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Influencing Factor Analysis of Safety Risks of Highway Large-cargo Transportation with DEMATEL–ISM Method

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Abstract

The safety problem of large-cargo transportation has always been one of the key issues that impede industrial development. How to identify the safety risk factors of highway large-cargo transportation and clarify their action mechanism has become the focus of current research among business and academic circles. To more effectively identify the key factors that may affect large-cargo transportation safety and clarify the action mechanism of the factors, the large-cargo transportation process was systematically analyzed based on literature analysis and field investigation, and the basic units for risk factor identification and evaluation of the large-cargo transportation system were determined. Then, a comprehensive analysis was performed from five aspects, namely, "personnel, vehicle, cargo, environment, and management", and a total of 10 risk factors were extracted. Next, a large-cargo transportation safety system model was established by integrating the DEMATEL and ISM methods, the mutual influencing degree between the risk factors was analyzed, the causation degree of the risk factors was divided, the factors that can influence large-cargo transportation safety risks and their action mechanism were probed into, and the transfer path between the risk factors at different levels was clarified. Results show that the lack of professional knowledge of the management personnel is the essential factor affecting the safety of large-cargo transportation; human and management factors are important causes; increasing personnel's safety awareness and behavior and enhancing the specialization level of the management are key to decreasing accident rates and improving large-cargo transportation safety. The conclusions provide a decision-making idea and an analytical method for managing and controlling large-cargo transportation safety risks.

Keywords: Large-cargo transportation; Safety accidents; Risk factors; DEMATEL-ISM method

1. Introduction

The transportation demands of large-scale facilities and equipment have increased continuously with the implementation of the "Belt and Road Initiative" and the development of infrastructure construction in China in recent years. Large-cargo transportation provides transportation support to key national engineering projects in China; thus, guaranteeing the safety of large-cargo transportation engineering is extremely important. According to the national regulations on large-cargo transportation, when a single cargo that cannot be disassembled is transported, at least one of the parameters, namely, the total vehicle cargo length, the total width, the total height, the total mass, or the axle load, should exceed the provisions specified in the Limits of Dimensions, Axle Load and Masses for Motor Vehicles, Trailers and Combination Vehicles (GB1589). However, China's highway large-cargo transportation had a late start but developed rapidly despite the use of immature technologies and is accompanied by the low safety management levels of enterprises and the frequent occurrence of safety accidents during transport, which can endanger the life and safety of personnel and damage surrounding facilities and equipment. Moreover, such transportation can cause economic losses from the damage of large cargoes, which can impede the promotion of national key engineering projects. In addition, large-cargo transportation is characterized by ultra-large sizes and weights and loading/unloading requirements that differ from those of ordinary cargo transportation, as well as higher transportation risks. Scientific methods for managing and controlling large-cargo transportation risks are lacking. Therefore, elevating the safety guarantee and service levels of large-cargo transportation at the management and technology levels and decreasing accident rates have become urgent.

Most of the previous studies on large-cargo transportation risks in various countries focused on the safety assessment of large cargoes when passing over bridges [1, 2] and paid little attention to human factors, such as low safety awareness, low management levels, and technical operation errors, and material factors, such as vehicle faults, inherent vehicle defects, and inherent cargo defects. Large-cargo transportation accidents are not triggered by a single factor but result from the mutual influence of multiple factors. An effective method for decreasing large-cargo transportation accidents is the adoption of preventive and control measures for the safety risk factors before, during, and after transport. Hence, this study aims to identify the safety risk factors of large-cargo transportation from various dimensions, namely, the personnel, vehicle, cargo, environment, and management, by integrating the DEMATEL and ISM methods; analyze the intensity and action relationship between the different influencing factors; identify the essential, transitional, and neighboring causes of accidents; clarify the risk transfer path in the system; and propose risk prevention and control measures for large-cargo transportation. Thus, this study has

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considerable practical significance for reducing large-cargo transportation risks.

2. State of the Art

Research on large-cargo transportation focused mainly on specific work links in transportation organizations, with transportation safety as the core. Research on specific work links mainly examined the selection of corridors and vehicles, binding reinforcements, bridge trafficability, and transportation route planning. In terms of transportation corridor and vehicle selection, Li et al. [3] used the PCA-improved analytic hierarchy process to construct a multiobjective decision model to provide the decision basis for large-scale transportation corridor selection. With regard to the binding schemes of large cargoes, He et al. [4] verified a feasible and effective programming method for binding reinforcements through three-dimensional modeling. The method involves establishing the criteria, formulating the schemes, creating the models, and checking their strength. Regarding the traffic safety of bridges, Sun et al. [5] presented a complete evaluation process for assessing bridge traffic capacity and expounded on several commonly used evaluation methods for determining the bridge bearing capacity. Meanwhile, Jia et al. [6] combined super-large cargo transportation experience in several international engineering logistics projects from the perspective of actual transportation and defined the super-large cargoes suitable for actual transportation levels. In addition, the authors summarized the realistic conditions required for super-large cargo transportation, analyzed the main modes of super-large cargo transportation in the current market, detailed the super-large cargo transportation risks, and proposed systematic countermeasures by comprehensively considering various risk factors. With regard to route selection for the transport of large cargoes, Huang et al. [7] used the optimal weight–TOPSIS combination method to analyze and calculate four routes applicable to large-cargo transportation in Suzhou, China and provided a basis for the selection of urban transportation routes for large cargoes. Luo et al. [8] established a route planning reconstruction model for super-large and heavy cargoes, introduced the K shortest path algorithm to solve the multiroute planning problem of the reconstructed multimodal transportation model, improved the model by using the A* algorithm, and specified a variety of transportation schemes to provide decision and risk prevention support to carriers. In the transportation process, safety accidents may be caused by not only the vehicles and the driving environment but also the safety assessment when transporting dangerous goods. The adverse impact of various risk factors during highway transport can increase the highway transport risk of dangerous goods; thus, Liang [9] proposed an evaluation method based on a 2D cloud model to comprehensively and objectively evaluate the highway transport risk levels of dangerous goods. Li et al. [10] proposed a risk assessment method based on combination weighting and regret theory to effectively assess the highway bridge transport risks of hazardous chemicals and address a shortcoming of existing risk assessment methods, namely, excess subjectivity. Zhang et al. [11] used the STAMP model to analyze and prevent accidents in the dangerous goods railway transportation system and identified the relevant safety constraints of the control structure, the insufficient control behavior and its causes, and the dynamic changes in the system. Moreover, the authors analyzed the correlation between the accident risk factors by using the ISM algorithm and divided them into different levels. Furthermore, the authors proposed a system improvement scheme based on the analysis results of the STAMP and ISM methods. In summary, research on the comprehensive safety management of large-cargo transportation is lacking, correlations among the risk factors have scarcely been analyzed, and the action mechanism of the risk factors and the inducement and evolution of large-cargo transportation safety accidents have yet to be revealed. The integrated DEMATEL–ISM method is applicable to the action mechanism analysis of the safety risk factors of large-cargo transportation.

Therefore, given the gaps in existing research, this study identifies the potential risk factors in each link from the whole-process perspective of large-cargo transportation, explores the correlations among the risk factors and causation path, and proposes risk prevention and control measures and requirements to decrease large-cargo transportation accident rates.

The remainder of this study is organized as follows: Section 3 describes the method for extracting the safety risk factors of large-cargo transportation from the literature, establishes the influence matrix, calculates the centrality and cause degree, and expounds on the construction of the accessibility matrix and the explanatory structural model. Section 4 analyzes the results, and Section 5 summarizes the study and presents the conclusions.

3. Methodology

3.1 Analysis Framework for Safety Risk Factors of Large-cargo Transportation

The extracted influencing factors were the basis of the influencing mechanism analysis. To ensure the comprehensive identification and evaluation of the risk factors and avoid omissions, this study divided the overall large-cargo transportation process and determined the basic units for the identification and evaluation. After reviewing the literature and conducting a field investigation, this study divided the overall large-cargo transportation process into three stages: scheme formulation, transportation preparation, and transportation execution. The three stages served as the basic units for the risk factor identification (Fig. 1).

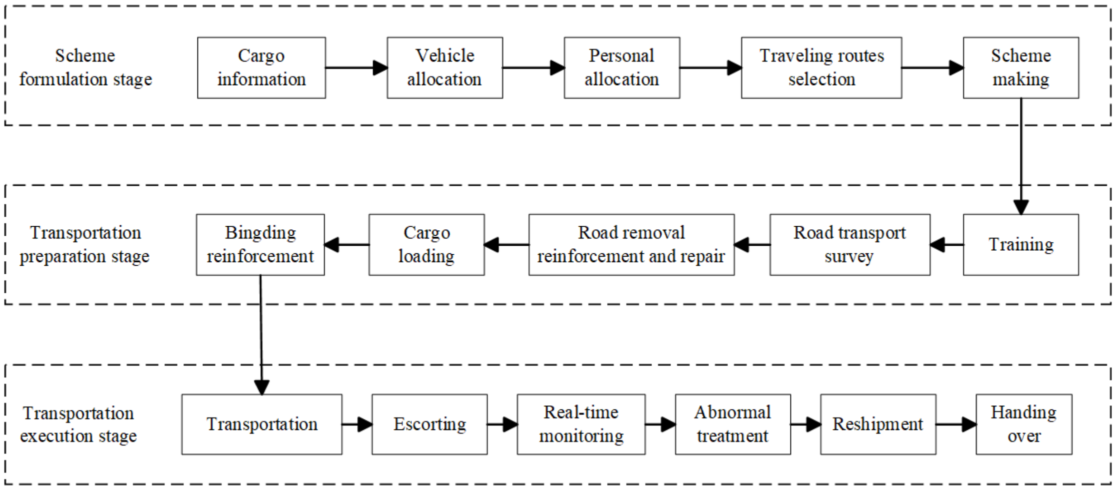

Fig.1. System units for safety risk factor identification in large-cargo transportation

When undertaking a transportation project, an enterprise qualified for large-cargo transportation should first understand the information about the goods to be transported, the place of departure and destination, the general situation of the traffic routes, the configuration of the self-owned vehicles, and the personnel. Second, the enterprise must formulate a transportation plan to determine the feasibility of the project. The two steps comprise the scheme formulation stage. After a preliminary evaluation, the enterprise should take a series of preparation measures before the transport based on the improved general plan, including personnel training, road reconnaissance, obstacle removal, loading, and reinforcement, which are the steps involved in the transportation preparation stage. The final stage is the transportation execution stage, which involves supervision and handling during transport, as well as transshipment and handover operations upon arrival at the destination.

3.2 Identification Method for Safety Risk Factors of Large-cargo Transportation

In this study, risk identification for highway large-cargo transportation was performed through two means, namely, data analysis and field investigation, and a risk factor index system was established. The research steps are described below.

First, the relevant influencing factors and accidents related to large-cargo transportation were extracted from the literature. Relevant scholars were referenced in the division of the large-cargo transportation risk factors, as seen in Table 1. Considering the overlong, overwide, overhigh, and overheavy characteristics of large-cargo transportation vehicles and cargoes, this study conducted risk identification from five aspects: the personnel, vehicle, cargo, environment, and management.

Table 1. Risk factor division in large-cargo transportation and literature sources

Literature source	Risk factor division in large-cargo transportation
Leng, C. B. [12]	Highway transportation risk, railway transportation risk, waterway transportation risk, and transportation mode conversion process risk
Li, F. [13]	Environmental risk, technical risk, economic risk, bidding risk, management and organization risk, and transportation process risk
Min, D. [14]	Personnel risk, vehicle risk, cargo risk, and environmental risk

The risk factors from the five aspects were concretized by combining the large-cargo transportation accident cases then statistically analyzing overpass collisions by large-cargo transport vehicles on the Shanghai–Chongqing Expressway in 2020, bridge pier collisions and breakage by large-cargo transport vehicles on the Hailar–Zhangbei Expressway, collisions of large-cargo transport heavy semitrailer vehicles in 2015, water-related falling accidents of large-cargo transport vehicles owing to bridge collapse, curve rollover accidents of large-cargo transport vehicles in mountainous areas, and rollover accidents of large equipment bridge-type truck groups on expressways. Such accidents can be attributed to the "unsafe behaviors of humans," such as illegal operation or driver fatigue, the low safety awareness of the relevant personnel, failure to conduct road reconnaissance, or large reconnaissance errors, as well as the "unsafe state of things," including vehicle breakdown, unreasonable cargo loading, and low road traffic capacity.

Second, through a field investigation of large-cargo transportation enterprises in Hebei, Sichuan, and Chongqing, China, this study analyzed the development status of large-cargo transportation and actual operation risk points that should be investigated, such as the feasibility of the transportation route planning, the personnel configuration, and the cargo loading based on the cargo characteristics. Third, the risk factor system was further improved from the perspective of the carrier enterprise. The information collected from the field investigation is listed in Table 2.

Table 2. Field survey results

Survey enterprise	Main business	Operation time	Survey time
Hebei Hongda Large-cargo Transportation Co., Ltd.	Wind power heavy-cargo transportation	21years	09:00–12:00, August 11, 2022
Baoding Erbiao Transportation Co., Ltd.	Wind power heavy-cargo transportation	16 years	14:00–17:00, August 12, 2022

Shijiazhuang Ludean Automobile Rental Co., Ltd.	Automobile rental	13 years	09:00–12:00, August 13, 2022
Sichuan Dongfang Logistics Group Co., Ltd.	Electromechanical engineering projects	19 years	14:00–16:30, November 25, 2022
Dongfang Electric Group Large-cargo Logistics Co., Ltd.	Electromechanical product transportation	16 years	14:00–17:00, November 26, 2022
Chongqing Yajie Transportation Co., Ltd.	Heavy-cargo transportation	23 years	09:00–11:30, January 19, 2023
Chongqing Xindayun Logistics Co., Ltd.	Wind power heavy-cargo transportation	22 years	14:00–17:00, January 20, 2023

3.3 Safety Risk Factor Model for Large-cargo Transportation

To explore the importance of the various influencing factors and the accident causation mechanism in the complex accident system, this study analyzed the accident data by using statistical models, namely, a finite mixed regression model and the quantile regression method [15, 16]. However, statistical methods assume that factors are mutually independent, and the quantitative analysis results may be divorced from reality. Large-cargo transportation accidents result from correlations among complex causations; thus, the adoption of the factor correlation analysis method would be practical [17, 18]. However, quantifying the influencing degree of the causal factors would be difficult. To further explore the action mechanism of the influencing factors, this study analyzed the factors that can influence enterprises to choose specific logistics patterns [19, 20]. Despite its ability to analyze the causal relationships among system factors, the DEMATEL method is unable to clarify the influencing mechanism of the factors. The ISM algorithm can transform the complex relationships among system factors into an intuitive and clear multilevel hierarchical structural model, but the calculation process is complicated. The two methods are correlated and complementary [21]. The safety accident risk factor system for large-cargo transportation is a typical "man–machine–environment–management" system. A complex large-cargo transportation safety system can be described as a multilevel hierarchical system model with satisfactory structural relations that integrates the DEMATEL and ISM methods to analyze the causal relationships among the risk factors and their action mechanism. The DEMATEL–ISM modeling process for the safety accident risk factors of large-cargo transportation is displayed in Fig. 2.

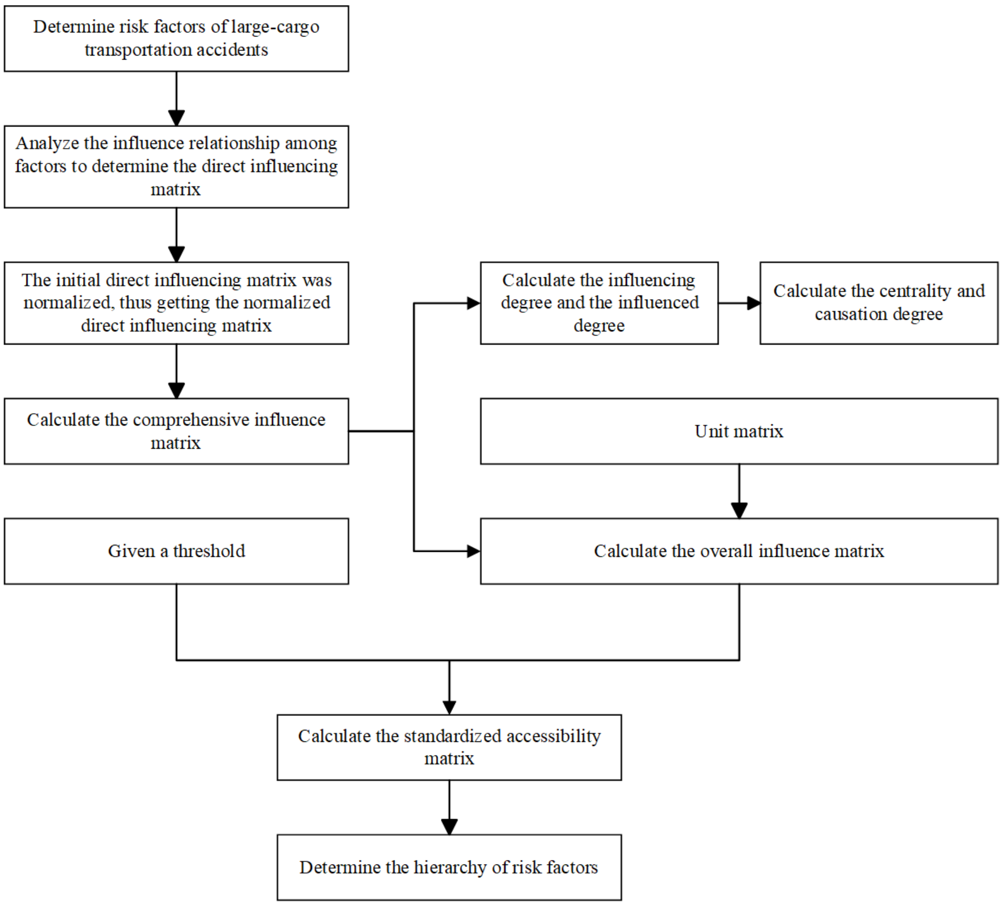

Fig.2. DEMATEL–ISM modeling process for large-cargo transportation safety system

The specific steps of the process are presented below.

(1) Determine the safety accident risk factors a_1, a_2, …a_n of large-cargo transportation, where n represents the number of risk factors.

(2) Generate the initial direct influence matrix. The values of 3, 2, 1, and 0 were assigned to four levels, namely, "strong," "general," "weak," and "N/A," based on the experience of the experts in the large-cargo transportation industry and field technicians k ($k = 1, 2, ..., m$) to judge the mutual influencing degree to acquire the direct influence matrix B between the factors. The evaluation results of the multiple experts were summarized by averaging their data, and the initial direct influence matrix B was obtained.

$$\beta_{ij}=\frac{1}{m}\sum_{k=1}^{m}\beta_{ij}^{k}\left(k=1,2,\cdots,m\right) \tag{1}$$

(3) Normalize the initial direct influence matrix to obtain the normalized direct influence matrix *C*.

$$C=\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}\beta_{ij}}B \tag{2}$$

(4) Calculate the comprehensive influence matrix *T*.

$$T=C^1+C^2+\ldots+C^n=\sum_{i=1}^{n}C^i \tag{3}$$

(5) Calculate the influencing degree f_i and the influenced degree e_i of each risk factor. The influencing degree of each factor is the sum of the values in each *T* row, and the influenced degree is the sum of the values in each column.

(6) Calculate centrality M_i and causality N_i, which are the sum and difference of the influencing degree and influenced degree, respectively.

(7) Calculate the overall influence.

$$H(H=\left[h_{ij}\right]_{n\times n})H=I+T \tag{4}$$

(8) Process the elements in the overall influence matrix to obtain the standardized accessibility matrix and threshold λ. Calculate the accessibility matrix.

$$K(K=\left[k_{ij}\right]_{n\times n})k_{ij}=1,\ if\ h_{ij}\ge\lambda(i,j=1,2,...,n) \tag{5}$$

$$k_{ij}=0,\ if\ h_{ij}<\lambda(i,j=1,2,...,n) \tag{6}$$

(9) Perform the interstage division of the accessibility matrix *K*. Divide the risk factors into different levels based on the concepts of a reachable set, an antecedent set, and a top-level factor set, and draw the hierarchical diagram of the factors.

4. Results Analysis and Discussion

4.1 Safety Risk Factor Set for Large-cargo Transportation

The safety accident risk factors of highway large-cargo transportation were identified and classified from “three stages and five aspects” by combining the data analysis and field investigation results [22]. Through multiple rounds of discussions and revisions, the relevant experts from the China Water Resources and Electric Power Association on Physical Distribution refined the factors to 10 risk factors (Fig. 3) covering five dimensions: personnel, vehicle, cargo, environment, and management. Subsequently, the influencing factor set $a=(a_i)_{1*n}$, i=1, 2, …, 10 was formulated.

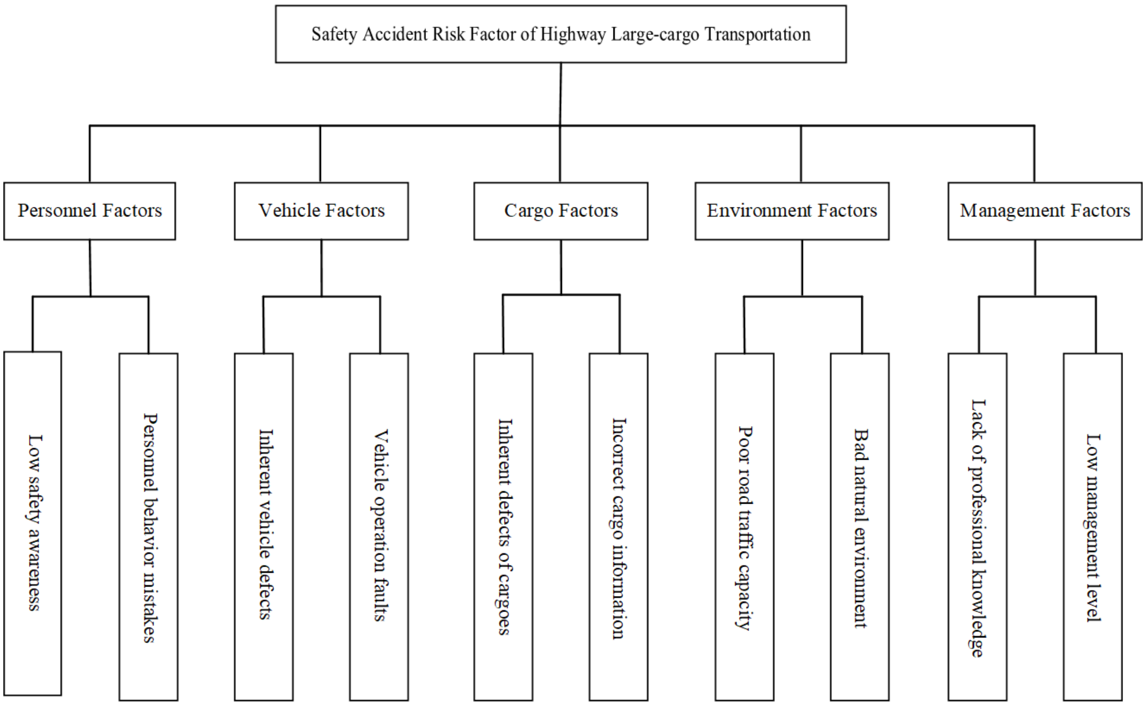

Fig.3. Safety accident risk factor system of highway large-cargo transportation

(1) a_1: Low safety awareness refers to the behavior of operators that can bring about risks, which does not play a direct role in the human–computer interaction but can affect safety through low safety awareness of operation activities, such as lack of knowledge on safety signs and risk awareness.

(2) a_2: Personnel behavior mistakes refer to risks caused by the unsafe behavior of operators in the process of interacting with the equipment during operation activities, such as using unsafe facilities, equipment, and tools; touching dangerous parts; lacking proficiency in operation technology; not cooperating properly in multiperson operations; and fatigue driving.

(3) a_3: Inherent vehicle defects refer to those related to the vehicle’s moving and stopping processes owing to its design, manufacturing, installation, and other factors that may cause safety accidents, such as the exposure of sharp and keen-edged parts, unclear safety signs, and nonstandard and irregular vehicle manufacturing.

(4) a_4: Vehicle operation faults refer to the failure of a specified function of a certain part or component of the vehicle that may bring about risks, such as control device failure, protection device failure, warning device failure, uncontrollable energy, or the loosening or fracture of parts and mechanisms.

(5) a_5: Inherent defects of cargoes are those that may cause safety accidents during the loading, unloading, handling, or transport process owing to the inherent properties of the cargoes. Such defects may cause the spontaneous combustion of a cargo or the decay of radioactive materials.

(6) a_6: Incorrect cargo information may cause traffic accidents during the loading, unloading, handling, or transport process. Incorrect cargo information may be provided by the shipper, consignee, or escort, such as underreported weight. This risk factor included poor packaging, the intentional hiding of reports, and the misreporting of the name and attributes of the cargo.

(7) a_7: Poor road traffic capacity is related to road and traffic problems or inaccurate road reconnaissance information that can cause safety accidents during operation, such as the pavement quality, slopes, bend trafficability, bridge bearing capacity limitations, traffic congestion, accidents, imperfect road reinforcements, and obstacle removal or repair.

(8) a_8: Bad natural environment indicates that the natural and work environments can directly or indirectly affect the normal operation of large-cargo transportation, such as inclement weather conditions, bad work environments, and force majeure natural disasters, such as floods, earthquakes, tsunamis, and megastorms.

(9) a_9: Lack of professional knowledge refers to the management's lack of relevant professional knowledge and skills, which may bring about risks. Lack of such knowledge may cause the vehicle configuration to not meet the cargo transportation requirements, the cargo bundling and reinforcement scheme or loading and unloading method to not be properly designed, or the operators to not be properly equipped.

(10) a_{10}: Low management level can bring about potential risks from failure to establish a sound cargo transportation safety guarantee system, the implementation of imperfect rules and regulations, and the assignment of unclear responsibilities, such as unreasonable transportation schemes; poor vehicle maintenance; unreasonable staffing; unrealistic driving hours; inadequate driver, cargo, and vehicle running status monitoring; and incomplete safety alarm mechanisms.

4.2 Centrality and Cause Degree Analyses

(1) Calculation of factor set influence matrix

The accident risk factors of large-cargo transportation constituted a complex system, among which direct or indirect action relations existed. Generally, the intensity of action relations can be determined by the Delphi method or expert opinions. In this study, a questionnaire with a five-point Likert scale was designed based on the influencing factor set of the safety accident risk factor system of large-cargo transportation and distributed to the relevant enterprise personnel and experts. The mutual influencing degree of the factors was determined through expert scoring. After the scores were averaged, the initial direct influence matrix *B* of the factor set was established by using Formula (1), as seen in Table 3. Matrix *B* was normalized by using Formula (2), and the comprehensive influence matrix *T* was obtained with Formula (3), as seen in Table 4.

Table 3. Direct influence matrix *B* of large-cargo transportation accident risk factors

B	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
a_1	0.0	2.5	0.3	1.0	0.0	0.8	0.8	0.8	1.0	1.3
a_2	0.5	0.0	0.0	1.5	0.0	1.0	0.5	0.5	0.5	1.3
a_3	0.0	1.3	0.0	2.8	0.0	0.3	0.8	0.5	0.8	1.0
a_4	0.0	1.0	0.3	0.0	0.3	0.0	1.5	1.3	0.0	0.8
a_5	0.0	0.3	0.0	0.3	0.0	1.0	0.5	0.0	0.3	0.0
a_6	0.0	0.3	0.0	0.5	0.0	0.0	0.5	0.0	0.5	0.5
a_7	0.0	1.5	0.0	1.5	0.0	0.0	0.0	0.5	0.5	0.3
a_8	0.3	1.3	0.0	1.5	0.0	0.0	1.8	0.0	0.0	0.3
a_9	2.0	1.8	0.0	1.8	0.0	0.8	0.0	0.0	0.0	2.3
a_{10}	1.5	1.8	0.0	0.5	0.0	1.3	0.0	0.0	1.3	0.0

Table 4. Comprehensive influence matrix *T* of large-cargo transportation accident risk factors

T	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
a_1	0.1817	0.6409	0.0564	0.4531	0.0156	0.2752	0.2938	0.2333	0.2749	0.4272
a_2	0.1713	0.2613	0.0187	0.3708	0.0128	0.2259	0.1999	0.1562	0.1666	0.3196
a_3	0.1435	0.4655	0.0252	0.5872	0.0202	0.1762	0.2888	0.2032	0.2168	0.3473
a_4	0.0858	0.3243	0.0446	0.2081	0.0417	0.0933	0.2935	0.2265	0.0898	0.2245
a_5	0.0346	0.113	0.005	0.1093	0.0038	0.1477	0.1018	0.0321	0.0695	0.0641
a_6	0.0576	0.1469	0.0072	0.1507	0.0052	0.0532	0.1101	0.043	0.1034	0.1384
a_7	0.0852	0.347	0.0145	0.3347	0.0115	0.0881	0.1221	0.1431	0.1278	0.1795
a_8	0.1096	0.3557	0.0162	0.3598	0.0124	0.088	0.3282	0.1041	0.086	0.1817
a_9	0.4133	0.6224	0.0326	0.5309	0.0183	0.3062	0.2217	0.1677	0.2003	0.5557
a_{10}	0.3145	0.505	0.0221	0.3261	0.0112	0.3027	0.1585	0.1171	0.2818	0.2564

(2) Calculation of centrality and cause degree

The influencing degree, influenced degree, cause degree, and centrality of the factor set were calculated by following the DEMATEL–ISM method steps (3–7), and the attribute of each factor was judged, as seen in Table 5. The influencing degree represents the comprehensive strength of a factor that is affected by other factor sets, and the influenced degree represents the comprehensive strength of the influence exerted by a factor on other factor sets. A causation map of the risk factors was drawn (Fig. 4), with centrality as the horizontal axis and the cause degree as the vertical axis.

Table 5. Comprehensive evaluation of large-cargo transportation accident risk factors

Factor	Accident factor	Influencing degree	Influenced degree	Cause degree	Centrality	Centrality ranking	Factor attribute
a_1	Low safety awareness	2.852	1.597	1.255	4.449	5	Cause
a_2	Personnel behavior mistakes	1.903	3.782	-1.879	5.685	1	Result
a_3	Inherent vehicle defects	2.474	0.242	2.232	2.716	8	Cause
a_4	Vehicle operation faults	1.632	3.431	-1.799	5.063	2	Result
a_5	Inherent defects of cargoes	0.681	0.153	0.528	0.834	10	Cause
a_6	Incorrect cargo information	0.816	1.757	-0.941	2.572	9	Result
a_7	Poor road traffic capacity	1.454	2.119	-0.665	3.572	6	Result
a_8	Bad natural environment	1.642	1.426	0.215	3.068	7	Cause
a_9	Lack of professional knowledge	3.069	1.617	1.452	4.686	4	Cause
a_{10}	Low management level	2.295	2.694	-0.399	4.990	3	Result

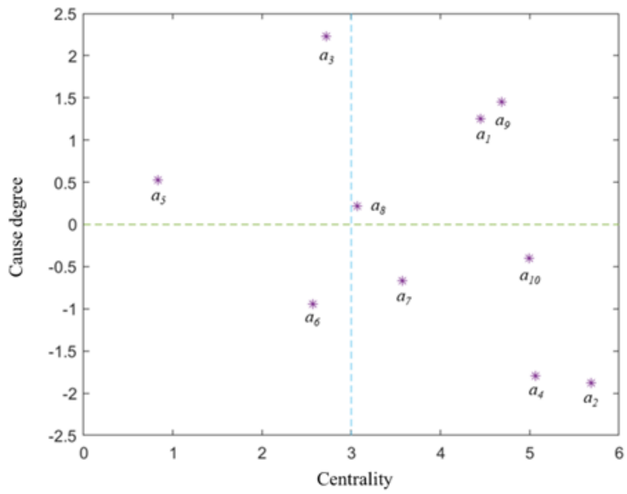

Fig.4. Causation map of safety risk factors of large-cargo transportation

(3) Cause degree analysis of factor set

In Table 5, the factors with a high cause degree were a_3 (inherent vehicle defects), a_9 (lack of professional knowledge), and a_1 (low safety awareness). The results indicated that such factors can easily affect the other risk factors in the system and should be the focus of risk prevention and control. The factors with high centrality were a_2 (personnel behavior mistakes), a_4 (vehicle operation faults), and a_{10} (low management level). The results revealed that such factors exerted a considerable influence on the occurrence of safety accidents in the large-cargo transportation risk system.

4.3 Explanatory Structural Model Analysis

Based on step (8) and the expert opinions, $\lambda = 0.43$ was used to establish the accessibility matrix K (Table 6) of the factor set. The accessibility matrix K was divided according to step (9), as seen in Table 6, and a hierarchical structural model of the large-cargo transportation risk factors was established (Fig. 5).

Table 6. Accessibility matrix K of large-cargo transportation accident risk factors

K	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
a_1	1	1	0	1	0	0	0	0	0	0
a_2	0	1	0	0	0	0	0	0	0	0
a_3	0	1	1	1	0	0	0	0	0	0
a_4	0	0	0	1	0	0	0	0	0	0
a_5	0	0	0	0	1	0	0	0	0	0
a_6	0	0	0	0	0	1	0	0	0	0
a_7	0	0	0	0	0	0	1	0	0	0
a_8	0	0	0	0	0	0	0	1	0	0
a_9	0	1	0	1	0	0	0	0	1	1
a_{10}	0	1	0	0	0	0	0	0	0	1

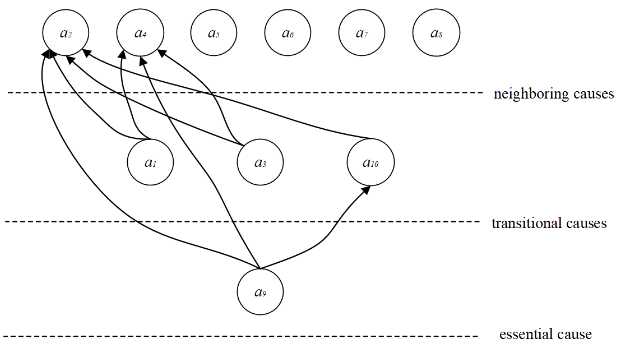

Fig.5. Hierarchical structural model of safety accident risk factors in large-cargo transportation system

The model in Fig. 5 shows that in the large-cargo transportation safety system, a management factor, that is, lack of professional knowledge (a_9), was an essential cause. Thus, large-cargo transportation enterprises should focus on improving the professional knowledge and skills of the management. Meanwhile, low safety awareness (a_1), inherent vehicle defects (a_3), and low management level (a_{10}) were transitional causes that may be influenced by the essential causes and the neighboring causes. Personnel behavior mistakes (a_2), vehicle operation faults (a_4), inherent defects of cargoes (a_5), incorrect cargo information (a_6), poor road traffic capacity (a_7), and bad natural environment (a_8) were the neighboring causes and the factors that directly affected large-cargo transportation safety. The results of the analysis of the interaction mechanism between the risk factors with the integrated DEMATEL–ISM method basically conform to the "2-4 accident model," that is, lack of a safety culture and a safety management system at the organizational level was the root cause, and habitual behavior at the individual level, one-time behavior, and the material state were the direct or indirect causes. Under the comprehensive action of organizational and individual behaviors, the result of "accidents and losses" will emerge [23].

By observing the action mechanism of the factors, this study determined that lack of professional knowledge (a_9) can lead to a low management level (a_{10}) and personnel behavior mistakes (a_2) and thus safety accidents. Risk factors such as low safety awareness (a_1), inherent vehicle defects (a_3), and the management's lack of professional knowledge (a_9) can influence personnel behavior mistakes (a_2) and vehicle operation faults (a_4), which can cause safety accidents. However, the inherent defects of cargoes (a_5), incorrect cargo information (a_6), poor road traffic capacity (a_7), and bad natural environment (a_8) exerted an independent influence and directly affected the occurrence of safety accidents.

5. Conclusions

To determine the safety risk factors of large-cargo transportation and their action mechanism, this study analyzed the direct influence relationship between the factors and their influencing degree by integrating the DEMATEL and ISM methods. Moreover, this study constructed a causation map of the influencing factors and an explanatory structural model, determined the importance of each influencing factor, and distinguished the essential, transitional, and neighboring causes of safety accidents. This study drew the following research conclusions:

(1) The cause degree and result degree of the large-cargo transportation safety risk factors were effectively distinguished by the DEMATEL–ISM analysis model. Factors such as low safety awareness, inherent vehicle defects, inherent defects of cargoes, bad natural environment, and leaders' lack of professional knowledge demonstrated a high cause degree, whereas personnel behavior mistakes, vehicle operation faults, incorrect cargo information, poor road traffic capacity, and low management level exhibited a high result degree. Furthermore, the factors that demonstrated a high result degree were affected by those that exhibited a high cause degree.

(2) The influencing hierarchy of the risk factors and the risk transfer paths were accurately divided by the DEMATEL–ISM analysis model. A management factor was the essential cause of large-cargo transportation safety accidents, whereas low safety awareness, inherent vehicle defects, and low management level were transitional causes. Meanwhile, operators' behavior mistakes, vehicle operation faults, inherent defects of cargoes, incorrect cargo information, poor road traffic capacity, and bad natural environment were neighboring causes and the factors that directly influenced large-cargo transportation safety. Furthermore, the influence path between the factors was the path of safety control improvement.

(3) The influencing relationship between the risk factors and their action mechanism were analyzed comprehensively by the DEMATEL–ISM analysis model, which provided a simple and reliable analysis model for distinguishing the importance of the risk factors, the influencing hierarchy, and the influence path in large-cargo transportation safety management.

When used for the safety risk factor analysis of large-cargo transportation, the DEMATEL–ISM method can determine the influencing hierarchy of the risk factors and places emphasis on the improvement and handling of causal factors to effectively control large-cargo transportation safety risks. The outcomes of this study are the causation map of the large-cargo transportation safety risk factors and the explanatory structural model. This study distinguished between the causal and result factors to divide the influencing hierarchy and the influence path of the factors and provide accurate theoretical support for large-cargo transportation safety risk control. However, how large-cargo transportation safety risks are transferred on the influence path, and how the safety risk transfer path can be intercepted and the large-cargo transportation safety risk prevention and control system be improved should be investigated further.

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