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Identifying Technologies Fields using SNA (Social Network Analysis) for Construction Safety Management in China

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ABSTRACT

There is a high frequency of safety accidents occurring in the construction industry in China, which results in large numbers of casualties and substantial property damage and losses. So to find out an effective way of reducing safety accidents and identify the major cause of safety accidents arising from the construction sites, it is essential to improve the management of construction safety. The patent information is effectively utilized to analyze technology, based on which the types of construction safety accidents are summarized and the major influencing factors in the occurrence of safety accidents on construction sites are identified. In this paper, through the patent analysis method based on the network analysis, Netminer 4.0 was applied to construct a technology field network to gain understanding as to the structure of construction safety. Based on the specific analysis of the critical nodes with the assistance of Netminer 4.0, the major causes for the occurrence of construction safety accidents were identified. Finally, the core patents were analyzed to provide a theoretical basis for the reduction of accident rate.

Keywords: Construction safety management; Patent analysis; Social network analysis (SNA)

INTRODUCTION

Due to the poor working environment, the construction industry has been listed as one of the "high-risk industries". Remaining in the labor-intensive stage, the construction industry in China is characterized by the high mobility of personnel, low educational levels and the inadequacy of professional training. Compared with other industries and many other countries around the world, the probability of accidents occurring in the construction industry in China is significantly higher. The number of occupational accidents happening in the construction industry is one or two of the number in each industry [1].

According to the Ministry of Housing and Urban-Rural Development of the People's Republic of China, the number of accidents and fatalities in the construction safety in China basically showed a decreasing trend prior to 2015. In the year 2015, however, the number of accidents and fatalities dropped significantly. During the period between 2015 and 2018, there was a sharp rise in both incident and the death toll. In 2018, there were 776 accidents happening, which caused 877 fatalities. Based on the aforementioned figures, it can be seen that the current state of construction safety remains quite concerning, which makes it imperative for the relevant safety mechanism of construction to be improved. In the meantime, the relevant legal system shall be put in place possibly soon, and the management of construction safety needs to be enhanced progressively. In particular, the death toll from 2016 to 2018 increased significantly, which makes the issue of safety management attract increasing attention.

According to the national standard GB6441-86 regarding the classification of casualties and accidents for the staff members of enterprises, there are totally 20 types of accidents that may occur to employees, of which there are 10 types of accidents that tend to occur on a frequent basis in the field of municipal engineering. Depending on the exact cause of accident, they can be categorized into fall from height, object strike, collapse, mechanical injury, lifting injury, electric shock accident, fire and explosion (including fire house, gunpowder explosion), poisoning and asphyxiation, vehicle injury and so on. The fall from height accounts for more than 50% of the total number of accidents happening each year, which means the accident caused by the fall from height is considered as the most common type of accident occurring at the construction site, which is the case not only in China but also in the rest of the world. Besides, the frequency of fall from height is the highest among all types of accidents [2].

Allowing for this, this study is aimed at identifying not only the types of construction safety accidents but also the major influencing factors in construction safety. To achieve this purpose, patent analysis is conducted on the basis of Social network analysis(SNA). It provides a method that can facilitate the systematic analysis of specific technologies and the current trends of technology. In this regard, patent analysis is effective in providing the relevant information to the development of building safety technologies. Therefore, this study proposes the application of Netminer 4.0 based SNA as a systematic approach to applying two techniques. Firstly, network visualization is performed to construct a technology field network to gain understanding as to the structure of construction safety. Based on an analysis of the collected patents as a whole, it is concluded that these technologies (patents) play a significant role in the analysis of construction safety. Secondly, critical node analysis is carried out. Through the specific analysis of the key nodes, the primary reasons for the occurrence of construction safety accidents in recent years are identified, which is conducive to guide the application of core technologies for reducing the accident rate, thus providing reference for the further research on construction safety in China to some extent.

LITERATURE REVIEW

Construction safety management in China

From the perspective of historical development, it can be known that the first step in preventing or reducing the occurrence of safety accidents is the passage of legislation. As emphasized by the report of the 18th National Congress of the Communist Party of China held in 2012, “we should strengthen the public safety system and the work safety infrastructure of enterprises, and curb serious and major safety accidents”. It was in 2014 that the new work safety law came into force formally in China, which marked a shift of the work safety policy from “the principle of safety and prevention first” to “the principle of safety and prevention first，comprehensive treatment”. This is conducive to clarifying the importance attached to work safety and the main tasks required by it. In 2015, an amendment was made to the regulations on the administration of work safety licenses for all construction enterprises registered within the jurisdiction of PRC.

Technologies for construction safety management

Since 1970, sociologists and economists have started to conduct study on the hidden safety problems in relation to engineering constructions. At present, it has been increasingly recognized by experts that a rigorous and standardized management system is significant to the prevention of construction accidents.

As early as in 1976, foreign scholars [3] suggested the important role played by senior management in reducing the costs incurred by accidents [4]. laid emphasis on the significance attached to the formulation of safety plans and safety precautions before the commencement of a specific project and proposed to carry out safety education and training for creating “Zero Accident Techniques", with the purpose of enhancing the management of construction safety. In recent years, [5] developed a 4D CAD model to construct an integrated system of safety and construction management, which is capable of automatic identification of the safety hazards associated with high homework and setting out the necessary precautionary measures. In the meantime, it allows for the collaboration between designers, project engineers, security personnel and other project participants. To some extent, it increases the collective awareness of work safety while improving the chance of success in safety management. In [6], a study was carried out on the correlation between safety investment, safety culture and project risk as well as their impact on the performance in building safety, which led to the finding that the synergistic effect of safety investment, safety culture, and project risk could have the most significant impact on the safety performance of building projects. If the level of safety investment and safety culture in the project is high, the safety risk involved in the project is low, as a result of which the safety performance of the project is superior [7]. proposed BIM 3D modeling for the planning of construction projects to identify the basic hazards that may cause accidents on the site and to construct a fit-for-purpose security system for guarding against these safety risks.

In China, there is much significance attached to the management of construction safety as well, which has prompted many scholars to conduct some wide-ranging research on it. Based on the current state of safety management enforced by construction engineering owners in China, [8] analyzed and summarized the advanced approach to safety management adopted by foreign project owners, based on which the developmental trend of safety management in China was indicated, that is, the compulsory-guidance-conscious three-stage management. From the perspective of construction enterprises, [9] identified the major risk factors in the construction process by conducting both expert survey and undergoing the network analytic hierarchy process, based on which the factors were sorted by weight. Further with this, the fuzzy comprehensive evaluation method was applied to carry out a comprehensive evaluation of a specific project and develop the risk response measures under different scenarios. In

[10], it was proposed that there is a necessity to put in place a sound safety management accountability system for the prevention of serious injury, death, fire, poisoning, collapse target, and civilized construction guarantee measures for construction sites and first-aid prevention [11]. applied BIM and RFID technology to deal with safety management, conducted research on the building information model, safety monitoring and early warning model, emergency model for safety dimension, developed a prototype of safety management system for the building of engineering project based on C# language, and made suggestions on safety system for practical application [12]. combined BIM and AR technology to practice building security management, and the whole process of project life cycle to discuss the security management problem，which will improve the level of building safety management of the whole industry .

Traditional methods and current trends in patent analysis

Social network analysis (SNA) represents a methodology applied for network structure analysis, which originates from sociology and anthropology. SNA provides a range of methods applied for quantitative analysis to reveal the overall structure of the network. The value of SNA lies in its capability to map networks and illustrate connections, interactions, and behavioral patterns.

The rapid growth of research studies with SNA applied in construction project management (CPM) research; Compared with that of permanent organizations such as firms and public organizations, the organization of a construction project is temporary in nature and has a limited life cycle; this temporary organization is intentionally designed to achieve the objectives or goals of a permanent organization or certain shareholders through complex problem-solving processes [13]. Therefore, SNA is deemed suitable for the analysis of organizational behaviors in construction projects [14,15] and capable to provide a more relational, contextual, and holistic picture of project organizations in construction [16]. In SNA research, the focus is placed on the issues at the intra-organizational level rather than at the inter-organizational level. These issues include the communication problems among key individuals involved in a project network, such as clients, project managers, architects, and construction managers [17,18]. In addition, the application of SNA is beneficial to explain the actual management structures of construction projects, identify the major characteristics of a construction project organization and explore the potential risks presented by engineering mistakes.

Patent documents are more effective in analyzing a considerable amount of bibliometrics information including abstracts, assignees, inventors, classes, and citations than other documents sources, for example, academic papers [19,20]. Patents are capable of facilitating the systematic analysis of specific technologies and the ongoing trends of technology, thus indicating the direction of technological advancement.

In the patent analysis, the patent number is used in the first place. Depending on the exact classification system, the patent number is different. In this study, the longest existing classification system is applied, that is, International Patent Classification (IPC), which consists of eight parts, A-H. Moreover, they can be further categorized into class, subclass, group and subgroup [21]. All IPC sections are shown in Table I [22].

TABLE I. INTERNATIONAL PATENT CLASSIFICATION (IPC) SECTIONS [22]

Section	Entity
A	Human Necessities
B	Performing operations, Transport
C	Chemistry, Metallurgy
D	Textiles, Paper
E	Fixed Constructions
F	Mechanical engineering, Lighting, Heating, Weapons; Blasting engines or Pumps
G	Physics
H	Electricity

RESEARCH METHODOLOGY

The purpose of this paper is to identify the significant factors or technologies that could have impact on construction safety by conducting SNA and patent analysis where the data for the last five years is analyzed. The generic process of network model research based on SNA is detailed as follows. Firstly, the nodes in the social network are identified. Secondly, the meaningful and actionable relationships are evaluated. Thirdly, a visual network is constructed and the network data is analyzing. Lastly, the analytical results and recommendations are indicated [23]. The structure of this paper is shown in Figure I.

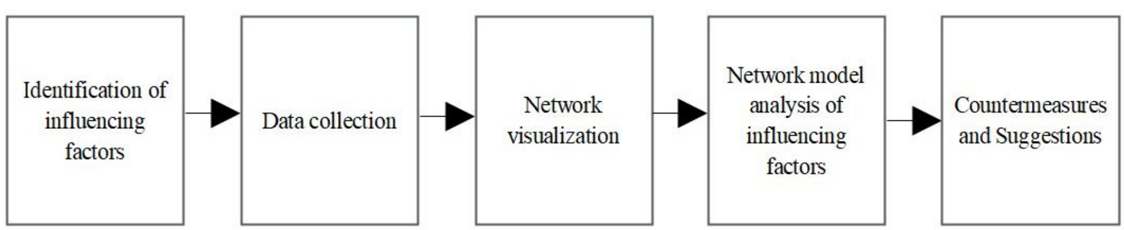

FIGURE I. THE STURCTURE OF THIS PAPER

Identification of influencing factors

Each network consists of two parts, which are nodes and lines. The first step is to identify the node, which refers to the research object involved in the network and can be collected usually by investigating the relevant content or from the research results of others. In this paper, it refers to the influencing factors for construction safety through literature research.

Data Collection

Capable of facilitating a systematic analysis on a given technology, patents can indicate technological trends and the direction of technological advancement. As this paper studies the building safety industry in China, the research data is comprised of the number of patents registered in the National Intellection Property Administration(CNIPA), PRC through Worldwide Intellectual Property Service(WIPS) which provides patent search service.

Firstly, the query of keywords used for search is structured with AND gate of construction and safety and technology. It is possible for patents to be collected in different ways by conducting search through different queries. In the second step, International Patent Classification (IPC) was adopted to select valuable data. In this study, the unnecessary fields were removed from IPC and "Fixed Constructions" in part E related to construction was selected for research. The data was collected from January 1, 2014 to December 31, 2018. Initially, there were 751 pieces of data collected according to keywords, many of which were related to architecture but not to security. Since the research field for this paper is safety, there were 226 pieces of data obtained after the removal of irrelevant data to safety. Then, upon the review of these 226 patents, it was found out that there are some patents not involved in the technical field despite the relevance to safety. Finally, as a result a total of 113 data that are consistent with the construction safety field and also belong to the technical field as the analysis target. The main IPCs on construction safety technology fields from the collection patent data are indicated in Table II.

Network visualization

In this paper, Netminer 4.0 is employed to construct and analyze the network model of the influencing factors in construction safety. Developed by CYRAM Korea, Netminer 4.0 provides a software tool for the exploration and analysis of network data. Netminer 4.0 is primarily used in SNA to construct a visual network model and integrate the model with SNA for the purpose of data mining.

First of all, collected on construction safety technology patent input to software Netminer 4.0, choose # of links, density, average degree, inclusiveness, diameter and so on five attributes, with the result presented in Table III. Density provides a way of measuring a network and requires an analysis of the entire network rather than the nodes and lines in the network. It refers to the number of existing lines compared to the number of lines generated mostly by all nodes connected to each other in the network [24]. The range of network density is [0,1]. The higher the density, the greater the interaction between factors.

Critical node analysis

As an actor-related variable at the individual level in the whole network, critical node analysis excludes the value of each node by means of node centrality [25]. There are three methods that can be applied to measure the impact of nodes on the network through either direct or indirect connection between individual nodes.

Node degree analysis

Firstly, node degree is used to represent the characteristic of a factor to be directly connected. A patent citation carries a link to it, which is either citing or cited. With regard to citing relationships, the nodes that cites many other nodes are considered in-degree. In a cited relation, a node is cited by more than one other node, for which it is called

TABLE II. MAIN IPC DESCRIPTIONS RELATED WITH CONSTRUCTION SAFETY TECHNOLOYG

Level	Code	Descriptions
Section	A	Human necessities
Class	A62	Life-Saving; Fire-Fighting
Sub-class	A62B	Devices, Apparatus or Methods for Life-Saving
Main-group	A62B-001	Devices for lowering persons from buildings or the like
	A62B-035	Safety belts or body harnesses; Similar equipment for limiting displacement of the human body, especially in case of sudden changes of motion
Section	B	Performing Operations; Transporting
Class	B23	Machine Tools; Metal-Working not Otherwise Provided for
Sub-class	B23K	Soldering or Unsoldering; Welding; Cladding or Plating by Soldering or Welding; Cutting by Applying heat Locally
Main-group	B23K-037	Auxiliary devices or processes, not specially adapted to a procedure covered by only one of the other main groups of this subclass
Section	E	Fixed construction
Class	E01	Construction of Roads, Railways, or Bridges
Class	E04	Building
Sub-class	E04B	General building constructions;walls,e.g.partitions;roofs;floors;ceilings;insulation or other protection of buildings
Main-group	E04B-001	Constructions in genera; Structures which are not restricted either to walls
	E04B-002	Walls, e.g. partitions, for buildings; Wall construction with regard to insulation; Connections specially adapted to walls
Sub-class	E04C	Structural Elements; Building Materials
Main-group	E04C-002	Building elements of relatively thin form for the construction of parts of buildings, e.g. sheet materials, slabs, or panels
	E04C-003	Structural elongated elements designed for load- supporting (as building aids E04G)
	E04C-005	Reinforcing elements, e.g. for concrete; Auxiliary elements therefor
Sub-class	E04F	Finishing Work on Buildings, e.g. Stairs, Floors (windows, doors E06B)
Main-group	E04F-021	Implements for finishing work on buildings
Sub-class	E04G	Scaffolding；Form；Shuttering；Building implements or other building aids, or their use; Handling building materials on the site; Repairing, breaking-up or other work on existing buildings
Main-group	E04G-001	Scaffolds primarily resting on the ground
	E04G-003	Scaffolds essentially supported by building construction
	E04G-005	Component parts or accessories for scaffolds(connections E04G 7/00)
	E04G-007	Connections between parts of the scaffold
	E04G-011	Forms, shutterings, or falsework for making walls, floors, ceilings, or roofs
	E04G-013	Falsework, forms or shutterings for particular parts of buildings
	E04G-015	Forms or shutterings for making openings, cavities, slits, or channels
	E04G-017	Connecting or other auxiliary members for forms, falsework structures, or shutterings
	E04G-019	Auxiliary treatment of forms, e.g. dismantling; Cleaning devices
	E04G-021	Preparing, conveying, or working-up building materials or building elements in situ ; Other devices or measures for constructional work
	E04G-023	Working measures on existing buildings
Sub-class	E04H	Uildings or Like Structures for Particular Purposes

TABLE II. MAIN IPC DESCRIPTIONS RELATED WITH CONSTRUCTION SAFETY TECHNOLOYG (CONTINUED)

Level	Code	Descriptions
Main-group	E04H-001	Buildings or groups of buildings for dwelling or office purposes
	E04H-017	Fencing
Section	F	Mechanical Engineering
Class	F16	Engineering Elements or Units; General Measures for Producing and Maintaining Effective Functioning of Machines or Installations
Sub-class	F16B	Devices for Fastening or Securing Constructional Elements Or Machine Parts Together
Main-group	F16B-047	Suction cups for attaching purposes; Equivalent means using adhesives
Section	G	Physics
Class	G08	Physics
Sub-class	G08B	Signalling or Calling Systems; Order Telegraphs; Alarm Systems
Main-group	G08B-013	Burglar, theft or intruder alarms

the out-degree [26]. As shown in Equation (1). each node degree represents the sum of the weights assigned to the line based on the correlation between the point and those points adjacent to it. The higher the difference between the in-degree and out-degree, the stronger the influence of this node on other nodes [24].

$$C_d(v_i) = d_i^{in}(\text{prestige}) \qquad \text{Eq. (1)}$$

Where:

di indicates the degree (number of adjacent edges) of node vi.

Closeness centrality analysis

Secondly, closeness centrality is taken as the sum of the distances from one node to all the remaining nodes. It is indicative of the whole connectivity in the network structure [27].

Based on an analysis of the centricity in the directional social networking to closeness centrality, the results of the analysis, both in-closeness centrality and out-closeness centrality are determined. The in-closeness centrality is integration while the out-closeness centrality is radially, as shown in Equation (2).

$$C_i(i) = \frac{n-1}{\sum_{j-1}^{n} d(i,j)} \qquad \text{Eq. (2)}$$

Where:

d (i, j) represents the geodesic distance between two actors (i and j) and n refers to the number of nodes / actors.

Betweenness centrality analysis

Thirdly, based on the assumption that information primarily flows over the shortest paths between them, betweenness centrality is taken as a measure of the impact of a vertex on the flow of information between each pair of vertices [28]. According to the betweenness centrality, the patents with the most excellent control ability index and mediation effect among all the patents can be identified, as shown in Equation (3).

$$C_c(i) = \sum j < k \frac{p_{jk}(i)}{p_{jk}} \quad \text{Eq. (3)}$$

Where:

P_{jk} denotes the number of geodesic paths between two actors (j and k),

P_{jk} (i) indicates the number of geodesic paths between j and k that contains actor i.

RESULTS AND DISCUSSIONS

Network visualization

In combination with SNA analysis method, Netminer 4.0 is applied to calculate the data of the measurement network, as shown in Table III. The network shows a small average degree of 0.938 with a lower density of 0.03, with the level of inclusiveness approaching 1 (0.844), which suggests that most technologies applied in the network are either directly or indirectly connected and that some nodes could have impact on the entire network. This network has a small diameter (7), which indicates that these technologies are capable to spread quickly across the network. Therefore, it is complex to impact accidents of technology. The influence of them could pass through the network, while these technologies that indirect each other could indirect the impact accidents. It is essential to determine how to reduce the number of accidents by analyzing the correlation between those technologies (nodes) and the network consisting of those technologies (nodes).

TABLE III. NETWORK DENSITY AND COHENSION INDEX

	Links	Density	Average Degree	Inclusiveness	Diameter
Network	38	0.03	0.938	0.844	7

Critical node analysis

Node degree analysis

Table IV presents the results of node degrees in the social network that applies Netminer4.0. The node degree values of different patents are obtained and then the results are extracted and sorted to finalize the ranking of node degree, as shown in Table V.

TABLE IV. IN-DEFREE AND OUT-DEGREE CENTRALITY

	IPC	In-degree centrality	Out-degree centrality
1	E04G-021	0.161290	0.161290
2	E04G-001	0.000000	0.064516
3	E04G-003	0.032258	0.161290
4	E04B-002	0.032258	0.032258
5	E04B-001	0.032258	0.129032
6	E04G-005	0.129032	0.064516
7	E04C-003	0.032258	0.064516
8	E04C-005	0.032258	0.000000
9	E04G-011	0.000000	0.096774
10	E04F-021	0.000000	0.064516
11	E04G-019	0.032258	0.000000
12	E04G-023	0.032258	0.032258
13	E04H-001	0.032258	0.000000
14	E04C-002	0.032258	0.000000
15	E04H-017	0.000000	0.064516
16	G08B-013	0.032258	0.000000
17	E04D-013	0.000000	0.000000
18	E04F-G17	0.000000	0.000000
19	E01H-003	0.032258	0.000000
20	E04G-007	0.000000	0.000000
21	E04G-017	0.032258	0.032258
22	B23K-037	0.032258	0.000000
23	B64D-001	0.032258	0.000000
24	A62B-035	0.032258	0.000000
25	E04G-013	0.032258	0.000000
26	D04B-021	0.032258	0.000000
27	F16B-047	0.032258	0.000000
28	E04F-013	0.000000	0.000000
29	E04G-015	0.032258	0.000000
30	A62B-001	0.032258	0.000000
31	E04H-003	0.000000	0.000000
32	B66F-011	0.032258	0.000000

Through the Table V “E04G-021” ranked first in both in-degree and out-degree centrality, which implies that the patents fall into this IPC cluster most frequently cite and cited other patents. “E04G-003” exhibits the most significant difference between in-degree centrality and out-degree centrality, suggesting that the stronger the influence of this node on other nodes. Both “E04B-001” and “E04G-011” show a high value of out-degree centrality and node degree difference, which indicates that these two nodes are easy to be cited by other nodes and have a significant impact on other nodes. “E04G-005”, “E04G-001”, “E04F-021”and “E04H-017” all have relatively significant differences in node degree, which evidences that they have a relatively considerable impact on other nodes. "A62B-001", devices for lowering persons from buildings or the like, and "A62B-035" is also frequently cited by other patents.

TABLE V. TOP8 NODE DEGREE SORT

Rank	IPC	In-degree centrality	Rank	IPC	Out-degree centrality	Rank	IPC	The difference of node degree
1	E04G-021	0.161290	1	E04G-021	0.161290	1	E04G-003	0.129032
2	E04G-005	0.129032	2	E04G-003	0.161290	2	E04B-001	0.096774
3	A62B-001	0.032258	3	E04B-001	0.129032	3	E04G-011	0.096774
4	A62B-035	0.032258	4	E04G-011	0.096774	4	E04G-005	0.064516
5	E04B-003	0.032258	5	E04G-001	0.064516	5	E04G-001	0.064516
6	E04B-001	0.032258	6	E04G-005	0.064516	6	E04F-021	0.064516
7	E04G-002	0.032258	7	E04H-017	0.064516	7	E04H-017	0.064516
8	E04C-005	0.032258	8	E04F-021	0.064516	8	A62B-001	0.032258

Closeness centrality analysis

According to Figure II, the in-closeness centrality is substantially greater than the out-closeness centrality, suggesting that the aggregate of these patents are quite large. Figure III shows the results of the closeness centrality analysis, which reveals that "E04G-021"is in the most central position. In combination with node degree analysis, it is suggested that this patent is most frequently cited by other patents either directly or indirectly. Another major patent in closeness centrality is "E04G-005". Moreover, "A62B-035", "A62B-001", "D04B-021", "B23K-37"and "E01H-003" have a high closeness centrality as well. Combined with node degree analysis, it can be known that "E04G-005", "A62B-035"and "A62B-001" have not only a high degree centrality but also a high closeness centrality, which indicates that these patents play a significant role in reducing safety accidents.

- **Output Summary**

DISTRIBUTION OF CLOSENESS CENTRALITY SCORES

MEASURES	VALUE	
	In-Closeness	Out-Closeness
MEAN	0.058	0.053
STD.DEV.	0.056	0.075
MIN.	0	0
MAX.	0.201	0.217

NETWORK CLOSENESS CENTRALIZATION INDEX
18.179% (IN), 5.946% (OUT)

FIGURE II. THE VALUE OF CLOSENESS CENTRALITY

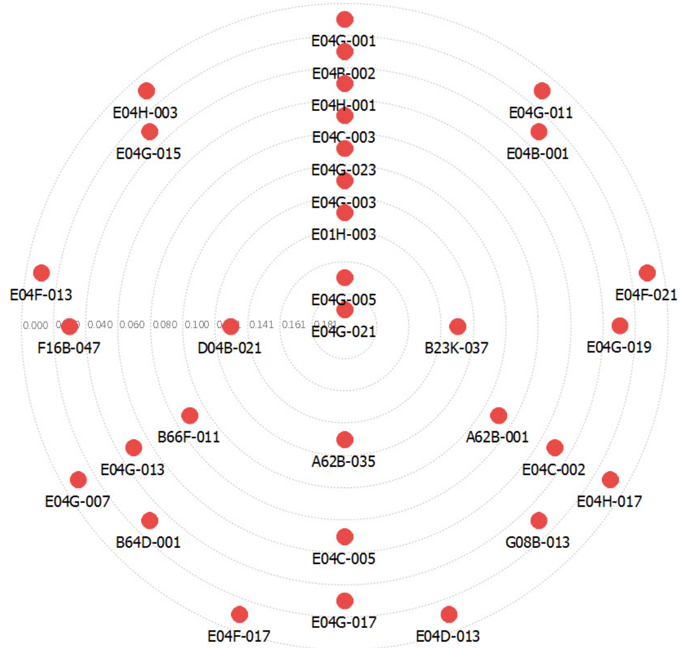

FIGURE III. CLOSENESS CENTRALITY ANALYSIS

Betweenness centrality analysis

From a traditional point of view, only the significance of some technologies is taken into consideration for the research of technology. However, the importance of the relationship between technologies is worth further study through social network analysis. Netminer4.0 is applied to calculate the betweenness centrality of notes and the links in the social network, based on which the betweenness centrality value of different technologies and technologies relationships is obtained, as shown in Figure IV and V, which reveal that there are plenty of nodes with a higher centrality existing in the links with a higher centrality, and that the patent of the link with a higher centrality contains higher nodes betweenness centrality as well. "E04G-021" ranked top in both node and link betweenness centrality, suggesting that this patent has the highest control ability index and most significant mediation effect among all the patents. In addition, "E04G-005" and "E04G-003" are the major patents in terms of betweenness centrality. Moreover, "E04G-023", "E04G-011", "E04B-001"and "E04C-003" all have relatively high betweenness centrality, which evidences their relatively strong capability of control among other patents.

Discussions

This paper is purposed to determine how the construction industry could reduce the occurrence of safety accidents through technical means through the SNA and patent analysis of the data for the last five years. For network analysis, network visualization analysis and critical node analysis were conducted.

Based on the network visualization analysis of the whole network, it can be concluded that the related

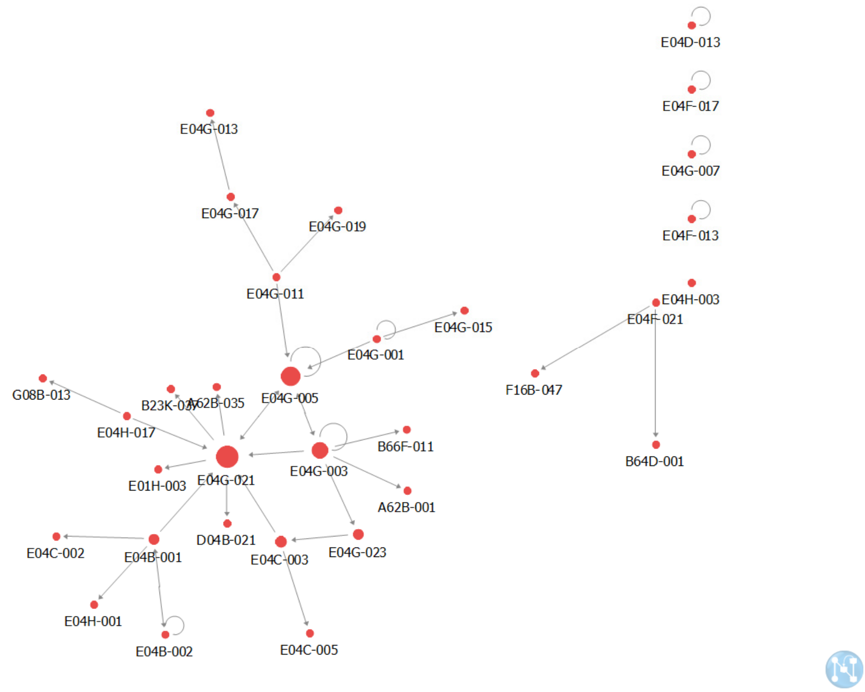

FIGURE IV. NODE BETWEENNESS CENTRALITY

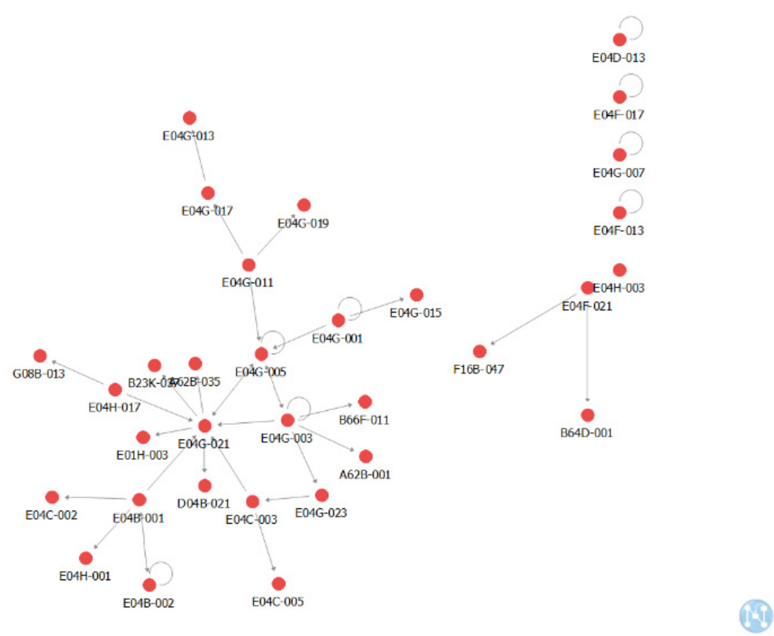

FIGURE V. LINK BETWEENNESS CENTRALITY

technologies affecting the construction safety are complicated. Moreover, their mutual impact will be transmitted through the network, which makes these technologies have impact on construction safety through the influence of each other. Therefore, it is necessary to consider the corelation between these technologies and to establish the network constituted by these technologies for analyzing the technologies affecting building safety.

In the critical node analysis, three methods were applied to measure the impact of nodes on the network, which are degree centrality analysis, closeness centrality analysis and betweenness centrality analysis.

The degree centrality analysis shows that “E04G-021”, preparing, conveying, or working-up building materials or building elements in situ; Other devices or measures for constructional work. These patents demonstrate that the development of materials transportation, hoisting, safety protection mesh, guard and construction auxiliary equipment in buildings plays an important role in building safety. “E04G-003”, scaffolds essentially supported by building construction; “E04G-005”, component parts or accessories for scaffolds. These patents are related to the improvement of construction site scaffolding and safety protection hanging basket, which belongs to the construction equipment category. All the equipment is to effectively play the role of safety and anti-falling, so as to ensure the safety of the construction personnel on the operating platform. Additionally, most of the hoisting technologies in these patents are related to assembly type buildings, which have been a major trend in recent years. Therefore, the development of construction safety is closely related to The Times.

With regard to closeness centrality analysis, the core technology field “E04G-021” has been highly centrality value. The same “E04G-005” occupies a central position as well and most of the patents they contain are related to the fall from height and the protection for work at height. With the rapid process of urban development, the construction of high-rise buildings expands on a continued basis. Consequently, the risks of high-altitude operation have been gradually enlarged, so that the diversity of high-rise construction devices can meet the requirements of high-altitude operation. In addition , “A62B-001” Devices for lowering persons from buildings or the like. “A62B-035”,safety belts or body harnesses; Similar equipment for limiting displacement of the human body, especially in case of sudden changes of motion. It is further illustrated that the measures to ensure high altitude safety is significant to reducing safety accidents.

Finally, in the betweenness centrality analysis, “E04G-021” is identified as the key node, which plays an important role in the liaison, suggesting that all the technologies in the “E04G” class move to other technical fields and act as crucial intermediaries. Besides, “E04G-021” is equally important as its representational role means that most technical “E04G” classes, especially “E04G-005” and “E04G-003”, scaffolding；Form；Building implements; Handling building materials on the site; Repairing, breaking-up or other work on existing buildings. Therefore, these patents are all related to the safety of working at height. Moreover, “E04G-023” is also a major patent in betweenness centrality. The application of machines to replace manual labour for high-altitude operation indicates that smart technology is also a trend to reduce the development of high-altitude safety accidents.

CONCLUSION

From Germany industry 4.0 to Made-in-China 2025, the blueprint has led to the transferal and upgrading of the traditional manufacturing industry and making a great leap towards the realization of high-tech manufacturing. As the backbone of national economy, the construction industry plays a crucial role in driving the development of national economy. However, the frequency for safety accidents to occur in the construction industry is overly high, which is likely to cause massive casualties and severe property losses. Therefore, in order to find out how to reduce the occurrence of safety accidents, and to identify the most common types of building safety accidents, it is essential to change the current style of passive management adopted across the construction industry, and to improve the level of building safety management. This paper collates and analyzes the data on building safety technology in China in recent years, based on which the patent analysis method is applied to reverse the results obtained by SNA analysis. The highlight of this study is that the major type of safety accident occurring in recent years is the fall from height. Besides, through the analysis of patents, it is concluded that, different from the earlier safety factors. Back in the 1970s, the risk of human error, rather than technology, was classified as unsafe behavior [29]. At present, however, the main factor in operation safety is identified as the equipment.

The analysis of building safety in this paper is subject to some innovation and limitations. Based on the search of China National Knowledge Infrastructure(CNKI), the largest paper search engine in China, there is basically a lack of papers where patent analysis method is applied to analyze the trend of building safety technology in China. Therefore, this paper relies on patent analysis method, which is an innovation in the field of construction safety analysis in China. On the other hand, this paper is subject to some limitations. For data collection, the initial research time is limited, so the latest data is the end of 2018, and 751 patents have been obtained through key words. However, when the unnecessary data are screened out, the deviation may be caused by human reasons. In addition, when Netminer 4.0 is applied, three critical node analysis methods are selected, which also brings some limitations to the research of this paper. In the future study, as soon as possible to update the database, the development of science and technology is very rapid. Therefore, it is particularly important to use the latest data to analyze accident safety. In addition, a full understanding of other algorithms in Netminer 4.0 shall be gained to draw more comprehensive and authoritative conclusions. Only in this way can we make more contribution to improving construction safety in China.

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