Research on Construction Crane Accidents Cause Evolution Based on Complex Network

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Abstract. Construction crane accidents are a serious threat to the safety of people and projects. In this study, a causes framework for crane accidents was developed. Based on 249 accidents and association rules, a crane cause complex network is formed. Through the network analysis, the critical causes and critical links of crane accidents were obtained. The findings of this study provide practical recommendations for accidents prevention and safety management.

Keywords: Complex Networks, Construction Crane Accidents, Safety management

1 INTRODUCTION

In recent years, China's construction industry has developed rapidly, making outstanding contributions to stabilizing people's livelihoods, advancing the new urbanization progress and promoting economic development. However, the safety situation in China's construction industry is not optimistic, and the construction accidents occur frequently. Especially the mega and complex projects such as transportation, ports , terminals and High-rise buildings are gradually increasing, crane equipment is becoming more widespread. Crane accidents are becoming increasingly common, and are highly likely to cause large safety accidents [1][2]. It is important to study and control the causes of construction crane accidents so as to ensure the construction workers and projects' safety.

Extant research about crane accident causes is mainly carried out from crane equipment management, overall causes management and industry governance perspectives. In the crane equipment management stream, researchers focus on the unsafe factors that occur during the installation, operation and dismantling of crane machinery [2][4][5][6]. For example, Jiang, L et al. simulated the operation of crane machines using Random forest (RF) and machine learning methods based on historical construction crane towers accidental data that collected in the field, and finally predicted the accidental phases of the towers [3]. In the overall causes management perspectives, scholars have used questionnaires, structured interviews, case studies, and analytic hierarchy process (AHP) to identify all the key causal factors in the construction crane process [7][8][9][10]. Some studies have also used the combination of factor clustering

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and prioritization to establish a crane accident database based on man-machine-environment, prioritize the causes of accidents, and provide guidance for the management of crane safety [11]. In terms of industry governance, Cho et al. focused on the governance role of relevant laws and regulations for the prevention of crane accidents and provided suggestions for further improvement of the regulations [12]. However, the existing studies have not formed a comprehensive categorization framework for the causes of construction crane accidents, resulting in differences in the extraction and identification of key accident causes. Meanwhile, the judgment of the crane causes importance mostly relies on subjective qualitative analysis by experts, and lacks quantitative research.

Therefore, this study attempts to refine the classification framework of crane accident causes based on the Human Factors Analysis and Classification System (HFACS). Moreover, we will utilizing the association rule approach and complex network modeling to explore the key causes and their inter-causal relationships based on the accident case reports. The study will further enrich the application scenarios of the HFACS framework and provide new ideas for understanding the crane accidents causes. Adopting a quantitative research approach to identify the key causes, the relationships between them, and then deriving the key causes links, will help to further reveal the intrinsic mechanisms of crane accidents and provide practical recommendations for building safety management.

2 THEORETICAL BACKGROUND

2.1 Human Factors Analysis and Classification System (HFACS)

Human factors analysis and classification systems (HFACS) originated from the cheese model and were first applied to human error causes analysis in aviation accidents [13]. The HFACS classifies accident causation into four levels, namely, organizational influences, unsafe supervision, prerequisites for unsafe acts and unsafe acts. Different causes are also categorized in the four levels. The methodology can identify both explicit human causation and implicit organizational causation, providing a comprehensive framework system for sorting out accident causes. Apart from aviation, HFACS is now widely used in railroads, mining, energy, petroleum extraction and construction accidents [14]. Scholars would adapt and modify the HFACS framework according to different accident types' characteristics to ensure better identification of accident causes [15].

2.2 Association Rules

Association rule mining is a data mining technique widely used in various industries to identify specific data patterns from large databases or specific datasets and obtain specific knowledge about the problem under study by interpreting them. Its result quantitatively describes how a set of elements in a database record indicates the presence of other different sets of elements in the same record, reflecting the associative relationships between attributes or values in the database, such as simple associative relationships, causal associative relationships, etc [16]. Extant studies have applied association rules to the study of the occurrence patterns of crisis emergencies and road traffic accidents in scenic areas [17].

Support and confidence are significant metrics in the association rule mining process, reflecting the importance and reliability of the association rules. The researcher needs to set the minimum support (min_Sup) and minimum confidence (min_Conf) thresholds as association rule selection conditions. Relationships that satisfy both threshold conditions are considered to be strong association rules. Meanwhile, some studies have introduced the lift degree as an index for judging the causal relationship between the antecedent (X) and the consequent (Y). The lift degree is the confidence level of X on Y divided by the support level of Y. When the lift degree is greater than 1, it can be considered that X has a positive causal relationship on Y.

2.3 Complex Network Theory

Complex network is defined as a network structure consisting by a large number of nodes and edges which characterize the complex relationships between the nodes. It has complex topology and dynamical behavior [18]. The nodes of the network represent the components of the system and their characteristic properties, and the edges between the nodes represent the interactions between the components [19]. The complex network's topological characteristics mainly include parameters such as out-degree, in-degree, total-degree, clustering coefficient, betweenness centrality, network density and so on. Through the study of the topological characteristics, evolutionary rules and functional properties, we can deeply cognize the structure, function and intrinsic mechanism of the complex network system, and then propose effective methods to manage and control the complex system.

3 METHODOLOGY

3.1 Sample

The research data comes from the emergency management departments public cases in the provinces, cities and counties of China. We also collected accident reports from the safety management network, websites of housing and Urban-Rural Development Ministry and official WeChat public platforms. In order to ensure the timeliness of the study, we crawled 756 construction crane accident reports from the above sources through the Python crawler language with the time range of 2000 to 2022. Based on the data screening principles, we removed duplicates, abbreviated descriptions, missing content, and non-construction crane accident reports such as factory workshop and harbor operations. Finally, 249 reports were obtained as a data source on accident causes and accident types.

3.2 Causes Framework for Crane Accidents

In this research, we extended the original HFACS model by assigning all construction crane accident causes into five levels: site external, organizational influences, supervision, preconditions of unsafe actions, and actions. We also categorized the types of construction crane accidents. The final causal framework is shown in Table 1.

Table 1. Causes Framework for Crane Accidents

External site (e)	Regulations (e1)	E11. inadequate government safety regulations; e12.weak industry safety enforcement;	
	Owner (e2)	E21.failure to review contractor's qualifications; e22. owner's illegal dismemberment of subcontracted works; e23.owner's inadequate pre-feasibility study for the project; e24. owner's inadequate review of the project's design; e25. owner's inadequate resource support for contractors; e26. owner's inadequate qualification; e27 owner's failure to select the supervisory unit in accordance with the regulations;	
Organizational influences (o)	Safety culture (o1)	O11. contractor managers' lack of safety mindset; o12. inadequate contractor safety organization and regulations; o13. unclear contractor safety responsibilities;	
	Resource management (o2)	O21. inefficient allocation and selection of human resources by contractors; o22. inadequate safety training by contractors; o23. lack of investment in safety by contractors; o24. purchase of inappropriate materials and equipment by contractors orlack of acceptance testing;	
	Organizational processes(o3)	O31. contractor develops ineffective contingency plans; o32. contractor neglects safety management o33. contractor fails to fulfill safety management responsibilities; o34. contractor fails to place safety managers on site;	
Supervision (s)	Inadequate work design (s1)	S11. ineffective site safety plans and construction programs; s12.excessive construction task loads and intensities; s13. poor site staffing and labor organization;	
	Field management defects(s2)	S21. failure to complete technical safety briefings in the field; s22. failure to correct unsafe operations in a timely manner; s23. ineffective identification and control of safety hazards; s24. ineffective management of safety tracking in the field; s25. incorrect signaling commands, irregularities in commands, or lack of commands;	
	Violation of supervision (s3)	Violation of supervision (s3) s31. failure to comply with safety rules and regulations; s32. violation of command; s33. authorizing unqualified work crews to perform without review; s34. ineffective site supervisor;	
Preconditions of unsafe	Status of operators (p1)	Poor psychological state (p1a)	P11. nervousness; p12. abnormal mood swings; p13. gambling, experience, impulsivity, and others;
		Poor physical state (p1b)	P14. physical fatigue; p15. illness; p16. poisoning; p17. physical defects;

actions (p)		Poor mental state (p1c)	P18. interference; p19. poor safety awareness; p110. overconfidence;
		Inadequate skills (p1d)	P111. inexperience; p112. inadequate or unqualified safety knowledge and skills;
	Crane equipment and materials (p2)	Defective design of on-site machinery (p2a)	P21. lack of conspicuous warnings and markings; p22. poor design or location of lifting equipment operation;
		Improper use and operation (p2b)	P23. crane equipment in violation of operation regulations; p24. use of defective crane equipment; p25. excessive (overtime or overloading) use of equipment; p26. failure to maintain or overhaul crane equipment in a timely manner; p27. failure to use or failure of safety equipment; p28. unscientific manner of stacking, lifting or lashing of lifting materials;
	Environment (p3)	Dirty work environment; p32. noise/illumination and unclear ground conditions; p33. confined spaces; p34. insufficient ventilation and oxygen; p35. poor geology; p36. extremely bad weather;	
Actions (a)	Errors (a1)	Awareness error (a1a)	A11. incorrect equipment, environmental and personal perceptions; a12. incorrect perception of sops;
		Decision error (a1b)	A13. poor risk perception; a14. lack of competence; a15. poor decision or action error;
		Skill error(a1c)	A16. choosing the wrong workmanship procedure or simplifying procedure;
	Irregularities(a2)	A21. operational violations;	
Crane accidents (c)	C1. ground collapse; c2. collapse of crane; c3. falling objects; c4 fall of personnel; c5. injury to personnel on ground; c6. crush injury accident; c7. electricity shock accident; c8. damage to crane; c9. damage to other property on ground		

3.3 Procedure

The construction crane accident report contains: title, accident profile, detailed occurrence process, accident cause analysis, accident lessons and expert comments. We use crawling tools to remove information that is not relevant to the study, and retain information on accident time, accident casualties and damages, and accident causation analysis. Following that, referring to the causes framework, we extract and analyze the keyword groups combining the causes and accident results in the cases, categorize the phrases and words, and convert and identify to get the causes data of each case.

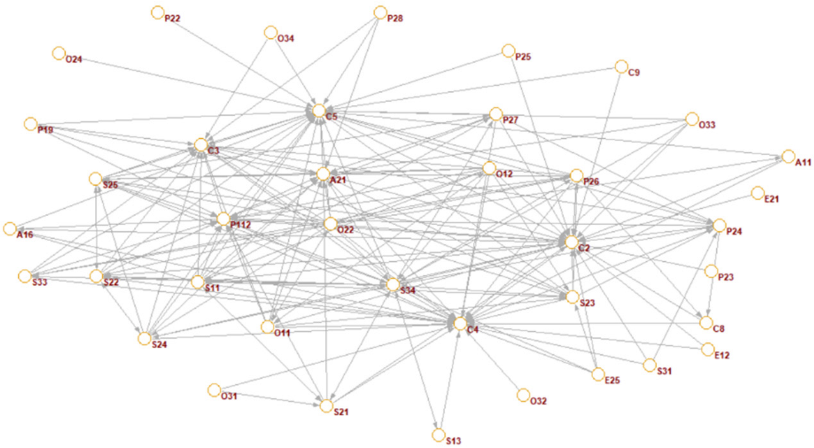

Fig. 1. Complex network of construction engineering crane accidents

The cause data of 249 cases were summarized to obtain the overall cause data set. The Python algorithm was edited to input this dataset into the database, and the number of antecedent and consequent terms of all association rules was set to 1. The strong association rule thresholds were min_Sup=0.03, min_Conf=0.2, and min_Lift=1. After the association algorithm was calculated, 236 strong association rules were obtained. It contains 3 nodes of site external factors, 8 nodes of organizational influences, 10 nodes of unsafe supervision level, 9 nodes of prerequisite level of unsafe behaviors, 3 nodes of unsafe behavior level, and 6 nodes of accident types (see Fig. 1).

4 ANALYSES AND RESULTS

We analyzed the out-degree, in-degree, total-degree, clustering coefficient and betweenness centrality of the causes nodes in the complex network respectively. The nodes with higher values are shown in Table 2.

Table 2. Critical nodes of construction complex networks

Topological Structure	Critical Nodes
Input-Degree	A21,P112,S34,S23,P26
Output-Degree	S34,O22,O12,S22,S11
Total-Degree	C2,S34,C5,C4,P112
Clustering Coefficient	E12,O34,P25,E25,P28,S31
Betweenness Centrality	S34,P112,C5,C2,S21,P26

In the site external level, the clustering coefficients of E12 and E25 are larger. In the organizational influences level, S34 scored higher in degree value and the highest betweenness centrality. Preconditions of unsafe actions level, P26, P112 are considered as critical nodes. In the level of unsafe actions, A21 has the highest input-degree. The key nodes in the type of crane accidents are C2 and C5. Based on the above critical nodes, combined with the complex network model, the critical links of the construction crane accident causes are constructed (see Fig.2). Taking the O12-S34-P26-A21-C2 link as an example, the contractor's corporate safety rules and regulations are not implemented will in increase the possibility of on-site supervisory personnel dereliction of duty. Because in the necessary supervision of construction operations, the construction side needs to take the initiative to notify the supervisory personnel to carry out the work of bystanders, inspections, parallel inspections and so on. Supervision failure is likely to lead to crane accidents overuse. Coupled with the fact that the construction personnel did not check the crane equipment before the lifting operation following the regularities, which ultimately led to the crane collapse. In addition, there are two short cross-level paths that are critical, namely E12→C2 and O34→C5, suggesting that two causal factors may directly lead to the accident.

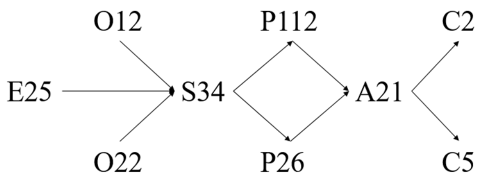

Fig. 2. Critical links of construction crane accidents

5 CONCLUSIONS

The analysis of the critical links shows that when government enforcement agencies are slack in inspecting construction crane work, other causes at other levels are likely to emerge, leading to accidents. When the owner does not support the contractor's resources, for example, by not paying for the work that is due, the contractor may reduce the resources for safety, which may result in accidents. Inadequate self-supervision and control by contractors, inadequate safety organization and regulations, or insufficient safety training of workers can easily sow accidental safety hazards. Many crane accidents can be avoided by guaranteeing that construction workers are licensed and equipments are repaired before building. Finally, it is necessary to reduce the irregularities of the workers to maintain the workers' life and safety, ensuring the effectiveness of the project.

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