Analyzing a behavioral-risk-chain network of accidents in the Chinese building construction

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Analyzing a behavioral-risk-chain network of accidents in the Chinese building construction

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Abstract. To deeply understand the impact of unsafe behavior on accidents, this paper analyzes a behavioral-risk-chain-network of accidents (BRCNA) in the Chinese building construction based on complex networks theory. Firstly, unsafe behaviors are classified from safety standards and operating procedures. Secondly, rules to form behavioral risk chains are defined, and then BRCNA is established from accident cases in the Chinese building construction. Besides, Pajek is used to construct the network model. Finally, the average path length, diameter and clustering coefficient are calculated and analyzed in BRCNA. The results show BRCNA has short average path length and high clustering coefficient, which indicates it has the characteristics of a small-word network with high transmission efficiency. The interactions among unsafe behaviors on building construction accidents are identified. It is of theoretical and practical significance on safety management and accident prevention in the Chinese construction industry.

1. Introduction

Construction is one of the most dangerous jobs worldwide [1]. Owing to mass construction projects and poor safety management, there are still frequent incidents and accidents happening in the construction industry of China. Fig. 1 shows fatalities in the construction industry from government websites [2-3]. Compared to Japan, fatalities in the Chinese construction industry are much more from 2013 to 2017, which reflects that accident prevention remains as a critical issue.

Construction accidents can be prevented by identifying the root causes of accidents, which has been explored by accident causation theory [4]. Among the causes, unsafe behavior is regarded as an important one affecting accidents. However, existing studies mainly discussed the position of unsafe behavior among various factors such as unsafe condition, inadequate management and organization, but rarely explored interactions within behavioral factors leading to accidents. In fact, multi-unsafe behaviors involved in accidents have time sequences (are objectively occurred in chronological order), and thus form behavioral risk chains of accidents. Through exploring these chains, critical unsafe behaviors can be identified and their impacts on accidents can be deeply understood. It has a great significance on accident prevention of construction. In recent years, complex networks (CN) theory has been studied for solving practical problems of large-scale complex systems such as transportation networks, social networks and computer networks [5]. For the heterogeneity of directions, networks can be divided into two types, in which directed networks can more clearly reflect the links among nodes [6]. Behavioral-risk-chains of accidents can be built as a network, and thus a directed one is suitable to represent interactions among unsafe behaviors and explain the behavioral mechanism causing accidents. This paper uses a case study that accidents of building construction in China are selected for analyzing.

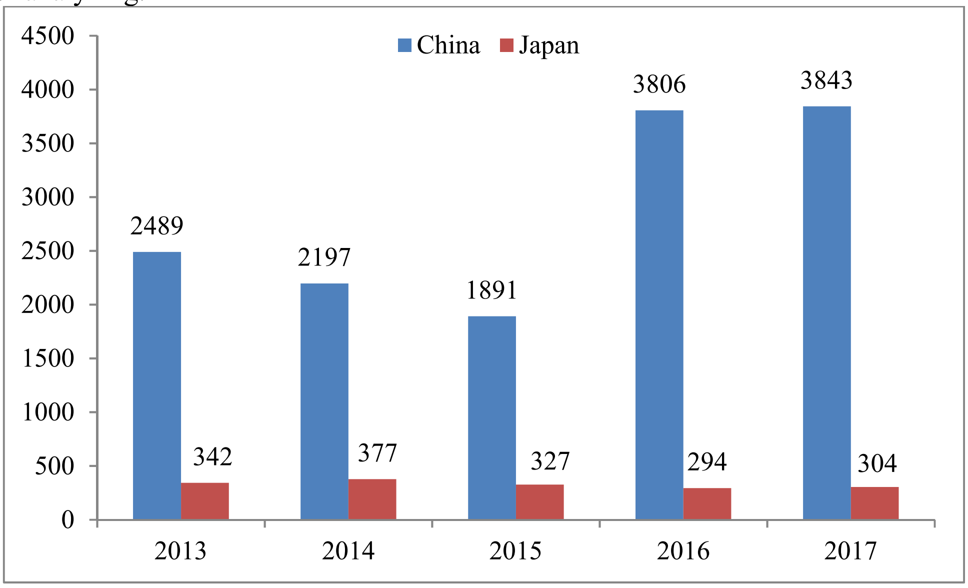

Figure 1. Number of fatalities in China and Japan involved from 2013 to 2017

2. Classification of unsafe behaviors in building construction

Unsafe behaviors are mainly extracted from *Classification standard for casualty accidents of enterprise workers* (GB 6441-1986), which includes 49 unsafe behaviors. Other safety standards and operating procedures in China are also used as references to list unsafe behaviors, such as *Technical code for safety of working at height of building construction* (JGJ 80-2016) and *Code for construction and acceptance of crane installation engineering* (GB 50278-2010). From these data sources, a total of 73 unsafe behaviors are identified and classified in building construction. Then, unsafe behaviors are encoded in form of *xxxx*, the first two represent the type code, and the last two represent the name code, seen in Table 1.

Table 1. Examples of unsafe behaviors in the classification

Type	Code	Name	Code
Personal protective equipment (PPE)	11	Do not wearing safety glasses while welding	1101
Machine operation	16	Operating machines against procedures	1601

3. Establishment of the behaviral-risk-chain network of accidents

249 accident cases of building construction in China are collected from government websites between 2010 and 2017 in several cities, such as Beijing, Shanghai and Guangzhou. Among the types of accidents, the rates are fall (64.26%), collapse (12.45%), struck-by (10.44%), lifting (7.63%) and else (5.22%).

Then, behavioral risk chains of these accidents are extracted. The behavioral risk chain is directed, in which node indicates the unsafe behavior, and edge indicates time sequences of unsafe behaviors in an accident case. Because these accident cases have detailed investigation reports, behavioral risk chains can be extracted through analyzing the process and reason of these accidents.

Finally, the behavioral-risk-chain network of accidents (BRCNA) is visualized as a directed and unweighted network through the software Pajek (5.02a). As seen in Fig. 2, 191 behavioral risk chains constitute the network.

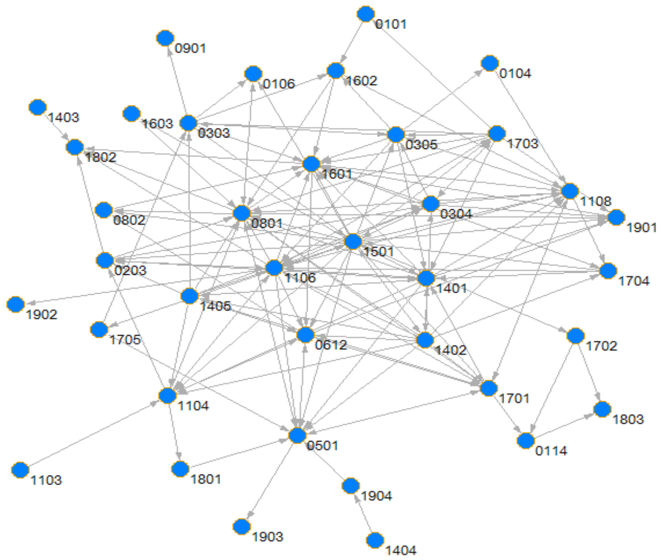

Figure 2. Model of BRCNA

4. Network analysis

4.1. Average path length

The value of average path length is 2.79 that means a node connected to another requires no more than three nodes in BRCNA. For example, the two independent unsafe behaviors of vertex 1701 (not erecting or removing scaffolds as required) and vertex 1106 (not wearing safety belts) can form a behavioral risk chain by the link passing through vertex 1402 (safety nets are not set as required) and vertex 1104 (not wearing safety helmets). This indicates that BRCNA is of high transmission efficiency, which strengthening the necessity of collaborative control of different unsafe behaviors.

4.2. Diameter

The diameter of BRCNA is 7. Vertex 1404 (Working in the foundation pit without sufficient protection on steep slopes) and vertex 0901 (Cleaning machines while they are running) is a pair of nodes with the most distance in network. There are six nodes between them, vertex 1904 (not setting drainages and impermeable layers as required), vertex 0501 (improper storage of subjects such as construction materials), vertex 1701 (not erecting or removing scaffolds as required), vertex 1401 (insufficient border protection), vertex 1501 (engaging in special works without qualification certificates and work licenses), and vertex 0303 (using machines or equipments without inspection).

4.3. Clustering coefficient

It is observed that there are some nodes get the value of 99999998 because the degrees of all these nodes are equal to 1. These nodes are eliminated in analysis process. The lowest and highest values of clustering coefficient are 0 and 0.6333, respectively. The large clustering coefficient denotes that there exists behavioral risk chain between neighbors which will cause accident. It also implies that the connectivity between these nodes is high. There forms a small center around these nodes, such as vertex 1704 (not setting up work platforms as required), vertex 1603 (not lifting objects as required), vertex 1803 (not concreting as required), vertex 0106 (wrong operation such as operation of buttons, valves, wrenches and handles), vertex 0104 (forgetting to turn off machines or equipments). Otherwise, the average clustering coefficient is 0.3211, which is larger than that in a random network calculated by Pajek (5.02a) with the similar node set (number of nodes and edges are similar with BRCNA) with the value of 0.2214 (the value will change on a very small scale under different circumstances, but generally be less than 0.23), seen in Fig. 3.

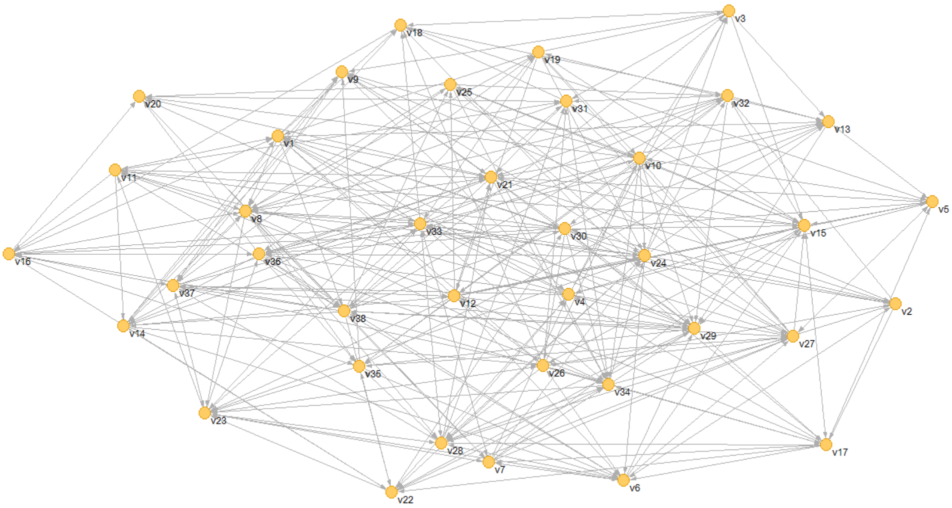

Figure 3. Graph of equal-sized behavioral-risk-chain network in random

As analyzed above, BRCNA follows small-world properties with large clustering coefficient and short average path length [7]. It illustrates that a behavioral risk chain can be formed with two seemingly unrelated unsafe behaviors by passing through few other unsafe behaviors, and thus results in accidents. This characteristic reflects collaborative control of multiple associated unsafe behaviors can be an effective solution for accident prevention.

5. Conclusion

Unsafe acts are regarded as the main factor causing accidents, but few studies analyze interactions among them within accidents. This paper proposed a concept of behavioral risk chain, and then found BRCNA was a small-world network through complex networks theory. Therefore, critical unsafe behaviors leading building construction accidents were identified and interactions among unsafe behaviors were further explained.

From theoretical aspects, accident causation theory is improved. Small-world properties of BRCNA explain interactions among unsafe behaviors leading accidents. From practical aspects, behavioral risks can be initially controlled on the building construction sites. Controlling these central unsafe behaviors of BRCNA during daily safety management can help reduce the probability of occurrence of related unsafe behaviors. Furthermore, secondary or derived accidents can also be avoided by controlling these central unsafe behaviors that already happened in an accident.

Acknowledgments

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