collaborative system and analyzed its reliability by using Bayesian analysis method. Wang Weiqiang et al[5](2017) based on the subjective attitude and risk awareness of decision-makers, and combined with the cumulative prospect theory, the emergency logistics transportation path selection model was constructed. Guo Yongmei et al[6](2018) applied the theoretical approach of reliability engineering to the research of emergency logistics system, and constructed, optimized and solved the reliability model for emergency logistics distribution system and emergency logistics material system. Jiang et al[7](2020) used the analytical network model to determine the critical factors affecting ELSR, and the research results showed that the emergency material supply system and the emergency logistics organization and control system occupy a significant position in emergency relief.

In summary, existing domestic and international studies on the emergency logistics systems reliability mainly involve the reliability analysis and optimization of emergency logistics systems, or the reliability study of a single emergency logistics subsystem, and fewer studies have explored the key influencing factors impacting on the emergency logistics systems reliability from a holistic perspective. The paper constructs the reliability assessment index system of emergency logistics system, analyzes the degree of influence and relationship among the factors impacting on the emergency logistics system reliability of by using DEMATEL-AISM model, derives the critical influencing factors, and clarifies the hierarchical structure among the factors.

3. Emergency logistics system reliability assessment index system construction

The emergency logistics system is a complex organic whole, From a microscopic point of view, the system consists of many smaller subsystems, and whether the emergency logistics system can meet the emergency needs when an emergency event is encountered depends on the degree of synergy and cooperation of the subsystems. Therefore, the research on the emergency logistics system reliability can be shifted to the research on the reliability of smaller subsystems.

Firstly, the previous mature research results were sorted out, and the factors impacting on the reliability of emergency logistics system were collected and summarized, and indexed. Secondly, the emergency logistics system was subdivided, and after subdivision, some more easily quantifiable indicators were selected to describe each subsystem. Finally, a questionnaire survey was conducted on emergency logistics-related enterprises and emergency logistics experts, and after several rounds of consultation and feedback, the reliability assessment index system of emergency logistics system containing four primary indicators and seventeen secondary indicators was finally constructed. Specifically, as shown in Table 1.

Table 1. Emergency logistics system reliability assessment index system.

Dimension	Influence factor	Number
Emergency Logistics Information System	Timely feedback	X_1
	Accuracy of information	X_2
	Real-time sharing	X_3
Emergency Logistics Coordination and Control System	Rapid response capability	X_4
	Organizational coordination ability	X_5
	Ability to establish emergency planning mechanism	X_6
	Support of advanced technology	X_7
	Expert consultants	X_8
Emergency logistics transportation and distribution system	Reasonable path planning	X_9
	Reasonableness of dispatch center setting	X_{10}
	Reasonableness of transportation volume	X_{11}
	Reasonable transportation and distribution tools	X_{12}
Emergency material supply system	Timeliness of emergency material supplies	X_{13}
	Accuracy of emergency material supplies	X_{14}
	Security of emergency material supplies	X_{15}
	Satisfiability of emergency supplies reserve	X_{16}
	Flexibility of production system	X_{17}

Table 2. Expert evaluation of semantic scales

Semantic variables	No effect	Lower impact	Moderate impact	Higher impact	High Impact
Scale	0	1	2	3	4

4. Assessment of Key Influencing Factors of Emergency Logistics System Reliability Based on DEMATEL-AISM Model

4.1. Overview of DEMATEL and AISM

The Decision-making Trial and Evaluation Laboratory (DEMATEL) is an effective method used to study the key influence factors of a system. The initial direct influence matrix is constructed by analyzing the logical relationships among the factors in the system, and the influence degree and the influenced degree of the factors are calculated, and finally the centrality degree and the cause degree of the factors are obtained[8]. However, the DEMATEL method can only clarify the degree of interaction between factors, but cannot reveal the interactions relationship between factors.

The Adversarial Interpretive Structure Modeling Method (AISM) introduces the game adversarial idea into it based on the Interpretive Structure Model (ISM). In essence, without losing the system function, according to the opposite hierarchical extraction rules, and combined with the skeleton matrix, a pair of minimal hierarchical topological diagrams is finally obtained[9]. the AISM model can only reflect the inter- impact relationship among the influencing factors, but cannot reveal the degree of inter- impact among the factors.

The advantage of integrating DEMATEL and AISM is that it can not only determine the degree of impact between factors, but also reveal the interplay between factors and determine the cause-result relationship between factors to get the most critical impacting factors.

4.2. DEMATEL-AISM model construction ideas

The DEMATEL-AISM model is constructed as follows:

Step 1: Determine the initial direct influence relationship matrix W, $W = \left[w_{ij} \right]_{n \times n}$, where w_{ij} indicates the degree of direct influence of factor X_i on factor X_j and when $i = j$, $w_{ij} = 0$.

Step 2: Calculate the normalized impact matrix P. The normalized impact matrix is obtained by normalization at $P = \left[p_{ij} \right]_{n \times n}$.

$$P = \left[p_{ij} \right]_{n \times n} = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} w_{ij}} W \tag{1}$$

Step 3: Calculate the integrated impact matrix T.

$$T = \left[t_{ij} \right]_{n \times n} = P + P^2 + \cdots + P^n = \sum_{i=1}^{n} P_i = P\left(1 - P\right)^{-1} \tag{2}$$

Step 4: Calculate the degree of influence d_i, the degree of being influenced c_i, the degree of centrality Mi and the degree of cause Ni of the factors:

$$d_i = \sum_{j=1}^{n} t_{ij} \tag{3}$$

$$c_i = \sum_{j=1}^{n} t_{ji} \tag{4}$$

$$M_i = d_i + c_i \tag{5}$$

$$N_i = d_i - c_i \tag{6}$$

Step 5: Determine the global relationship matrix Y.

On the basis of the integrated impact matrix T obtained by the DEMATEL method, plus the effect of factors on themselves, as shown in Equation (7), where E denotes the unit matrix.

$$Y = \left[y_{ij} \right]_{n \times n} = T + E \tag{7}$$

Step 6: To simplify the system structure, a threshold λ (λ ∈ [0, 1]) is introduced. Based on the global relationship matrix Y and the threshold λ, the elements of the reachable matrix K ($K = [k_{ij}]_{n \times n}$) are determined, as shown in Equation (8).

$$\begin{cases} k_{ij} = 1, y_{ij} > \lambda \\ k_{ij} = 0, y_{ij} < \lambda \end{cases} \tag{8}$$

Step 7: Construct the skeleton matrix S. The point and edge reduction calculation is performed on the reachable matrix K. The purpose is to remove the existence of loops and duplicate paths in the reachable matrix. The reachable matrix S` is derived after keeping the longest path according to the rule of equation (9), and the skeleton matrix S is adjusted after the shortest path.

$$K \xrightarrow{\text{Point reduction operation}} K' \xrightarrow{\text{Edge reduction operation}} S' \xrightarrow{\text{Minimal link as loop}} S \tag{9}$$

$$S' = K' - (K' - E)^2 - E \tag{10}$$

Step 8: Regional decomposition and inter-level decomposition of K. The reachable set $R(X_i)$, the antecedent set $Q(X_i)$ and the common set $S(X_i) = R(X_i) \cap Q(X_i)$ of each factor are established based on the reachable matrix, and the adversarial hierarchy is divided by the result-first and cause-first rules, respectively.

$$\begin{cases} R(X_i) = S(X_i), & \text{Result First} \\ Q(X_i) = S(X_i), & \text{Cause First} \end{cases} \tag{11}$$

4.3. Results of DEMATEL-AISM model construction

Through various ways such as questionnaires and expert interviews, the logical relationships among the factors influencing the reliability of emergency logistics system are explored, and on top of this, they are scored, and the initial direct influence matrix W is constructed based on the scoring results, as Table 3 shows.

Table 3. Initial direct impact matrix of each influence factor

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}
X_1	0.0	2.0	2.5	2.0	1.0	2.0	1.0	1.5	3.5	1.5	1.0	2.0	3.0	1.0	2.0	1.5	1.5
X_2	2.0	0.0	1.5	1.0	1.5	3.0	2.0	1.0	3.0	3.0	2.5	2.5	3.0	3.0	2.0	1.0	3.0

X_3	2.0	1.0	0.0	1.0	1.5	2.0	1.5	1.0	3.5	2.5	1.0	1.5	2.5	0.5	2.0	2.0	3.5
X_4	1.5	2.0	1.5	0.0	1.0	3.5	3.0	3.0	3.5	3.0	3.0	2.0	3.5	3.5	3.0	2.5	4.0
X_5	3.0	2.5	2.5	2.0	0.0	3.5	3.0	3.0	3.0	3.0	3.0	2.5	3.0	3.5	3.0	3.5	3.0
X_6	1.0	2.0	0.5	0.5	1.0	0.0	0.5	2.5	2.0	1.0	3.5	2.0	1.5	3.0	2.5	1.0	2.5
X_7	3.0	2.5	2.5	1.5	1.5	3.0	0.0	2.0	3.0	1.5	2.0	3.5	3.0	1.5	3.0	2.0	4.0
X_8	2.5	2.5	3.0	2.0	2.0	3.5	2.5	0.0	3.0	2.0	2.5	2.0	3.0	2.5	3.0	2.0	3.0
X_9	2.0	1.0	2.0	0.0	1.0	2.0	2.0	0.5	0.0	0.5	3.0	2.0	2.0	1.5	1.5	0.5	3.0
X_{10}	3.0	2.0	2.5	2.0	1.5	2.0	2.0	2.0	3.0	0.0	2.0	2.5	3.0	3.0	2.5	2.0	3.0
X_{11}	0.5	1.0	1.5	2.0	2.0	1.5	1.5	2.5	1.0	1.0	0.0	1.0	3.0	3.0	2.0	1.5	3.0
X_{12}	0.5	1.0	2.5	2.5	3.5	2.0	1.0	2.0	2.0	1.5	2.0	0.0	2.0	2.0	2.0	1.5	2.0
X_{13}	2.5	2.5	3.0	2.0	1.0	2.0	3.0	1.0	3.0	1.5	0.5	2.0	0.0	1.5	2.0	1.0	3.5
X_{14}	2.0	2.0	2.0	1.5	1.0	3.5	1.5	1.5	2.5	1.5	1.0	3.0	2.0	0.0	2.5	2.0	2.0
X_{15}	2.5	1.0	2.0	1.5	2.0	1.5	2.0	2.0	2.5	1.0	2.0	2.0	2.0	1.0	0.0	1.0	3.0
X_{16}	2.5	3.5	2.5	2.5	2.0	3.0	2.0	1.5	3.0	2.0	2.0	2.0	3.5	2.0	3.0	0.0	3.0
X_{17}	1.0	1.0	1.0	2.0	1.5	2.0	1.5	1.0	2.0	0.0	1.0	0.5	1.5	3.0	1.5	2.5	0.0

Through the calculation of equations (1)-(6), the influence degree, influenced degree, centrality degree and cause degree of each influence factor are finally obtained as shown in Table 4. then, the cause-result graph of each factor is drawn according to the centrality and cause degree values, as Figure 1 showns.

Table 4. Calculated values of each influencing factor

	Degree of influence d_i Value	Degree of being influenced c_i Value	Centrality $d_i + c_i$ Value	Cause degree $d_i - c_i$ Value	Weights Ranking
X_1	1.977	2.147	4.125	-0.17	16
X_2	2.348	2.005	4.353	0.343	14
X_3	1.962	2.254	4.215	-0.292	15
X_4	2.93	1.784	4.714	1.145	4
X_5	3.196	1.735	4.931	1.461	1
X_6	1.827	2.702	4.529	-0.876	8
X_7	2.639	2.058	4.697	0.581	5
X_8	2.769	1.901	4.671	0.868	6
X_9	1.625	2.944	4.569	-1.319	9
X_{10}	2.572	1.758	4.33	0.813	13
X_{11}	1.963	2.191	4.154	-0.228	17
X_{12}	2.117	2.249	4.366	-0.133	12
X_{13}	2.161	2.776	4.938	-0.615	2
X_{14}	2.135	2.422	4.558	-0.287	10
X_{15}	1.987	2.537	4.523	-0.55	11
X_{16}	2.713	1.876	4.589	0.837	7
X_{17}	1.617	3.194	4.811	-1.577	3

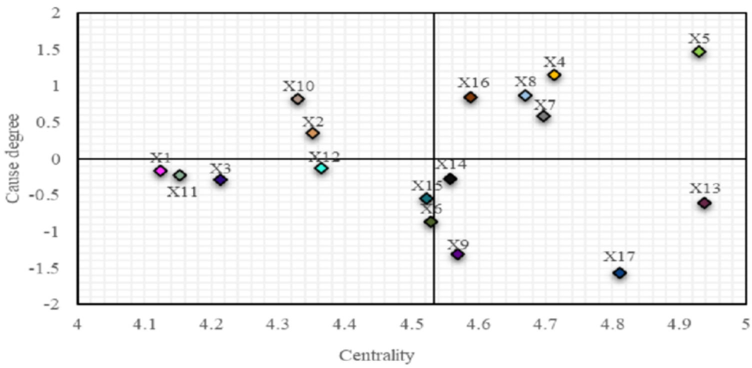


Figure 1. Graph of the cause-result of each influencing factor

On the basis of the integrated influence matrix T, the skeleton matrix S of each influence factor is obtained according to Eqs. (7)-(10). as shown in Table 5.

Table 5. Skeleton matrix S of each influencing factor

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}
X_1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
X_2	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
X_3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
X_4	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1
X_5	1	0	1	0	0	1	1	0	1	0	1	0	1	1	1	1	1
X_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X_7	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	1
X_8	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	0	1
X_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X_{10}	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
X_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
X_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X_{13}	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
X_{14}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
X_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
X_{16}	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1
X_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The reachable set, antecedent set and common set of each influence factor were derived using equation (11) and stratified according to the stratified extraction rule of result-first and cause first, and the results are shown in Table 6.

Table 6. Hierarchy division results

Levels	Result first-UP type Extraction process	Cause first-DOWN type Extraction process	Shared Factors	Activity Factors
L1	X_6, X_9, X_{12}, X_{17}	X_6, X_9, X_{17}	X_6, X_9, X_{17}	X_{12}
L2	X_1, X_3, X_{11}, X_{13}, X_{14}, X_{15}	X_{12}, X_{13}, X_{14}, X_{15}	X_{13}, X_{14}, X_{15}	X_1, X_3, X_{11}
L3	X_2, X_4, X_7, X_8, X_{10}, X_{16}	X_1, X_3, X_7, X_{10}, X_{11}, X_{16}	X_7, X_{10}, X_{16}	X_2, X_4, X_8
L4	X_5	X_2, X_4, X_5, X_8	X_5	X_2, X_4, X_8

Combining the skeleton matrix S and the results of the adversarial hierarchy division, the result-first and cause-first recursive structure models are plotted separately, as shown in Figures 2 and Figures 3:

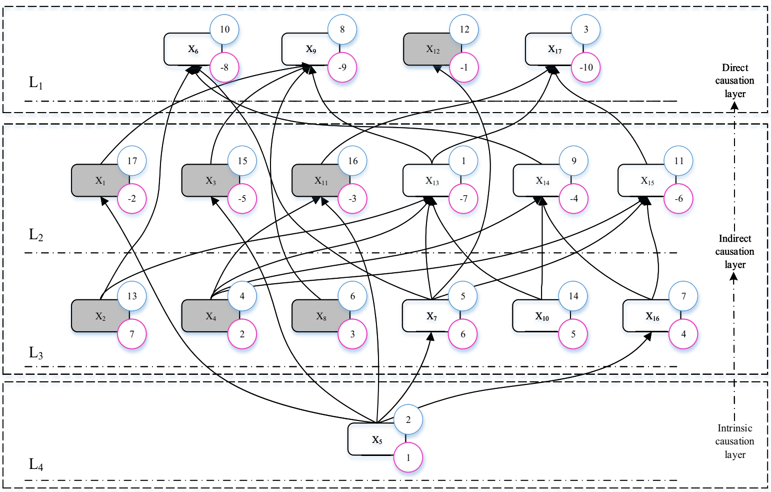


Figure2. Result-first recursive structural model

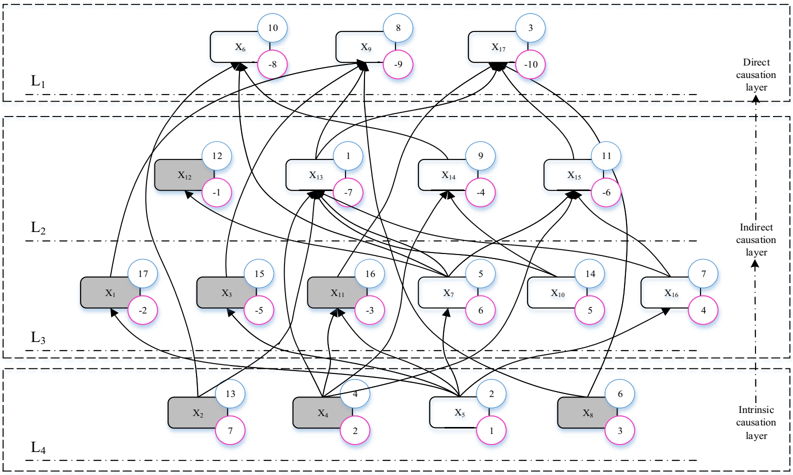
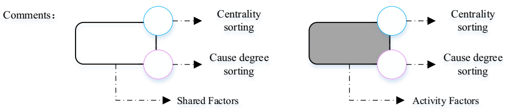


Figure 3. Cause-first recursive structure model



5. Analysis of results

5.1. Centrality and Cause degree analysis

(1) Centrality analysis

Centrality is a positive indicator, which means the role of an element in the system, the greater the centrality means the more critical the element is in the system. From Table 4 it follows that the centrality of the reliability influencing factors of emergency logistics system, in descending order, the top six are: Timeliness of emergency material supply X_{13}, Organizational coordination ability X_5, Flexibility of production system X_{17}, Rapid response ability X_4, Support of advanced technology X_7, and Expert consultants X_8. These factors occupy a significant position in the system of factors impacting the emergency logistics systems reliability and should be focused on.

(2) Cause degree analysis

Cause degree essentially refers to the causal attribute of factors, and is divided into positive cause degree and negative cause degree: factors with positive cause degree are called cause factors, and the higher the positive cause degree, the stronger the cause attribute of the factor; factors with negative cause degree are called result factors, and the larger the absolute value of the negative cause degree, the factor is more likely to be influenced by other factors. As can be seen from Table 4, the top six factors impacting the reliability of emergency logistics system in order of positive cause degree are Organizational coordination ability X_5, Rapid response capability X_4, Expert consultants X_8, Satisfiability of emergency supplies reserve X_{16}, Reasonableness of dispatch center setting X_{10}, Support of advanced technology X_7. In order to improve the reliability of emergency logistics system, we need to focus on the positive cause degree. The factors affecting the reliability of system are ranked according to the absolute value of negative cause degree, and the top four are Flexibility of production system X_{17}, Reasonable path planning X_9, Ability to establish emergency planning mechanism X_6, Timeliness of emergency material supply X_{13}. When controlling and managing these factors, special attention is paid to the upstream factors associated with them.

5.2. Loop analysis

From Figure 2 and Figure 3, the AISM model divides the 17 influencing factors into four layers. Among them, the direct influencing factors of system reliability are located in the first level, including the Ability to establish emergency planning mechanism X_6, Reasonable path planning X_9, Reasonable transportation and distribution tools X_{12}, and Flexibility of production system X_{17}, in case of failure of the emergency logistics system during the implementation of emergency activities, the factors of the direct causal layer are considered first. The deeper factors impacting the emergency logistics system reliability are located in the fourth layer, including Organizational coordination ability X_5, Rapid response ability X_4, Expert consultants X_8, and Accuracy of information X_2. These factors only act on other factors, and strengthening the management and construction of essential causal layer factors plays a decisive role in improving the reliability of emergency logistics system. The factors in the second and third layers are indirect factors affecting the reliability of system, and they are also the key nodes of the emergency logistics system. They play the role of influence transmission between the essential causative layer and the direct causative layer.

5.3. Correlation analysis of DEMATEL and AISM results

Through the analysis of the model construction results, it is found that there is a significant correlation between the level of the factors classified by the AISM method and the cause degree of the factors: the factors with positive cause degree are in the lower level in the adversarial topological hierarchy diagram, and the higher the positive cause degree, the lower the level of the factors, which means that the factors have a greater influence on the reliability of the emergency logistics system and can directly or indirectly influence other factors, and are the cause factors affecting the system reliability; while the factors with negative cause degree are in the higher level in the adversarial topological hierarchy diagram, indicating that the factor is more easily influenced by other factors, and the stronger the result attribute.

To sum up, the improvement of emergency logistics system reliability should focus on Organizational coordination capability X_5, Rapid response capability X_4, Support of advanced technology X_7, Expert consultants X_8, Satisfiability of emergency supplies reserve X_{16}, and Flexibility of production system X_{17}.

6. Conclusions and Recommendations

The research integrates the DEMATEL-AISM model to evaluate the critical influencing factors of the reliability of emergency logistics system. The model can provide scientific guidance for the assessment of emergency logistics system reliability under public health emergencies and help decision makers to effectively improve the reliability of emergency logistics system. Combining the six key influencing factors identified by the model analysis, the following recommendations are made:

Firstly, the government should establish an emergency logistics team led by enterprises and intervened by the government, develop multi-sectoral coordination and linkage mechanism, clarify the responsibilities of each department, and organize and coordinate cross-regional emergency logistics activities. According to the degree of harm, the scope of transmission and other factors, the development of emergency planning mechanisms at different levels and types, and timely emergency training to ensure the scientific and practical nature of emergency programs, so that timely action can be taken in the event of a public health emergency.

Secondly, on the basis of the current emergency technical means, increasing the investment in modern technology of emergency logistics system, and transform and upgrade the emergency logistics system. The use of big data analysis technology, 5G network technology and other advanced logistics information technology to establish an efficient and orderly emergency logistics information sharing platform, through information collection, real-time monitoring and data analysis to ensure the accuracy of information sources and information delivery, to provide effective, timely and accurate information technology for the government and enterprises to develop emergency plans.

Finally, emergency material reserve is an important basis for the construction and operation of emergency logistics system. The layout of emergency material reserve should be reasonably planned, the material reserve model should be optimized, and a network of emergency material reserve nodes with reasonable classification, clear hierarchy and high efficiency of coordination should be established. In addition, the relevant management system should be improved and perfected to ensure that the reserve of emergency supplies can meet the demand in case of public health emergencies.

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