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RESEARCH ARTICLE

Construction of Knowledge Graph of the Elevator Safety Accidents and Analysis of Key Risk Factors Based on KG-DEMATEL-ISM-MICMAC Method

FENFEN SHI AND ZHILEI WU
School of Management, China University of Mining and Technology (Beijing), Beijing 100083, China
Corresponding author: Zhilei Wu (18811176258@139.com)

ABSTRACT The safety of elevator, as a closely related equipment in people's daily life, is getting more and more attention. Once an elevator accident occurs, it will bring strong social impact. It is important to control the elevator safety risk from the source to reduce the accidents. This article combines the risk factor analysis methods of Knowledge Graph (KG), Decision Making Trial and Evaluation Laboratory (DEMATEL), Interpretative Structural Modeling (ISM) method, and Matriced Impacts Cross-Multiplication Appliance Classment (MICMAC) to analyses elevator safety accidents in a data-driven manner in order to minimize the reliance on experts. Firstly, the causal network of accident occurrence is extracted from the accident reports based on the knowledge graph approach. Secondly, complex correlations in the causal network are quantified from the application of DEMATEL. Then, the ISM method was used to construct a hierarchical structure of elevator safety risk factors, on the basis of which the MICMAC method was combined to classify the types of risk factors and analyses the degree of influence of risk factors at each level. Finally, targeted preventive measures for elevator safety accidents are proposed based on the results of the model analysis.

INDEX TERMS Elevator, safety incidents, knowledge graph, KG-DEMATEL-ISM-MICMAC.

I. INTRODUCTION

In recent years, along with the high-speed social and economic development, China has become a global elevator manufacturing and use of large countries. By the end of 2022, China's elevator ownership has exceeded 9 million units, reaching a volume of 9,644,600 units [1]. As an indispensable means of transportation in modern cities, elevator has become a necessity in people's daily life and work. It facilitates people's travel, improves the quality of life and work efficiency, and plays an important role in modern urban life. However, when the elevator brings people a lot of convenience at the same time, it also brings people troubles. Especially a considerable part of the elevator has a long service life, and accidents such as toppling, squatting and elevator door pinching may occur, which will pose a threat to the safety of people's life and property. The elevator, which has the attribute of public safety, is getting more and more attention from the government and the society. In addition, the safety of elevators not only reflects the level of safety management of our government, but also has a close relationship with the personal and property safety of the public. According to the Provisions on the Reporting and Investigation of Accidents of Special Equipment issued by the State Administration of Market Supervision and Administration in 2022, the causes of elevator safety accidents mainly include the causes of the equipment body, the equipment safety devices, and the damage and failure of the equipment accessories. In addition, elevator-related personnel violate elevator laws, regulations and safety technical codes. In the last twenty years or so, with the increasing investment in elevator safety management and safety supervision, the number of elevator accidents in China has generally shown a downward trend. According to relevant statistics, between 2002 and 2022, a total of 937 elevator accidents occurred in China, with an average of 44 accidents per year. The year with the most elevator accidents was

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2014, with 95 accidents. The years with the fewest elevator safety accidents were 2004 and 2022, both with 22 incidents. Although the number of elevator safety accidents has decreased significantly, elevator accidents cause widespread social concern and serious public reaction when they occur. It brings greater resistance to stable social development and continuous economic growth. For example, the 7-26 elevator accident in Jingzhou, Hubei Province in 2015, and the Zhanjiang elevator topping accident in 2021. These have caused a strong social impact after a lot of media reports.

Based on this, scholars have carried out a lot of research on elevator safety, which is now mainly focused on elevator safety supervision, elevator safety risk analysis methods, elevator safety risk warning methods and other aspects. Combined with the research theme of this paper, it focuses on the study of elevator safety risk analysis methods. At present, elevator safety risk analysis methods mainly contain qualitative analysis method, safety checklist method, system analysis method, rooting theory, data mining and so on. Among the qualitative analysis methods, for example, Liu et al. [2] designed an elevator safety evaluation method by combining expert recommendations as well as objective factors. Liu et al. [3] evaluated elevator risk by employing a safety checklist to collect data and using machine learning methods. Huang [4] constructed an AHP-YAAHP elevator safety risk assessment model based on hierarchical analysis and expert experience, which further improved the computational efficiency of elevator safety assessment methods. Cui [5] proposed an elevator safety evaluation model based on gray correlation analysis and hierarchical analysis method, and carried out model validation. In the analysis of the safety checklist method, Zhao et al. [6] applied a variety of research methods, including simple safety checklist inspection, risk evaluation, and deep learning, to evaluate elevator risk from multiple perspectives. Ying [7] proposed the application of expert review method, fuzzy comprehensive judgment method, safety checklist method, and hierarchical analysis to evaluate the safety of old elevators; in the system analysis method, the main methods include system dynamics analysis method [8], accident tree analysis method [9], failure type and impact analysis method [10], operation safety analysis method [11], hazard pre-analysis method [12], etc. At present, the system dynamics analysis method as well as the fault tree analysis method are mainly applied in elevators, for example, Liu [13] constructed a system dynamics model with the inspectors in inspection as the entry point, analyzed the causes and consequences that may lead to inspection-related safety accidents, and provided theoretical basis for the prevention of accidents in inspection. Feng et al. [14] used FTA-TFN (Fault Tree Analysis-Triangular Fuzzy Number) method to meticulously analyze the hazardous elements and their essential mechanisms in elevator safety accidents. In the rooted theory approach, Du et al. [15] used rooted theory to conduct a three-stage coding study of elevator safety risks, identified the main risk factors, and also explored the multiple risk factors and their mechanisms of elevator safety using structural equation modeling and conducted an empirical study. In the data mining analysis method, Li [16] proposed a new method to construct an elevator safety risk assessment model to solve the shortcomings of the traditional assessment method, which combines a fuzzy evaluation algorithm and an artificial neural network, and has been validated to prove its accuracy and timeliness. Zhang [17] used the G-SVM model to predict the risk of elevator operation through data analysis, from the perspective of principal components and the dimension of safety theory, and put forward the elevator safety prevention and control policy recommendations. Yang [18] constructed an elevator safety risk evaluation model based on big data analysis by identifying the risk factors of elevators in all aspects using cloud computing and big data related technologies.

As can be seen from the above study, there are two deficiencies in the current identification methods of elevator safety risk factors. First, methods such as qualitative analysis method, safety checklist method, system analysis method, and rooting theory may be affected by personnel's personal experience as well as knowledge limitations. This can produce problems such as omission of risk factors or high subjectivity. Secondly, the method of data mining is also in the preliminary research stage. While elevator safety accidents contain a large amount of data information, it is necessary to fully mine the characteristics of accident attributes to find the correlation factors of accident causation. However, there is a lack of effective methods to analyze unstructured text data in the current research. With the continuous development of information technology, knowledge graph technology provides new ideas for risk analysis, and at present, knowledge graph risk analysis mainly focuses on the fields of urban energy, enterprise credit, medical treatment, gas accident, etc. For example, Chi et al. [19] combined knowledge graph with deep learning algorithms to utilize the prediction of bond defaults based on multi-source information and macroeconomic data. Alam et al. [20] introduced a framework based on knowledge graph and XGBoost for loan default prediction using a household credit default risk dataset. Yang et al. [21] explored a multi-network approach to risk analysis based on migration learning, conditional random fields and BiLSTM for multi-network dynamic knowledge mapping to identify corporate risks using corporate domain entities and corporate news items. Patrick Behr et al. [22] introduced an innovative knowledge graph-driven credit risk assessment model (RGCN-RF) based on relational graph convolutional network (RGCN) and random forest (RF) algorithms. Jia et al. [23] proposed an improved decision-making experimentation and evaluation laboratory (KG-CN-DEMATEL) based on knowledge graphs and complex networks. Specifically, a knowledge graph with Gaussian embedding (KG2E) is used to vectorize risk-related textual information. Bai et al. proposed a novel risk assessment model integrating knowledge graph (KG), Decision Making Trial and Evaluation Laboratory (DEMATEL), and BN to analyze natural gas pipeline accidents in a data-driven manner in order to minimize the reliance on experts. The results showed that the KG-DEMATEL-BN model is an effective method for risk assessment and safety management of natural gas pipelines and other process units in practice [24]. Based on this, this paper tries to use knowledge mapping technology for structured extraction of textual knowledge on elevator safety accidents. Meanwhile, DEMATEL, ISM, MICMAC and other methods are introduced to complete the analysis of elevator safety risk factors. Firstly, this paper constructs a knowledge database about elevator accidents using knowledge graph method, and uses neo4j to visualize and display the knowledge. The extraction of unstructured text about elevator safety accidents was realized. Secondly, the direct influence matrix in DEMATEL was optimized by using the correlation relationship in the knowledge graph to avoid the subjectivity of expert scoring. The core risk factors were identified through the DEMATEL method. Finally, the hierarchical structure and factor attributes of elevator safety influencing factors were further analyzed using a combination of ISM and MICMAC methods. At the same time, the critical risk path of elevator safety risk is identified to provide decision support for elevator safety managers.

The rest of the article is organized as follows. In Section II, the article presents the KG-DEMATEL-ISM-MICMAC methodology for elevator safety risk factor analysis. The applicability of the KG, DEMATEL, ISM, and MICMAC methods and the reasons for combining the four methods are presented, respectively. In Section III, the article mainly constructs the knowledge map of elevator safety accidents. First, the seven-step method is used to construct the ontology of elevator safety accidents. Second, the structured extraction of elevator accident reports is realized using the UIE joint extraction model, and the similarity algorithm is used for knowledge alignment. Finally, ternary data storage was accomplished using Neo4j software. In Section IV, the article focuses on the analysis of key factors of elevator safety accident risk. First, the DEMATEL direct influence matrix was optimized using knowledge graph (KG). The core influence factors of elevator safety were identified using the DEMATEL method. The influence range and intensity of elevator safety risk factors were identified. Secondly, the hierarchical structure and factor attributes of elevator safety risk factors were analyzed using a combination of ISM and MICMAC methods. This combination of methods is able to assess the dependence and driving degree of elevator safety risk factors, as well as to rationally prioritize control actions. In Section V, the article summarizes the research and proposes future research directions.

II. RESEARCH METHOD

This paper carries out an optimization study on the basis of the DEMATEL-ISM method, integrating the KG, DEMATEL, ISM and MICMAC methods to form the

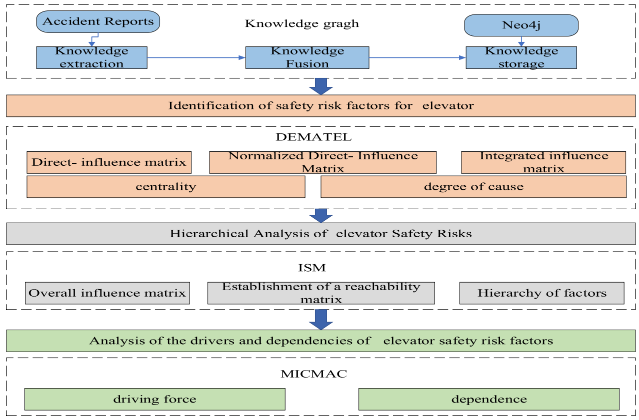

FIGURE 1. Flowchart of the KG-DEMATEL-ISM-MICMAC method.

KG-DEMATEL-ISM-MICMAC elevator safety risk analysis method. The method analyses the risk factors of elevator safety accidents from a data-driven perspective. On this basis, the article proposes prevention and control measures of safety risks to provide reliable decision support for elevator safety management. The detailed process of the method is shown in Figure 1.

A. KNOWLEDGE GRAPH

In recent years, it has been widely used with the rise of big data and the development of artificial intelligence. Knowledge graph describes concepts or entities with associated relationships in the real world, and knowledge graph can be categorized into general knowledge graph and domain-specific knowledge graph. More precisely, a knowledge graph consists of nodes (entities) and edges (relationships). By applying KG, the required information or knowledge can be easily obtained and further analyzed. The construction of knowledge graph includes knowledge extraction, knowledge fusion, and knowledge storage. In addition, the methods of knowledge graph construction vary according to the amount and type of data, and rule-based matching, machine learning, and deep learning are widely used methods [25], [26], [27], [28]. In this paper, combining the data characteristics of elevator safety accident text, the first step is to model the ontology of elevator safety accidents using a seven-step approach, followed by preprocessing the elevator safety accident text data for data annotation. Then, the annotated data are used to train the UIE unified extraction macro model to complete the knowledge extraction of elevator safety accident text. Finally, the knowledge fusion is performed and the text extraction structure of elevator safety accidents is visualized using Neo4j. The main purpose of using knowledge graph technology in this paper is to extract the textual knowledge of elevator safety accidents using knowledge graph technology (KG). It can transform unstructured text into structured text and fully explore the data information in elevator safety accident text. At the same time, the DEMATEL method is optimized by using the association relationship in the knowledge graph, which effectively avoids the subjectivity in the selection of elevator safety risk factors and objectively forms the elevator safety risk factor indicators. It lays the data foundation for effectively identifying the core factors in elevator safety risk factors.

B. DEMATEL

Decision Making Trial and Evaluation Laboratory (DEMATEL) is a system analysis method proposed using graph theory and matrix tools for solving complex and difficult system problems in the real world [29]. DEMATEL is a structured and practical technique for causal networks to quantify correlations and dependencies between factors [30]. By assessing the significance and correlation of individual factors, DEMATEL can distinguish causal relationships, determine rankings and weights, and support decision making [31], [32]. In this paper, the DEMATEL method was selected to effectively identify the core influencing factors affecting elevator safety, and determine the cause and effect factors of elevator safety risk factors. At the same time, it can determine the influence range and intensity of elevator safety risk factors, but it cannot judge the hierarchical relationship between the influencing factors and their dependence on each other. The specific steps of DEMATEL are shown below.

Step 1: The elevator safety risk elements summarized in the knowledge graph are labeledF1, F2…Fn in order.

Step 2: A data-driven determination of the direct influence matrix is derived based on the constructed knowledge graph. By counting the frequency of occurrence of each correlation, the direct impact matrix $O = [O_{ij}]_{m\times n}$ in Table 1 can be obtained.

$$O = \begin{bmatrix} 0 & O_{12} & \cdots & O_{1n} \\ O_{21} & 0 & \cdots & O_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ O_{n1} & O_{n2} & \cdots & 0 \end{bmatrix} \tag{1}$$

Step 3: Analyze the indirect influence relationships of the factors in the system and normalize he direct influence matrix O to obtain the normalized direct influence matrix $Z(Z = [Z_{ij}]_{mXn})$.

$$Z = \frac{O}{max \sum_{j=1}^{n} O_{ij}} \tag{2}$$

In the formula, $O \leq z_{ij} \leq 1$, and $max \sum_{j=1}^{n} z_{ij}$.

Step4: Calculate the integrated impact matrix $T(T = [t_{ij}]_{nxn})$ according to the formula. In the formula, the factor t_{ij} in the matrix T represents the combined influence level of factor i on factor j, including the direct and indirect influence levels. The calculation formula is shown below.

$$T = \frac{Z}{1-Z}(I \text{ is the unit matrix}) \tag{3}$$

Step 5: Calculate the degree of influence a_i, the degree of being influenced b_i, the degree of centre M_i, the degree of cause N_i for each element in the system. The specific calculation formula is as follows.

$$a_i = \sum_{j=1}^{n} t_{ij} \quad i = 1, 2, \cdots, n \tag{4}$$

$$b_i = \sum_{j=1}^{n} t_{ji} \quad i = 1, 2, \cdots, n \tag{5}$$

$$M_i = \sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ji} \quad i = 1, 2, \cdots, n \tag{6}$$

$$N_i = \sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji} \quad i = 1, 2, \cdots, n \tag{7}$$

According to the calculation results, the centrality degree M_i is ranked, and the key risk factors can be determined. Risk factor attributes are determined by the positivity and negativity of the cause degree N_i. Finally, the result factors and cause factors are derived [33].

C. ISM

The Interpretative Structural Modelling (ISM) method is a widely used system science method, a model proposed by Professor Warfield, an American economist, in 1973 when he explored complex economic structures. The ISM method lists the influencing factors of the system to be studied and draws a directed graph based on the relationships between the influencing elements. Through Boolean logic operations, the ambiguous hierarchy of factors and the complex system composition are transformed into a clear ISM model [34]. In this paper, based on the DEMATEL method, the ISM model is established and the calculation steps are simplified as follows. Step 1: Take the integrated matrix T derived from the analysis of the DEMATEL method as the basis, and add it with the unit matrix to derive the overall system impact matrix $H = T + I$, where I is the unit matrix. Step 2: Compute the reachable matrix $K{=}(k = [k_{ij}]_{nxn})$ according to equation (8).

$$K_{ij} = \begin{cases} 0, & h_{ij} < \lambda \\ 1, & h_{ij} \geq \lambda \end{cases} \quad i, j = 1, 2, \cdots, n \tag{8}$$

In the formula, λ is a set threshold, and the size is compared with the factor h_{ij} in the overall influence matrix H.

Step 3: Hierarchical division of reachable matrix K. Divide the factors in the reachable matrix K into reachable set $R(Fi)$ and prior set $Q(Fi)$. The reachable set $R(Fi)$ represents the set of elements in a reachable matrix or directed graph that are reachable by Fi. In a reachable matrix or a directed graph, a reachable set $R(Fi)$ denotes that Si is reachable to the set consisting of each of the other elements. the prior set $Q(Fi)$ denotes the set of other elements that are reachable to Fi.Step 4: Calculate and verify according to Eq. (9), if the formula is valid, the rows and columns belonging to it are delimited in the matrix K. The following steps are performed.

$$R(Fi) \cap Q(Fi) = R(Fi) \quad (\text{i} = 1, 2, \cdots \text{n}) \tag{9}$$

Step 5: Repeat steps 3 and 4 to delimit all the factors in the system. Finally, the hierarchical relationship of factors is established in the order in which the factors are delineated.

In this paper, the elevator safety risk factors can be split layer by layer according to the constructed accessibility matrix. It is able to transform the abstract sequence of safety risk factors in the system into an intuitive hierarchical structure diagram. At the same time, the influence factors are divided into three hierarchical structures: deep, middle and surface. Finally, through the analysis of the hierarchical structure as well as the influence path, the critical path of elevator safety risk is fully excavated.

D. MICMAC

In 1993, Duperrin and Godet proposed the introduced the method of cross-matrix multiplication (MICMAC) to explore the diffusivity of interrelationships among the factors within the system based on the ISM model to classify the factors into different types [35]. By calculating the dependencies and driving forces of the factors within the system, the key elements of the system were derived from the comprehensive analysis. The main calculation formula is as follows.

$$E_i = \sum_{i=1}^{n} k_{ij} \quad (\mathrm{i} = 1, 2, \cdots \mathrm{n}) \tag{10}$$

$$F_i = \sum_{j=1}^{n} k_{ij} \quad (\mathrm{j} = 1, 2, \cdots \mathrm{n}) \tag{11}$$

Specifically, in the reachability matrix K, each row is summed to get the value of the driving force of each risk factor, and each column is summed to get the value of the dependency, which enables us to get the values of driving force and dependency of each risk factor. The risk factor with a large value of driving force influences more other risk factors, and the risk factor with a large value of dependency is influenced by more other risk factors. According to formulas (10) and (11) to calculate the driving force and dependence, respectively, the factors can be categorized into autonomous (I), dependent (II), linked (III), and independent (IV) factors. Based on the dependence value and driving force value of each risk factor, each risk factor is traced in the coordinate system, and finally the elevator risk factor MICMAC analysis model is formed. The MICMAC method can analyze the position and role of elevator safety risk factors in the system. It is also able to assess the dependency and driving degree of elevator safety risk factors and rationally prioritize control actions.

In summary, the article combines the four methods organically, which can simultaneously analyze the roles between factors in terms of influence size and relationship complexity, and also obtain a hierarchical system structure model. This can deeply excavate the influence factors of elevator safety accidents and provide a strong theoretical basis for preventing elevator safety accidents.

III. CONSTRUCTION OF KNOWLEDGE GRAPH FOR THE ELEVATOR SAFETY INCIDENTS

A. ONTOLOGICAL MODELLING OF SAFETY ACCIDENTS

There are common ontology modelling methods that are more widely used, such as the skeleton method [36], the seven-step method [37], and the IDEF5 method [38]. Among them, the seven-step method is proposed by Stanford University School of Medicine for constructing domain ontology, which consists of seven steps: determining the scope of the domain ontology, reusing existing ontologies, listing the terms in the domain, defining the hierarchical relationship between classes and classes, defining the attributes of the classes, defining the faceted aspects of the attributes, populating the instances, and so on. Based on the perspective of elevator safety risk prevention and control, this paper divides the Elevator Safety Accident Ontology Model (Elevator Knowledge Concept, EKC) into three concepts: accident situation (Event Situation, ES), disaster-bearing carrier (Event Loss, EL), and accident analysis (Event Analysis, EA), which are used to represent the knowledge structure of accident cases. In this paper, we define the elevator safety incident knowledge ontology concept as EKC = {ES, EL, EA}, as shown in Figure 2.

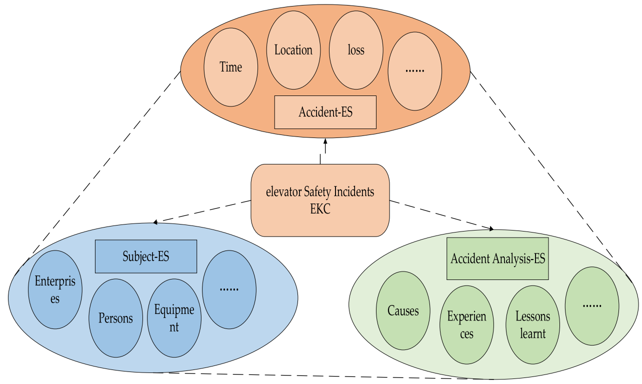

FIGURE 2. Ontology model of elevator safety accidents.

According to the ontology model of elevator safety accidents designed in Figure 2, the entities in the text of elevator safety accidents mainly contain safety accidents, enterprise organizations, enterprise personnel, accident equipment, accident causes, accident levels, accident responsibilities, and lessons learned. The attributes of the safety accident mainly contain the name of the accident, the place of occurrence, the time of occurrence, the loss of the accident, the characteristics of the accident, and the nature of the accident. Attributes of enterprise institutions enterprise name, unit type. Attributes of enterprise personnel contain personnel name, personnel position, etc. The relation-ships in the ontology model are mainly containment relationships, hierarchical relationships, the enterprise involved is, the personnel involved is, the equipment involved is, and other relationships.

B. KNOWLEDGE EXTRACTION

1) MODEL SELECTION

Information extraction usually consists of four common subtasks: entity extraction, relationship extraction, event extraction, and sentiment analysis. Existing studies mostly consider information extraction for a single task, but the structure of entities and events to be recognized varies from task to task. Specific models need to be trained for specific tasks, especially when multitask information extraction is involved at the same time, which requires customized coding and labelling representations, and is not universal. Unified Structure Generation for Universal Information Extraction (UIE) designed the structured extraction language SEL to unify the representation of different structures of text under different Information Extraction (IE) tasks [39]. Among them, the structural schema instructor SSI is designed to control the extraction, association and generation of UIE models. That is, the text of different structures is encoded uniformly, and the target objects are extracted adaptively through the schema-based Prompt mechanism to achieve the extraction of large-scale text to a specified structure. The general framework of UIE is shown in Figure 3.

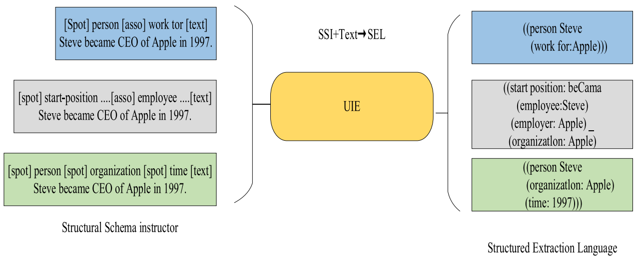

FIGURE 3. The general framework of UIE.

In addition, the joint extraction model UIE considers the problem of information extraction from the perspective of a generative model, so that these several subtasks can be performed by a single model. The UIE model is based on the learning method of Prompt, which reduces the need for large supervised datasets by learning a language model of the text's own probability and using this probability to predict the entity relationships of the output. Based on the textual characterization of elevator safety accidents, the accident report involves the extraction tasks of entities, relations and events simultaneously. Therefore, in this paper, we adopt the UIE unified extraction micromodel and use the knowledge enhancement model to synthesize new data by rewriting the existing data, adding noise and resampling. This improves the extraction effect, enhances the generalization ability and robustness of the model. At the same time, a comparative analysis is carried out with the Bert-base-Chinese based pre-trained model TPLinker [40] and GPLinker [41] joint extraction model to verify the effectiveness of the model.

2) DATA PREPROCESSING AND DATA LABELING

Firstly, formatting errors, unknown pronoun references, and content repetition were solved by preprocessing. Secondly, the doccano tool is used for training data annotation. As the UIE model has a strong on-demand adaptation ability, the few-shot can also achieve good results. Therefore, in this paper, 50 typical accident reports of different types are labelled for model pre-training. Since the model batch-size is not more than 512 characters per corpus (more than part of the model will be automatically truncated), the text is firstly cut in sentences with 256 Chinese characters as the maximum length, and then choose text line format to import into doccano annotation platform for annotation.

3) RESULT ANALYSIS

The article compares and analyzes the UIE model with the TPLinker and GPLinker models based on the Bert-base-Chinese pre-training model. The results of accuracy, recall and F1 value of the three models are shown in Table 1. It is confirmed that the UIE model has high F1 value. Then, 102 elevator safety accident texts were extracted using the trained model, and a total of 2981 entity relationship triples were obtained.

TABLE 1. Comparison of the effects of different models.

Model	Precision	Recall	F1value
TPLinker	0.648	0.361	0.464
GPLinker	0.683	0.547	0.608
UIE	0.662	0.758	0.707

C. KNOWLEDGE FUSION AND KNOWLEDGE STORAGE

Semantic similarity is first calculated two by two for entities in all the obtained triples. Then, the expert judges whether two entities have referential canonical representations or express the same content. Finally, entity alignment is performed according to the judgement result. As shown in Table 2, Example 1 standardizes the different pronouns of the subject. Example 2 finds redundant entities. Example 3 finds errors in the format of the extracted to entities.

TABLE 2. Knowledge fusion.

Serial number	Entity 1	Entity 2	Converged entity
Exampl e 1	State Administration of Market Supervision and Administration	State Administrat ion of Market Supervision	State Administration of Market Supervision and Administration
Exampl e 2	taking up a post without a certificate	Taking up duty without personnel qualification certificates	taking up a post without a certificate
Exampl e 3	Models TWJ2Z	Models TWJ2-Z	Models TWJ2-Z

The storage of the knowledge graph is to store the extracted triples using Neo4j graph database, and the storage process is to first create nodes in neo4j first and then connect the relationship between nodes. The article puts 102 collected texts of elevator safety accidents through the above model, and then after manual proofreading, a total of 1829 entities and 2918 entity-relationship triples are extracted,. Finally the elevator safety accident graph is obtained, which is partially shown in Figure 4.

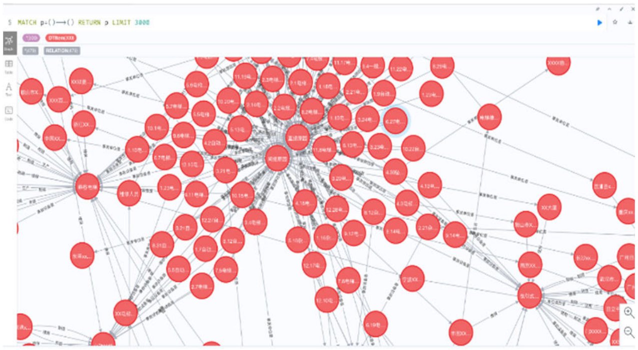

FIGURE 4. Visualization of the knowledge map of elevator safety incidents (partial).

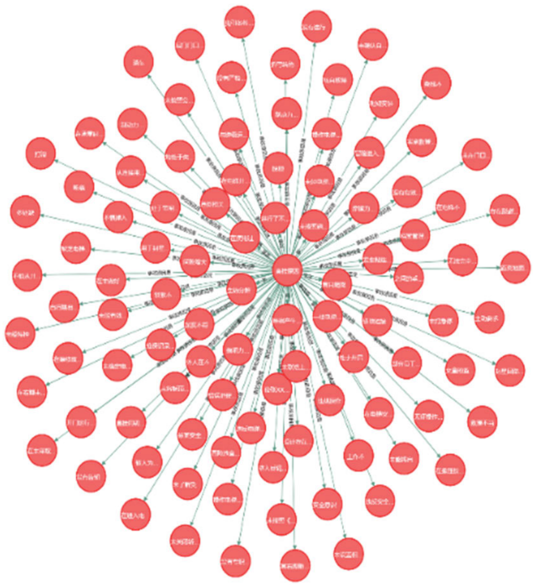

FIGURE 5. Direct causes of elevator safety accidents.

Combined with the research purpose of this paper, the article focuses on analyzing the causes of elevator safety accidents. The knowledge retrieval of the causes of elevator accidents is accomplished through the knowledge graph Cypher query language. The specific query code is shown below.

match (n: accident cause {title: "direct cause"}) –(b) return n, b LIMIT 100

match (n: Cause of accident {title: "Indirect cause"}) –(b) return n, b LIMIT 100

The above two queries represent the completion of the search for "direct cause" and "indirect cause", and the results are shown in Figures 5 and 6.

After knowledge retrieval, this paper uses the neo4j database to export statistical tables of direct and indirect causes in csv format for further statistical analysis of elevator safety risk factors. As the knowledge graph contains too many factors and correlations, it is difficult for further risk assessment. Based on this, DEMATEL is chosen for correlation quantification and causal network simplification in this paper.

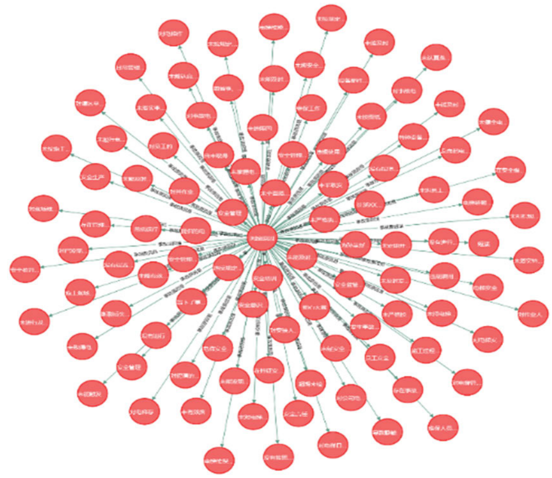

FIGURE 6. Indirect causes of elevator safety.

IV. ANALYSIS OF KEY FACTORS FOR RISK OF ELEVATOR SAFETY INCIDENTS

A. DIRECT IMPACT MATRIX

Firstly, according to the theory of accident causation, this paper divides the risk factors of elevator safety accidents into three categories: personnel factors, equipment factors and management defects, which mainly include personnel's unsafe behaviors, equipment's unsafe state, management defects and other issues. At the same time, with reference to the classification of causes in typical elevator accident cases prepared by the State Administration of Market Supervision and Administration, the article summarizes the elevator safety risk factors extracted from the knowledge graph, and combines the similar cause risks. For example, factors such as damage to mechanical parts of door locks, failure of safety protection devices, brake failure and failure of emergency alarm devices are unified and summarized as equipment parts failure. Failure to operate in accordance with technical requirements, failure to operate in accordance with rules and regulations and failure to operate in accordance with the requirements of the regulations are uniformly categorized as unauthorized operation. Through the above analysis, the article was finally summarized into 23 risk factors, as shown in Table 3.

In order to show the main causes of elevator safety accidents more intuitively, this paper provides statistics on the current causes of elevator safety accidents based on the factors divided in Table 3. According to statistics, there have been 937 elevator accidents in China as of 2022. However, the causes of elevator safety accidents are often complex, with different investigators, writers, and recording habits, which often leads to the phenomenon that the reported elevator safety accident files are de-missing. Considering the availability of data, this paper focuses on the

TABLE 3. Analysis of risk factors for elevator safety accidents.

Category	SERIAL NUMBER	risk factor
Personnel Factors	*F1*	Low safety awareness
	F2	Lack of elevator safety knowledge
	F3	Unauthorized operation
	F4	Improper operation
	F5	No license to work
	F6	Inadequate safety protection measures
Equipment Factors	*F7*	Unauthorized risky self-rescue
	F8	Failure of equipment parts
	F9	Defective design of equipment
	F10	Defective design drawings
Management Factors	*F11*	Inadequate safety management system
	F12	Safety education is not in place
	F13	Safety management is not in place
	F14	Safety supervision is not in place
	F15	Inadequate implementation of safety responsibilities
	F16	Hidden danger investigation is not in place
	F17	Chaotic on-site safety management
	F18	Failure to provide safety management personnel
	F19	Lack of emergency rescue measures
	F20	No qualification of related units
	F21	Lax quality control of key components
	F22	Inadequate maintenance
	F23	Illegal use of elevators

analysis of 423 typical elevator accident cases provided by the State Administration of Market Supervision, as well as 102 elevator accident reports with clear causes of accidents screened out in this paper. Finally, the statistical analysis of 525 elevator accident causes is formed, and the specific risk statistics are shown in Figure 7.

As can be seen from Figure 7, the top five risk factors in terms of frequency of occurrence of elevator safety causes mainly contain equipment component failures, unauthorized operation, lack of safety supervision, lack of safety management, lack of implementation of safety responsibilities, and illegal use of elevators. In order to further develop the analysis of the hierarchical relationship of elevator safety risk factors, this paper optimizes the DEMATEL method using the association relationship of knowledge graph. The typical DEMATEL relies on linguistic opinions from experts during the determination of the direct-influence matrix. Drawing on Yiping Bai's method [24], this paper derives a data-driven determination of the direct impact matrix of the constructed knowledge graph by counting the frequency of occurrence of each correlation. This is done by statistically analyzing the number of directed arcs for each risk factor in the knowledge graph of elevator safety accidents to derive the direct influence matrix ($O = [O_{ij}]_{23\times 23}$) of elevator risk factors. In the matrix O, the element O_{ij} indicates the degree of direct influence of the factor F_i on F_j. For example, $F_{13} = 6$ indicates that the directed arcs from F_1 to F_3 appear six times in the knowledge graph. If $i = j$ then $O_{ij} = 0$ The results of the direct influence matrix are shown in Table 4.

B. CALCULATION OF THE INTEGRATED IMPACT MATRIX

According to equation (2), the normalized direct impact matrix is obtained. Equation (3) is then used to obtain the integrated impact matrix, and the results are shown in table 5.

C. CENTER DEGREE AND CAUSE DEGREE CALCULATION

Then, according to equations (4)-(7), the influence degree a_i, the influenced degree b_i, the center degree M_i, the cause degree N_i of each risk factor are calculated. In addition, the article ranks the influence degree, influenced degree, centrality degree, and cause degree, and the results are shown in Table 6.

As can be seen from Table 6, the factors with high influence are inadequate safety supervision (F14), inadequate hidden danger investigation (F16), weak safety awareness (F1), inadequate safety management system (F11), and chaotic on-site safety management (F17). These factors in the elevator safety risk factor system on the other factors of the integrated influence of the larger, the effect of the influence is very strong. These factors belong to the main influencing factors.

The top five factors affected by other factors are unauthorized operation (F3), equipment parts failure (F8), improper operation (F4), inadequate maintenance (F22), and illegal risky self-rescue (F7). This type of factors in the elevator safety risk factor system by other factors of the combined influence of the larger, easy to influence and dominate.

The top five factors ranked in the center degree are unauthorized operation (F3), safety supervision is not in place (F14), equipment parts and components failure (F8), hidden danger investigation is not in place (F16), on-site safety management is chaotic (F17). This type of factor plays a large role in the elevator safety risk factor system, occupies the core position, and is an important influence factor.

The analysis about the cause degree is mainly divided into two categories. Factors with a cause degree greater than 0 and factors with a cause degree less than 0. The factors with a cause degree greater than 0 are inadequate safety supervision (F14), inadequate safety management (F13), inadequate safety education (F12), inadequate safety management system (F11), inadequate implementation of safety responsibility (F15), chaotic on-site safety management (F17), weak safety awareness (F1), and inadequate investigation of hidden dangers (F16). The above results show that these 8 factors have strong constraints and driving force, and are biased to influence other factors in the elevator safety risk factor system, which are cause factors. These factors play an important fundamental role in elevator safety management. Factors with a degree of cause less than 0 are related units without qualification (F20), lack of elevator safety knowledge (F2), not equipped with safety management personnel (F18), equipment design defects (F9), design drawing defects (F10), poor quality control of key components (F21), no license (F5), lack of emergency rescue measures (F19), illegal use of the elevator (F23), safety

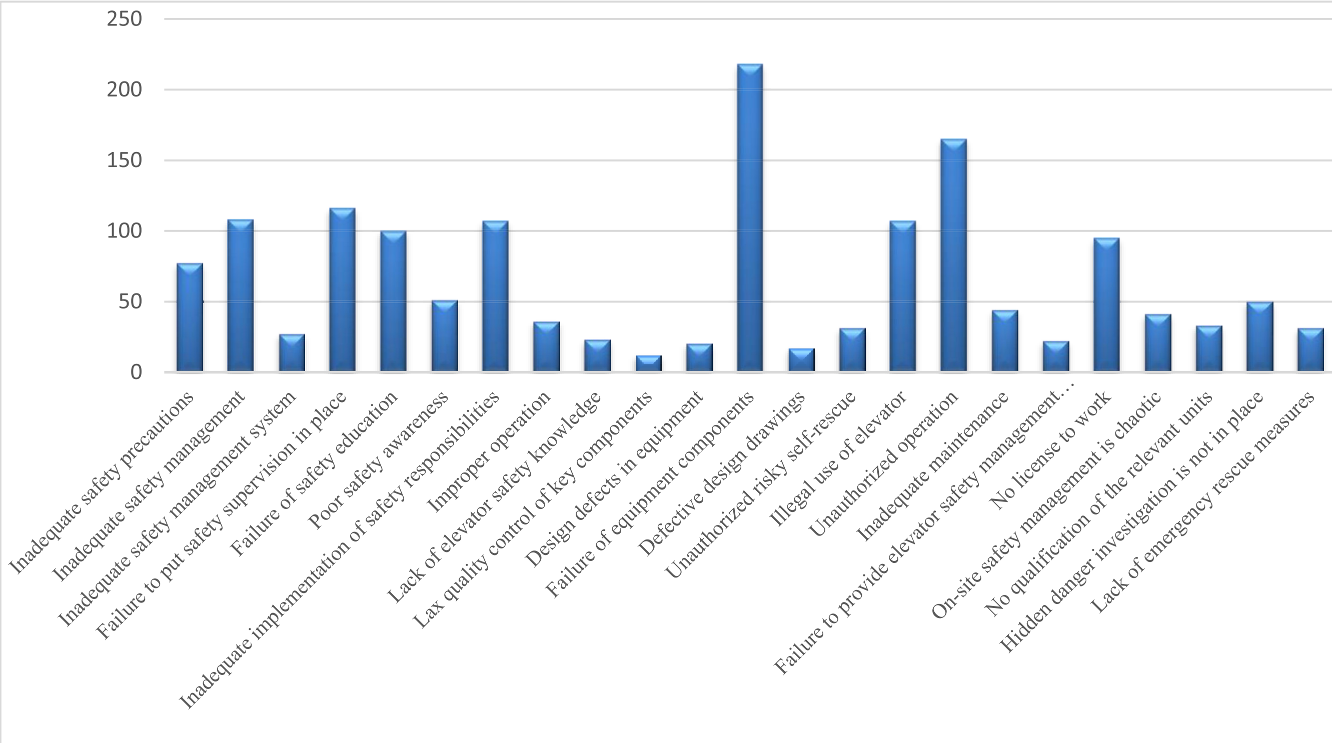

FIGURE 7. Statistics on the frequency of causes of elevator safety accidents.

TABLE 4. Direct impact matrix of elevator safety accident risk.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23
F1	0	0	6	3	0	3	3	0	1	0	0	2	2	3	2	1	2	3	2	0	1	2	2
F2	0	0	3	1	0	0	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
F3	0	0	0	4	0	3	2	6	0	0	0	0	0	0	0	0	0	0	1	0	0	3	2
F4	0	0	5	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
F5	0	0	3	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	1
F6	0	0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
F8	0	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
F10	0	0	0	0	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F11	3	2	4	3	2	2	2	1	1	2	0	1	1	1	1	1	2	2	4	3	3	2	2
F12	5	4	6	2	2	2	2	0	0	0	0	0	2	3	2	2	0	0	1	0	0	1	3
F13	4	3	8	4	2	0	0	5	0	2	0	0	0	0	3	2	5	3	0	0	0	0	3
F14	4	3	6	4	5	3	2	0	0	4	4	2	2	0	4	4	4	4	2	4	4	3	2
F15	3	2	2	3	0	2	2	0	0	4	4	0	0	0	0	3	2	2	4	3	3	3	2
F16	0	0	3	4	3	2	1	9	0	0	0	0	0	0	0	0	3	2	3	5	5	8	0
F17	0	0	3	4	5	2	2	4	0	3	3	0	0	0	3	2	0	1	4	4	0	3	4
F18	0	0	2	2	3	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	3
F19	0	0	2	0	0	0	3	0	0	0	0	0	0	0	0	2	1	3	0	0	0	0	0
F20	0	0	2	0	0	0	0	5	2	1	1	1	1	0	1	1	0	0	0	0	0	1	1
F21	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F22	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
F23	0	0	0	2	1	0	2	5	1	0	0	0	0	0	0	0	0	0	0	0		0	0

protection measures are not in place (F6), maintenance is not in place (F22), illegal risk self-rescue (F7), improper operation (F4), illegal operation (F3), equipment parts failure (F8). The above research results show that these 15 factors are inclined to be influenced by other factors in the elevator safety risk factor system, and belong to the outcome factors.

TABLE 5. Consolidated impact matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23
F1	1.008	0.006	0.114	0.069	0.012	0.058	0.058	0.032	0.016	0.007	0.006	0.030	0.032	0.045	0.035	0.026	0.037	0.051	0.038	0.008	0.021	0.046	0.044
F2	0.000	1.000	0.048	0.018	0.000	0.003	0.088	0.022	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.017	0.003
F3	0.000	0.000	1.013	0.066	0.001	0.045	0.032	0.097	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.015	0.000	0.000	0.046	0.030
F4	0.000	0.000	0.076	1.008	0.000	0.032	0.032	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.032	0.017
F5	0.001	0.000	0.049	0.048	1.001	0.004	0.019	0.007	0.001	0.001	0.014	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.030	0.001	0.001	0.004	0.017
F6	0.000	0.000	0.034	0.074	0.000	1.004	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.004	0.002
F7	0.000	0.000	0.029	0.002	0.000	0.001	1.001	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.015
F8	0.000	0.000	0.061	0.047	0.000	0.004	0.003	1.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.004	0.002
F9	0.000	0.000	0.004	0.003	0.000	0.015	0.000	0.048	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.029	0.000
F10	0.000	0.000	0.004	0.003	0.000	0.001	0.000	0.061	0.071	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
F11	0.047	0.032	0.087	0.066	0.037	0.041	0.046	0.049	0.020	0.034	1.005	0.017	0.018	0.018	0.020	0.025	0.035	0.037	0.066	0.049	0.047	0.045	0.042
F12	0.078	0.062	0.118	0.057	0.037	0.044	0.049	0.030	0.004	0.006	0.006	1.004	0.033	0.047	0.036	0.038	0.010	0.011	0.025	0.008	0.008	0.033	0.056
F13	0.060	0.045	0.146	0.089	0.039	0.018	0.021	0.106	0.005	0.035	0.007	0.002	1.003	0.003	0.048	0.036	0.077	0.050	0.014	0.010	0.006	0.023	0.059
F14	0.068	0.050	0.136	0.100	0.088	0.066	0.056	0.060	0.010	0.068	0.067	0.033	0.035	1.006	0.067	0.074	0.070	0.071	0.050	0.072	0.069	0.075	0.053
F15	0.046	0.031	0.056	0.064	0.009	0.041	0.045	0.039	0.008	0.062	0.060	0.003	0.004	0.004	1.005	0.053	0.035	0.038	0.068	0.052	0.050	0.061	0.040
F16	0.001	0.000	0.070	0.078	0.048	0.037	0.024	0.169	0.003	0.003	0.004	0.001	0.002	0.001	0.003	1.013	0.044	0.032	0.049	0.075	0.073	0.125	0.009
F17	0.004	0.003	0.071	0.081	0.077	0.039	0.043	0.092	0.007	0.048	0.048	0.002	0.002	0.001	0.045	0.039	1.006	0.021	0.068	0.064	0.007	0.058	0.067
F18	0.002	0.001	0.039	0.039	0.045	0.032	0.020	0.014	0.001	0.002	0.002	0.001	0.015	0.014	0.002	0.004	0.002	1.002	0.003	0.001	0.001	0.033	0.047
F19	0.000	0.000	0.035	0.007	0.004	0.004	0.046	0.010	0.000	0.001	0.001	0.000	0.001	0.001	0.001	0.030	0.016	0.044	1.003	0.003	0.002	0.007	0.005
F20	0.003	0.002	0.041	0.011	0.003	0.005	0.004	0.086	0.030	0.016	0.015	0.015	0.015	0.001	0.016	0.018	0.003	0.002	0.004	1.003	0.003	0.021	0.018
F21	0.000	0.000	0.004	0.003	0.000	0.000	0.000	0.072	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
F22	0.000	0.000	0.014	0.012	0.003	0.003	0.002	0.156	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.072	0.003	0.002	0.004	0.005	0.005	1.010	0.001
F23	0.000	0.000	0.008	0.033	0.014	0.002	0.030	0.074	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.002	1.001

These factors are highly sensitive and susceptible to influence and change, and require special attention.

In order to show the causal relationship of elevator safety risk factors more intuitively, this paper draws a scatter plot

TABLE 6. Causality indicators for all factors (R+C descending order).

Risk factors	Influence	Influence Ranking	Influenced	Influenced Ranking	Centrality	Centrality Ranking	Causal degree	Causality Ranking	Factor Attributes
F1	1.066	3	0.415	11	1.118	8	0.482	7	Causal factors
F2	0.256	16	0.148	20	0.450	20	-0.017	10	Resulting factors
F3	0.482	9	1.725	1	1.609	1	-0.905	22	Resulting factors
F4	0.317	13	1.329	3	1.209	6	-0.751	21	Resulting factors
F5	0.284	15	0.546	8	0.624	19	-0.215	15	Resulting factors
F6	0.152	20	0.690	6	0.624	18	-0.371	18	Resulting factors
F7	0.078	23	0.767	5	0.679	16	-0.568	20	Resulting factors
F8	0.183	19	1.681	2	1.394	3	-1.135	23	Resulting factors
F9	0.139	21	0.241	17	0.308	23	-0.105	12	Resulting factors
F10	0.193	18	0.025	23	0.427	21	-0.140	13	Resulting factors
F11	0.999	4	0.097	22	1.115	9	0.645	4	Causal factors
F12	0.973	6	0.142	21	0.905	12	0.691	3	Causal factors
F13	0.674	8	0.210	18	1.062	10	0.745	2	Causal factors
F14	1.538	1	0.188	19	1.584	2	1.302	1	Causal factors
F15	0.861	7	0.278	15	1.151	7	0.594	5	Causal factors
F16	1.096	2	0.488	9	1.304	4	0.424	8	Causal factors
F17	0.995	5	0.294	14	1.232	5	0.552	6	Causal factors
F18	0.414	10	0.392	12	0.687	15	-0.043	11	Resulting factors
F19	0.308	14	0.444	10	0.662	17	-0.220	16	Resulting factors
F20	0.412	12	0.337	13	0.688	14	-0.017	9	Resulting factors
F21	0.110	22	0.268	16	0.375	22	-0.214	14	Resulting factors
F22	0.413	11	0.925	4	0.973	11	-0.384	19	Resulting factors
F23	0.243	17	0.558	7	0.709	13	-0.351	17	Resulting factors

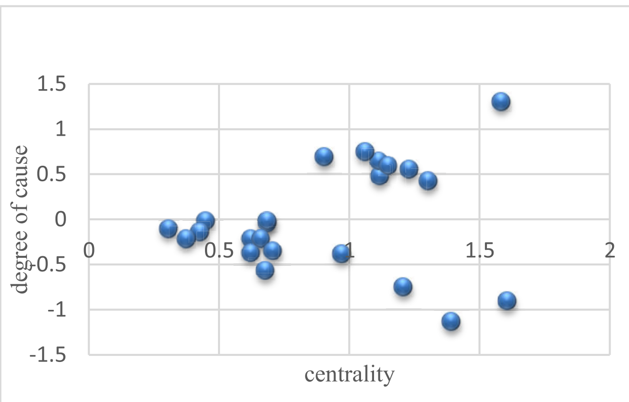

FIGURE 8. Causal scatter plot of elevator safety accident risk factors.

of causal relationship of elevator safety accident risk factors based on the results of Table 6, as shown in Figure 8. In Figure 8, the x-axis represents the center degree and the y-axis represents the cause degree. Where the cause factors are above the coordinate axis, representing that these factors directly affect the occurrence of elevator safety accidents. The result factors are below the coordinate axis, and these factors are influenced by the cause factors, which indirectly affect the occurrence of safety accidents. The larger the value of the center degree, the greater the importance of the factors.

D. REACHABILITY MATRIX

The method of converting from DEMATEL model to ISM model is that the reach-ability matrix can be calculated based on the integrated influence matrix T and the threshold value λ. Specifically, the overall impact matrix of the system is first calculated by Equation (3). Secondly, the threshold λ is set with reference to the research of Lin Yan and other scholars [42], [43], [44], [45], and the average value of the integrated influence matrix is chosen as the threshold of the reachable matrix, and the threshold in this paper is set to $\lambda = 0.066$. Finally, the reachable matrix K is calculated by using Equation (8), and the results are shown in Table 7.

E. DELINEATION OF THE HIERARCHICAL STRUCTURE

Based on the reachability matrix derived from Table 7, the matrix region is divided by the third step of the ISM method, which performs interval decomposition and inter-level decomposition of the matrix. Interval decomposition is to divide the elements into individual subsystems, and interlevel decomposition is to divide the elements within the same system into different hierarchies. The specific divisions are shown in Tables 8-10.

As shown in Tables 8-10, the first layer elements of elevator safety accident risk factors are divided into $L1 = \{3,4,5,7,8,9,18,19\}$. Then the rows and columns where F3, F4, F5, F7, F8, F9, F18, F19 are located are deleted, and the reachable and prior sets are divided to obtain the next layer of elements of this system model. Similarly, the second layer elements are obtained as $L2 = \{2,6,10,11, 20,21,22,23\}$. The third layer elements are $L3 = \{1,15, 16,17\}$ and the fourth layer elements are $L4 = \{12,13,14\}$. Finally, the system model is divided into four layers $L = \{L1, L2, L3, L4\}$. As a result, a multi-layer recursive order structure model of

TABLE 7. Reachable matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23
F1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F6	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F10	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F11	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
F12	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
F13	1	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
F14	1	0	1	1	1	1	0	0	0	1	1	0	0	1	1	1	1	1	0	1	1	1	0
F15	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	1	0	0	1	0
F16	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0
F17	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1
F18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
F20	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
F21	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
F22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
F23	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

TABLE 8. Division of elements in the first level.

Fi	R(Fi)	Q(Fi)	C(Fi)
F1	1,3,4	1,12,13,14	1
F2	2,7	2,12	2
F3	3,4,8	1,3,4,8,11,12,13,14,16,17	3,4,8
F4	3,4	1,3,4,6,11,13,14,15,16,17	3,4
F5	5	5,14,17	5
F6	4,6	1,6,14	6
F7	7	2,7	7
F8	3,8	3,8,10,13,15,16,17,20,21,22, 23	3,8
F9	9	9,10	9
F10	8,9,10	10,14,15	10
F11	3,4,11	11,14,15	11
F12	1,2,3,4,12	12	12
F13	1,3,4,8,13	13	13
F14	1,3,4,5,6,7,8,14, 16,18,20,22	14	14
F15	3,4,15,22	14,15	15
F16	3,4,8,16,22	16,22	16,22
F17	3,4,5,8,17,20,22	14,17	17
F18	18	14,18	18
F19	19	11,15,17,19	19
F20	8,20	14,17,20	20
F21	8,21	14,16,21	21
F22	8,16,22	14,15,16,22	16,22
F23	8,23	17,23	23

TABLE 9. Division of elements of the second level.

Fi	R(Fi)	Q(Fi)	C(Fi)
F1	1,6	1,12,13,14	1
F2	2	2,12	2
F6	6	1,6,14	6
F10	10	10	10
F11	11	11	11
F12	1,2,12	12	12
F13	1,13	13	13
F14	1,6,10,11,14,15, 16,20,21,22	14	14
F15	10,11,15,22	14,15	15
F16	16,21,22	14,16,22	16,22
F17	17,20,22,23	14,17	17
F20	20	14,17,20	20
F21	21	14,16,21	21
F22	16,22	14,15,16,17,22	16,22
F23	8,23	17,23	23

TABLE 10. Division of elements in the third level.

Fi	R(Fi)	Q(Fi)	C(Fi)
F1	1	1,12,13,14	1
F12	1,12	12	12
F13	1,13	13	13
F14	1,14	14	14
F15	15	14,15	15
F16	16	14,16	16
F17	17	17	17

elevator safety risk factors can be constructed as shown in Figure 9.

The first layer (L1) of factors belongs to the surface layer of direct factors, which is the direct factor causing elevator safety accidents. They mainly include unauthorized operation (F3), improper operation (F4), no license (F5), illegal risky self-rescue (F7), equipment parts failure (F8), equipment design defects (F9), not equipped with safety management personnel (F18), and lack of emergency rescue measures (F19).

The second (L2) and third (L3) layers of factors belong to the middle layer of indirect factors, which usually have an impact on the surface layer of direct factors, and are also

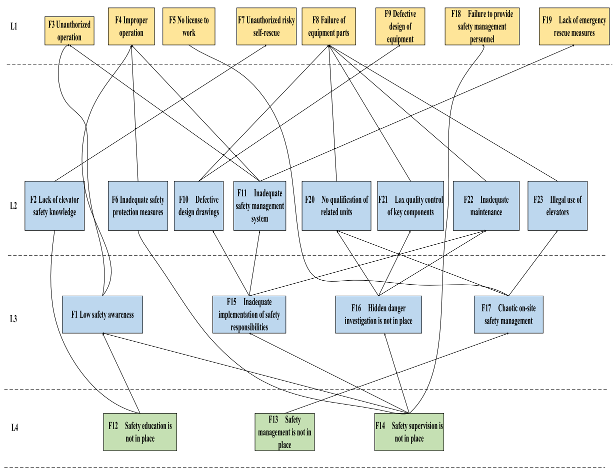

FIGURE 9. Multi-layer stepwise structural model.

TABLE 11. Risk factor path value.

paths	probability	paths	probability
F12→F2→F7	0.150	F14→F15→F10→F8	0.189
F12→F1→F3	0.192	F14→F15→F10→F9	0.200
F12→F1→F4	0.147	F14→F15→F11→F3	0.214
F13 → F17 → F5	0.158	F14→F15→F11→F4	0.193
F13 → F17 → F20→F8	0.227	F14→F15→F11→F19	0.193
F13 → F17 → F23→F8	0.218	F14→F15→F22→F8	0.283
F14→F6→F4	0.140	F14→F16→F20→F8	0.235
F14→F1→F3	0.182	F14→F16→F21→F8	0.219
F14→F1→F4	0.137	F14→F16→F22→F8	0.355

affected by the underlying fundamental factors. The main factors include poor safety awareness (F1), lack of knowledge of elevator safety (F2), safety protection measures are not in place (F6), defective design drawings (F10), inadequate safety management system (F11), inadequate implementation of the safety responsibility (F15), inadequate investigation of hidden dangers (F16), chaotic on-site safety management (F17), the relevant units are unqualified (F20), and poor quality control of the key components (F21), inadequate maintenance (F22), and illegal use of elevators (F23).

The fourth layer (L4) of factors belongs to the bottom of the fundamental factors, which will have a long-term impact on the upper layers of the system, and is not negligible and needs to be considered as a key factor. Including safety education is not in place (F12), safety management is not in place (F13), safety supervision is not in place (F14).

In order to further explore the probability of the occurrence of combined risk factors, this paper calculates the probability of the critical path of elevator safety risk factors based on the integrated impact matrix according to Table 5 and the multilevel structural model in Figure 9. The results show that the safety risk factors proposed in this paper can result in 19 risk-associated paths, and the corresponding probability values of each risk path are shown in Table 11.

It is assumed that the studied elevator safety risk must occur. Because of the correlation between the safety risk factors, the total value of the correlation strength of each risk path factor can then be interpreted as the value of the risk caused after a series of cascading risk factors occurring in the elevator safety process. For example, according to Table 11, when the safety supervision is not in place (F14), hidden danger investigation is not in place (F16), maintenance is not in place (F22), equipment parts failure (F8) and other factors occur in a series of collateral occurrence of the elevator safety caused by the risk value of 0.355. that is, the risk of risk caused by the risk of the impact of 35.5%. In this paper, the top five critical paths of risk value are selected for analysis.

As can be seen from Table 11, the three critical paths in the critical risk chain, F14→F16→F22→F8, F14→F16→F20→F8, and F14→F16→F21→F8, have a risk value of 35.5%, 23.5% and 21.9%, respectively. The government departments should strengthen the safety supervision of enterprises, focusing on the qualification management of related enterprises. Elevator-related enterprises should strengthen the safety supervision of personnel as well as equipment. In the process of supervision and management, they should focus on checking the safety inspection records and safety supervision records. At the same time to further investigate the hidden danger investigation situation and the quality control of key components. Through the hidden danger inspection records, quality inspection records, elevator maintenance records and other documents, focusing on checking the safety of equipment parts and components to reduce the failure of equipment parts. This can effectively guarantee elevator safety.

According to Table 11, it can be seen that the risk value of F14→F15→F22→F8 path in the key risk chain is 28.3%. The government departments should strengthen the safety supervision of enterprises. Elevator-related enterprises should strengthen the safety supervision of personnel as well as equipment, and government departments should focus on the implementation of corporate responsibility. Enterprises should implement their own safety responsibility. Elevator use units need to do a good job of elevator maintenance quality supervision, focusing on elevator safety maintenance. Moreover, the elevator maintenance records should be checked regularly to ensure the normal operation of the elevator parts and components, so as to ensure the safe operation of the elevator. F13→F17→F20→F8 path risk value is 22.7%. Elevator-related enterprises should focus on internal safety management and on-site safety management. In addition, elevator-related enterprises should strictly control the quality of key components, safeguard the integrity of

TABLE 12. Table of drive-dependence values.

number	risk factor	Driving	Depending
F1	Low safety awareness	3	4
F2	Lack of elevator safety knowledge	2	2
F3	Unauthorized operation	3	10
F4	Improper operation	2	10
F5	No license to work	1	3
F6	Inadequate safety protection measures	2	2
F7	Unauthorized risky self-rescue	1	2
F8	Failure of equipment parts	2	10
F9	Defective design of equipment	1	2
F10	Defective design drawings	3	3
F11	Inadequate safety management system	4	3
F12	Safety education is not in place	4	1
F13	Safety management is not in place	6	1
F14	Safety supervision is not in place	15	1
F15	Inadequate implementation of safety responsibilities	6	2
F16	Hidden danger investigation is not in place	7	3
F17	Chaotic on-site safety management	8	3
F18	Failure to provide safety management personnel	1	2
F19	Lack of emergency rescue measures	1	4
F20	No qualification of related units	2	4
F21	Lax quality control of key components	2	3
F22	Inadequate maintenance	3	4
F23	Illegal use of elevators	2	2

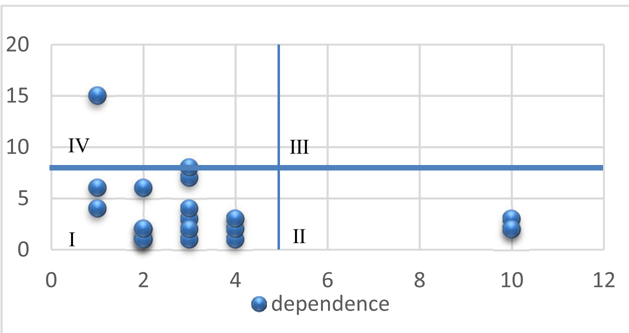

FIGURE 10. Driving force - dependency classification diagram.

elevator components from the source, and avoid the failure of equipment components.

F. MICMAC ANALYSIS

Based on formulas (10) and (11), the driving force and dependence were calculated respectively, and the factors were categorized into autonomy (I), dependence (II), linkage (III) and independence (IV). The results are shown in Table 12.

Based on the results in Table 12, a driver-dependency classification diagram of elevator safety risk factors was drawn, as shown in Figure 10.

Factors within the first quadrant (I) are autonomous factors. Factors in this quadrant have low dependence and drive, which are mostly located in the middle layer of the multi-layer hierarchical structural model and play the role of connecting the top and the bottom. Factors in this quadrant mainly include weak safety awareness (F1), lack of elevator safety knowledge (F2),, unlicensed work (F5), defective design drawings (F10), lax quality control of components (F21), poor maintenance (F22), illegal use of elevators (F23), and unqualified related units (F20).

Factors in the second quadrant (II) are dependent factors, which have a higher dependence but lower driving force, and are generally located in the middle and upper levels of the multilayered hierarchical structural model, with a lower degree of influence on other factors. Factors within this quadrant are operational violations (F3), improper operation (F4), and equipment component failures (F8).

Factors in quadrant IV are independent type factors. Factors in this quadrant are more strongly driven but less dependent, and other factors have less influence on them. They are generally at the bottom of a multilayered hierarchical structural model and are fundamental factors in the model that continue to deeply influence the system. Factors within this quadrant are inadequate safety supervision (F14), chaotic site safety management (F17).

Within the third quadrant (III) are linkage type factors. This type of factor has both high driving force and dependency, and is more unstable. The reason for the occurrence of this type of factor may be due to improper selection of factors or mingling of under-lying and surface factors. The absence of linkage type factors in this article indicates that the factors selected in the article are stable.

G. PREVENTIVE CONTROL MEANSURES

The bottom factors in the risk factors of elevator safety accidents are the three factors of inadequate elevator safety supervision, inadequate safety management, and inadequate safety education. They have relatively high driving force and low dependence. Therefore, in the process of elevator safety management, the relevant management departments need to pay attention to the three aspects of safety supervision, safety management and safety education. Specific practices include the following three aspects. First, a government elevator safety supervision and management organization with clear responsibilities and comprehensive coverage should be constructed. At the same time, the government departments should strengthen the coordination and communication of the various departments and organizations, and formulate the relevant rules and regulations of the supervision and management work. Secondly, enterprises should also improve the elevator safety management system, refine the content of elevator safety management, the implementation of elevator safety management. Third, both government departments and enterprises should strengthen the elevator safety education work, so as to improve the operators, the use of personnel awareness of elevator safety, strengthen the elevator safety knowledge.

The most direct risk factors in the risk of elevator safety accidents include unauthorized operation, improper operation, unlicensed work, illegal risky self-rescue, equipment parts and components failure, not equipped with safety management personnel, lack of emergency rescue measures and so on. This is the most direct cause of elevator safety accidents, mainly due to unsafe human behavior and the unsafe state of things. The elevator safety management process should strengthen the management of personnel and equipment. In terms of personnel, the enterprise should strengthen the management of personnel qualification certificate, staffing situation, personnel operation process, rescue process and other aspects. In terms of equipment, enterprises should focus on equipment parts failure, equipment defects management, focus on strengthening the equipment production process and maintenance process management, thereby reducing the incidence of elevator safety accidents.

Finally, the indirect factors of the middle layer of elevator safety risk have strong driving force and low dependence, and most of them belong to spontaneous factors, indicating that the factors in the middle layer are more stable. It mainly contains weak safety awareness, lack of elevator safety knowledge, lack of safety protection measures, defective design drawings, incomplete safety management system, lack of implementation of safety responsibilities, lack of hidden danger investigation, chaotic on-site safety management, no qualification of the relevant units, lax quality control of key components, poor repair and maintenance, and violation of the use of elevators. It can be seen that the intermediate level factors are mainly related to the management of the enterprise, which are more volatile, and at the same time are numerous and have a wide range of influence, and therefore are the core factors affecting the risk of elevator safety accidents. For enterprises, it is necessary to strengthen the internal management of the enterprise, such as improving the safety awareness, enhancing the knowledge of elevator safety, and implementing the main responsibility of the enterprise and so on.

Furthermore, government departments and elevator-related enterprises should focus on developing a perfect elevator safety supervision and management system. Elevator-related enterprises should focus on the development of elevator repair and maintenance manuals, hidden danger investigation system, key components control system and other safety management systems. Enterprises should regularly check the implementation of the relevant systems to prevent elevator safety risks from the source and reduce the probability of elevator safety risks.

V. CONCLUSION

In summary, the article constructs the KG-DEMATEL-ISM-MICMAC model method to analyze the elevator safety risk factors. Firstly, by simplifying the knowledge graph network, it is summarized as the direct influence matrix of elevator safety accident risk factors, and secondly, the normalized influence matrix is formed by using the normalization of the DEMATEL method, on the basis of which the comprehensive influence matrix is obtained. Then, the ISM method is used to divide the elevator safety risk factors into a hierarchical structure. Finally, the MICMAC method was introduced to analyze the drivers and dependencies of the risk factors. On this basis, the article further analyzes the fundamental factors, direct factors and key factors of elevator safety accident risk factors. The specific research conclusions are shown below.

The article constructed a knowledge graph of elevator safety accidents. Firstly, the article constructs an ontology model of elevator safety accidents using the seven-step method. Second, the text of elevator safety accidents was preprocessed by removing deactivated words and deleting invalid statements from the text of elevator safety accident reports, and the data was annotated using the doccano annotation platform. Then the knowledge extraction was completed by using the Universal Information Extraction Framework (UIE) model based on unified structure generation. Finally, the fusion of knowledge and the utilization of neo4j database to complete the knowledge storage, and the retrieval of the knowledge graph is completed by Cypher query statement.

The article proposes the KG-DEMATEL-ISM-MICMAC method for elevator safety accident risk analysis. The main purpose is to further optimize DEMATEL-ISM. The direct impact matrix in the traditional DEMATEL-ISM method mainly relies on the experts' judgment related to risk factors. In this paper, firstly, based on the data-driven perspective, the network simplification of the knowledge graph of elevator safety accidents, the direct influence matrix of elevator safety risk factors is constructed. Secondly, the DEMATEL method is used to calculate the comprehensive influence matrix, and the cause degree and center degree of each factor are analyzed. The ISM model theory was used to calculate the reachability matrix of the influence system, and the hierarchical structure model of elevator safety risk factors was further established. Finally, the MICMAC method was introduced to analyze the drivers and dependencies of elevator safety risk factors. Through the analysis of KG-DEMATEL-ISM-MICMAC method, not only can we fundamentally find the factors of elevator safety risk occurrence, but also can rank the risk factors, which makes the enterprise in the process of elevator safety management can find the management focus, and targeted to formulate preventive control measures. In addition, the analysis of elevator safety risk factors can also provide key regulatory direction for government departments.

From the theoretical point of view, for one thing, this study analyzed elevator safety risk factors using KG-DEMATEL-ISM-MICMAC, further expanding the methodology of elevator safety risk analysis. Second, the knowledge graph technology can convert the unstructured text of elevator safety accidents into structured text, which provides ideas for the utilization of other safety texts such as elevator failure text and elevator inspection text. Third, the optimization of DEMATEL method using the association relationship of knowledge graph can effectively avoid the subjectivity of expert scoring, and quantitatively analyzed the elevator safety risk factors from a data-driven perspective. Fourth, the results of the study can also provide methodological ideas for safety risk analysis in other fields. From a practical point of view, this study can provide safety management decision support for controllers. The KG-DEMATEL-ISM-MICMAC method analysis can effectively identify the core elevator risk elements, the hierarchical structure of elevator safety risk elements, and the key risk chain. This provides elevator safety managers with accurate decision-making, which can effectively prevent elevator safety accidents to a certain extent.

Based on this, this paper tries to use knowledge mapping technology for structured extraction of textual knowledge on elevator safety accidents. DEMATEL, ISM and MICMAC methods are also introduced to complete the analysis of elevator safety risk factors. The specific contributions of this paper are mainly reflected in the following three aspects. First, this paper tries to complete the structuring of elevator safety accident textual knowledge with knowledge graph technology, and optimizes the DEMATEL method by using the correlation relationship of knowledge graph. The elevator safety risk factors were determined from the data, which effectively avoided the subjectivity of expert scoring and further enriched the method of elevator safety risk analysis. Secondly, the optimized direct influence matrix is transformed into the overall influence matrix. Further, the ISM recursive model of influence factors is constructed to realize the recursive structured representation of disordered factors. Third, the MICMAC model of the influence factors is constructed based on the reachability matrix. The driving force-dependence relationship diagram of elevator safety risk factors is obtained, which is able to categorize and analyze each influencing factor according to its characteristics. The article integrates and forms the KG-DEMATEL-ISM-MICMAC elevator safety risk factor analysis method, which is able to dig deeper into the influence factors of elevator safety accidents. On the one hand, this method expands the research method of elevator safety risk and provides a strong theoretical basis for preventing elevator safety accidents. On the other hand, it also provides research ideas for other safety risk factor analysis.

This study has several limitations that can be addressed in future research. First, the current elevator safety risk factor analysis is mainly derived from elevator accident reports. Future research may further expand to other elevator safety hazard texts such as elevator failure records, elevator inspection records, and elevator maintenance records, which can enrich the risk factors of elevator safety accidents. Second, this paper chooses Knowledge Graph (KG) to optimize the DEMATEL method. However, with the continuous development of deep learning methods, more advanced models can be used in the future to identify the correlation relationship between elevator safety risk factors. Finally, elevator safety risk factors can be further refined in the future to provide decision makers with more accurate decisions.

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FENFEN SHI received the bachelor's degree in management from Hebei University, in 2017, and the master's degree in management from China University of Mining and Technology (Beijing), in 2020, where she is currently pursuing the Ph.D. degree in management science and engineering. Her research interests include elevator safety supervision, intelligent supervision, accident and emergency management, natural language processing, and knowledge graph. From 2017 to 2023, she received several university-level first-class scholarships, national scholarships, honorary titles, such as university-level three-good student and excellent graduate student, and the first prize for excellent thesis in China Specialty Equipment Industry Association (CSEIA).

ZHILEI WU received the B.S. degree in engineering from Zhengzhou University of Aeronautics, Zhengzhou, China, in 2014, and the M.S. degree in engineering from Beijing Wuzi University, Beijing, China, in 2017. He is currently pursuing the Ph.D. degree in management science and engineering with China University of Mining and Technology (Beijing), Beijing, China.

From 2017 to 2020, he was an Assistant Consultant with Huaxin Consulting Design and Research Institute. His research interests include security and emergency management, natural language processing, and knowledge graph.

Mr. Wu was a recipient of the First Prize of Excellent Thesis of China Logistics Productivity Promotion Center, the Second Prize of the second Beijing Undergraduate Innovation and Entrepreneurship Competition, the Third Prize of the first "Double Carbon" Innovation and Creativity Competition for Chinese Graduate Students, and the Third Prize of the ninth China College Students' 'Internet +' Innovation and Entrepreneurship Competition.