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Exploring evolutionary features of directed weighted hazard network in the subway construction*

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A better understanding of previous accidents is an effective way to reduce the occurrence of similar accidents in the future. In this paper, a complex network approach is adopted to construct a directed weighted hazard network (DWHN) to analyze topological features and evolution of accidents in the subway construction. The nodes are hazards and accidents, the edges are multiple relationships of these nodes and the weight of edges are occurrence times of repetitive relationships. The results indicate that the DWHN possesses the property of small-world with small average path length and large clustering coefficient, indicating that hazards have better connectivity and will spread widely and quickly in the network. Moreover, the DWHN has the property of scale-free network for the cumulative degree distribution follows a power-law distribution. It makes DWHN more vulnerable to target attacks. Controlling key nodes with higher degree, strength and betweenness centrality will destroy the connectivity of DWHN and mitigate the spreading of accidents in the network. This study is helpful for discovering inner relationships and evolutionary features of hazards and accidents in the subway construction.

Keywords: accident analysis, directed weighted network, complex network, evolutionary features

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1. Introduction

With the rapid growth of population and urbanization, traffic congestion and associated atmospheric pollution have become serious problems in various parts of the world.[1,2] The subway is an effective method to relieve these problems in major cities. It has advantages of high capacity, low energy consumption, high speed, comfort and low pollution to the environment.[3] Many modern cities, such as Beijing, Shanghai, New York, Moscow and London have continually increased investments in the subway construction in recent years. According to the statistics, the subway has been expanding at a rate of 30–50 km per year in China.[4] Meanwhile, up to October 31, 2018, 46 cities in China had been approved to construct subway systems, and 36 cities had already put into operation.

However, the subway construction has some disadvantages of long duration, large investment, and complex technical issues. As a dynamic open system, the subway construction is affected by inherent uncertainties and numerous safety risk factors, such as interacting roles of human, technology, materials, and complex environment, causing a particular high probability of hidden dangers and even accidents with serious consequence.[5,6] Taking two cases for instance, the collapse accident of Sao Paulo's Metro Line Four in Brazil on January 12, 2007, causing more than seven casualties.[5] On November 15, 2008, the collapse accident of Hangzhou Subway Line One project occurred suddenly, resulting in 21 fatalities, more than 24 injuries and the direct economic loss of approximately 49.61 million Yuan.[7] Such subway construction accidents not only caused huge economic loss, but also the casualty of life. In order to reduce and avoid similar accidents in the future, it has great significance to analyze accidents. During past decades, there are various typical methods adopted for accidents analysis, such as Analysis Hierarchy Process,[8–10] Artificial Neural Network Model,[11–14] Support Vector Machine,[15,16] AcciMap,[17–19] System-Theoretic Accident Models and Process,[20] Fuzzy Bayesian Network,[21,22] Human Factors Analysis Classification System,[23] Fuzzy Fault Tree Analysis,[24,25] and so on. These methods have got good application with practical significance in the aspect of industry accident analysis. However, they only focus on describing the static factors by analyzing a single accident or a few, lacking the holistic perspective to find the hidden dynamic interaction features among factors.

Recently, many scholars have introduced complex network theory to develop the inner transmission mechanism in order to better understand evolutionary features of the complicated system.[26,27] As an effective method, complex network theory has been widely applied in many scientific fields of Internet,[28,29] biology,[30–32] transportation,[33–37] World-Wide Web,[38,39] financial markets,[40,41] energy economics,[42,43] etc. In addition, Ma *et al.*[44] introduced complex network theory for the causation analysis of railway

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accident as a case "7.23" China Yongwen railway accident. Zhou *et al.*[45] integrated framework of modified accident energy release model and network theory to explore the full complexity of "11.15" Hangzhou subway construction collapse accident. Instead of analyzing a single accident, Zhou *et al.*[46] used network theory to understand the topological characteristics of subway construction accident network (SCAN). Li *et al.*[3] constructed metro operation hazard network (MOHN) to explore the complexity of metro operation hazard. However, from recent studies we can see that, most accidents networks are undirected or unweighted. Directed weighted networks can more clearly and in detail demonstrate interrelationships among nodes. Gao and Jin[47] proposed a reliable method for constructing a directed weighted complex network (DWCN) from a time series. Zheng *et al.*[48] built up a directed and weighted complex network model to explore the topological properties of Beijing urban public transit by analyzing the topological properties of node degree, node strength, strength distribution, average shortest path, and clustering coefficient. Zeng *et al.*[49] constructed directed weighted complex networks based on time series symbolic pattern representation in order to dig out the structural characteristics of time series. The above-mentioned directed weighted network modeling methods provide a new perspective for accident network analysis.

In this paper, we aim to study the multiple relationships among hazards and accidents on the collected accident cases from a whole perspective by constructing and analyzing the directed weighted hazard network (DWHN) in the subway construction. After the introduction presented in this section, the rest paper is organized as follows. Section 2 introduces the data and basic indicators used in this paper. Section 3 analyzes the basic topological characteristics of the directed weighted hazard network and discusses real properties of DWHN. Finally, the conclusion is given in Section 4.

2. Data and methods

2.1. Data

It is well known that accident databases have a remarkable effect on accident analysis for promoting safety management. However, the reality is that there are no professional and adequate accident databases of subway construction in existence for better exploring complex interrelationships among hazards and accidents. Hence, the data used in this paper are typical accident cases collected from authorities, media reports and literature review. Eventually, a subway construction accident database is developed, including 162 accidents which occurred in China, Japan, and Singapore from July 1, 2003 to July 31, 2018. These accidents can be summarized and divided into 11 types: collapse, object strike, falling, fire, mechanical injury, lifting injury, vehicle injury, electrocution, poisoning, explosion, and others. As can be seen from Fig. 1, collapse has the largest proportion (41%) of accidents in the database, including collapse of support structure, collapse of soil, collapse of template, inclination and collapse of building, road collapse, inclination and collapse of rebar, collapse of machinery, collapse of tunnel face, and secondary collapse. The following is the object strike and falling with the proportion of 12%. An example of subway construction accident is shown in Table 1.

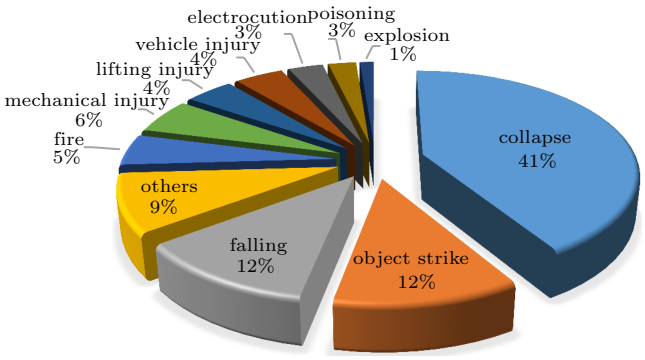


Fig. 1. Statistics of various types of subway construction accidents.

Table 1. Example of subway construction accident.

Case No.	Country	City	Time	Event chains
19	China	Nanjing	02-05-2007	
Description	aging water pipes close to the north of Hanzhong Road and Pailou Lane intersection had been leaking for a long time. Then water seepage gave rise to soil swelling, leading to collapse of soil and pipeline rupture, following with explosion and fire. There were no fatalities or injuries.			underground pipelines, unclear survey of underground pipelines → water seepage → soil swelling → collapse of soil → pipeline rupture → explosion → fire.

2.2. Methods

2.2.1. The construction of directed weighted network

Based on complex network theory, hazards and accidents are represented as nodes and complex interrelationships among hazards as edges. The direction of edges among nodes are the direction of accident causations, and the weight of edges are the occurrence number of repetitive relationships. In DWHN, if hazard i points to hazard j with the weight of

w_{ij}, then a link from i to j is drawn and $A_{ij} = a_{ij} \times w_{ij}$, otherwise no link is drawn and $A_{ij} = 0$. As shown in Fig. 2, if hazard A gives rise to hazard B, then the direction of the edge will be from hazard A to hazard B, and vice versa. The weight of the edge is the occurrence frequency of this relationship in DWHN.

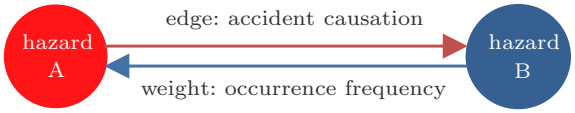


Fig. 2. Example of the directed weighted network model.

2.2.2. Topological characteristics of the network

There are a large number of indicators for analyzing the topological characteristics and evolution of the directed weighted network. Topological indicators from the complex network theory are adopted for analyzing DWHN, including network size and density, node degree, node strength, average path length and diameter, weighted clustering coefficient, and betweenness centrality.

The network density is defined as the ratio between number of transmission edges and the number of nodes. Network with higher density generally has greater influence on each node. The network density d is calculated by

$$d = \frac{l}{N(N-1)}, \tag{1}$$

where N is the total number of nodes and l is the number of edges in the network.

The node degree demonstrates the number of other nodes directly in contact with it. In a directed network, the degree is the sum of in-degree and out-degree of the whole network. While the in-degree k_i^{in} represents the number of outward lines directed to node i, the out-degree k_i^{out} refers to the number of inward lines

$$k_i^{\text{in}} = \sum_{j=1}^{N} a_{ji}, \quad k_i^{\text{out}} = \sum_{j=1}^{N} a_{ij}. \tag{2}$$

In a directed weighted network, it is typical to measure the strength of each node's connection to other nodes. There are two components of the total strength for a node, in-strength s_i^{in} and out-strength s_i^{out}, defined as the incoming weight and outgoing weight to the node i,

$$s_i^{\text{in}} = \sum_{j=1}^{N} w_{ji}, \quad s_i^{\text{out}} = \sum_{j=1}^{N} w_{ij}. \tag{3}$$

A higher strength indicates better connectivity.

The average degree $\langle k \rangle$ is the average connectivity of all nodes, likewise, the average strength $\langle s \rangle$ is the average weight of all nodes in the network, which are calculated as

$$\left\langle k_i^{\text{in}} \right\rangle = \left\langle k_i^{\text{out}} \right\rangle = \frac{1}{N} \sum_{i,j=1}^{N} a_{ij}, \tag{4}$$

$$\left\langle s_i^{\text{in}} \right\rangle = \left\langle s_i^{\text{out}} \right\rangle = \frac{1}{N} \sum_{i,j=1}^{N} w_{ij}. \tag{5}$$

Average path length L is the average number of steps along the shortest paths between any of two nodes in the network, which can measure the overall connectivity and the size of a network. It can be defined by

$$L = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij}, \tag{6}$$

where d_{ij} is the shortest distance between two random nodes i and j. The diameter is defined as the longest of all shortest paths in a network.

In a weighted network, the weighted clustering coefficient reflects the connectivity of its neighboring nodes. Meanwhile, it reveals whether a node is a core node in the network, which is defined by[50]

$$C_w(i) = \frac{\sum_{j,k} w_{ij} w_{jk} w_{ki}}{\max_j(w_{ij}) \sum_{j,k} w_{ij} w_{ki}}, \tag{7}$$

where w_{ij}, w_{jk}, and w_{ki} are the weight of edges between node i, j, k, respectively.

Betweenness centrality B_{a} is a centrality measure of communication which can quantify times a node serves as a bridge based on the shortest paths between two other nodes in a network. A higher betweenness centrality means the node more control over the network. The betweenness centrality B of a node a is defined as

$$B_{\text{a}} = \sum_{i,j \in N, i \neq j} \frac{n_{ij(\text{a})}}{n_{ij}}, \tag{8}$$

where n_{ij} is the number of shortest paths between node i and node j, $n_{ij(\text{a})}$ is the number of the shortest paths between node i and node j, passing through node a. Obviously, the value of node betweenness centrality is between 0 and 1.

3. Results and discussion

3.1. The visualization of directed weighted hazard network

Based on the statistics and analysis of typical accidents, it is acknowledged that an accident of subway construction is generated by various hazards including human factors, machine and material, technology and environment rather than a single one. Hazards and accidents are identified and complex interrelations among these different factors are explored to construct the subway construction accident network. As shown in Table 2, 53 factors are summarized and then divided into three levels according to the analysis of 162 accidents. For convenience, three levels of 20 original hazards, 15 secondary accidents and 18 derivative accidents are denoted by

node OH01 to OH20, SA01 to SA15, and DA01 to DA08, respectively. As a method of modeling accident causation, event chains are introduced to identify directed edges. As a consequence, 140 event chains (see Appendix A) can be acquired from the recorded accidents. Taking hazards as nodes, interrelations as edges and occurrence times of the repetitive relationship as weight, the directed weighted hazard network (DWHN) is constructed by integrating the aforementioned information. Figure 3 is a visualization of DWHN in the subway construction including 53 nodes and 213 edges. Different colors represent nodes belonging to different levels, different thickness of lines imply the different weight of edges. This network offers a new perspective to explore the evolution of construction safety by describing the complex relationships among different hazards and accidents in the subway construction.

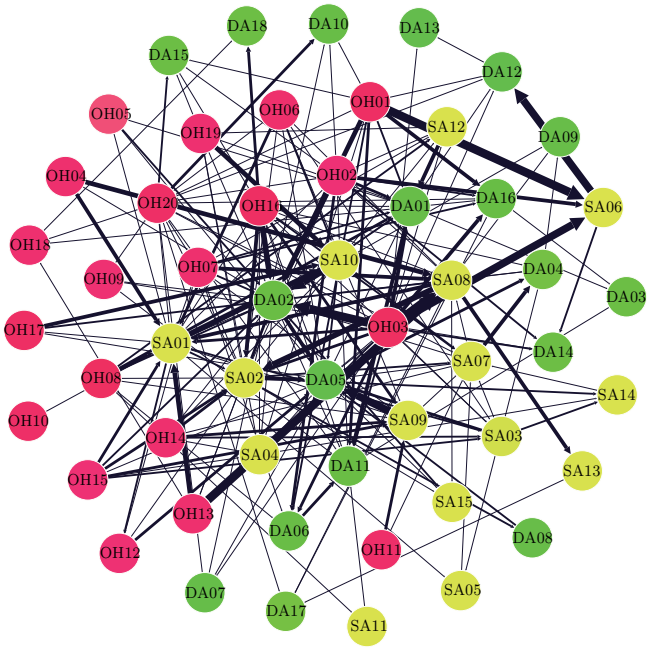


Fig. 3. The visualization of DWHN in the subway construction.

Table 2. List of original hazards, secondary accidents, and derivative accidents.

Original hazards	
OH01 lack of safety risk awareness	OH02 work against regulation
OH03 inadequate supervision and management	OH04 unclear survey of underground pipelines
OH05 unclear survey of geology	OH06 design mistake
OH07 misoperation of construction	OH08 substandard construction quality
OH09 worker without professional qualification	OH10 uncompacted backfill
OH11 improper control of earth pressure	OH12 stratum hole structure
OH13 underground pipelines	OH14 ground water
OH15 sandy silt	OH16 complex geology
OH17 soft ground	OH18 harmful gas
OH19 rainfall	OH20 mechanical failure
Secondary accidents	
SA01 water seepage	SA02 water burst
SA03 sand gushing	SA04 soil boiling
SA05 piping	SA06 tumble
SA07 differential settlement of ground	SA08 pipeline rupture
SA09 ground loss	SA10 soil swelling
SA11 sliding of cable support	SA12 sliding of steel support
SA13 gas leakage	SA14 tunnel structural failure
Derivative accidents	
DA01 collapse of support structure	DA02 collapse of soil
DA03 collapse of template	DA04 inclination and collapse of building
DA05 road collapse	DA06 inclination and collapse of rebar
DA07 collapse of machinery	DA08 collapse of tunnel face
DA09 secondary collapse	DA10 lifting injury
DA11 object strike	DA12 falling
DA13 vehicle injury	DA14 mechanical injury
DA15 electrocution	DA16 fire
DA17 explosion	DA18 poisoning

3.2. The basic topological characteristics of DWHN

The basic topological indicators originated from complex network theory are used for analyzing hazards evolution and the whole complexity of DWHN in the subway construction. Topological indicators including network size and density, node degree, node strength, average path length and diameter, weighted clustering coefficient, and betweenness centrality are applied to analyze DWHN. The analysis results are discussed in the following section.

3.2.1. Network size and density

The network size is the total number of nodes and edges that indicates how many hazards and interactions in DWHN of the subway construction. The network density is defined to describe the tightness among all of the hazards in DWHN. It implies that network density is the ratio of actual relationships to the number of possible links. The larger the network density is, the tighter relationships among all hazards will be. There are 53 nodes and 213 directed edges in DWHN. The maximum number of all possible relationships is 2756, thus the network density of DWHN is 0.077. This small value suggests that DWHN is a sparse network, that is to say, nodes in this decentralized structure have less relationships with all others in the network.

3.2.2. Node degree

The degree is one of the most important and basic measures of centrality of a node in the network which means the number of its direct connections to other hazards in DWHN. The node degree reflects the importance of nodes in the network. The larger the node degree, the more important the hazard in DWHN. The average degree of DWHN is 4.02, which indicates that each hazard has relationship with as many as four hazards averagely. The value of in-degree, out-degree, and total degree in the DWHN of the subway construction are presented in Fig. 4. We can see that "collapse of support structure" (DA02), "water seepage" (SA01), "water burst" (SA02), "road collapse" (DA05), "inadequate supervision and management" (OH03) have large total degree with the value of 27, 21, 21, 20, and 18, respectively, indicating that these hazards play important roles in the subway construction since they have more relationships with other nodes in DWHN. "Collapse of support structure" (DA02) also has the largest in-degree with the value of 20 while its out-degree is only 7, indicating that there are 20 hazards leading to the collapse of support structure in the subway construction. In addition, "inadequate supervision and management" (OH03) has the highest out-degree with the value of 18, followed by "complex geology" (OH16) and "work against regulation" (OH02) with the value of 15. It means that "inadequate supervision and management" (OH03) can lead to 18 kinds of hazards or accidents directly.

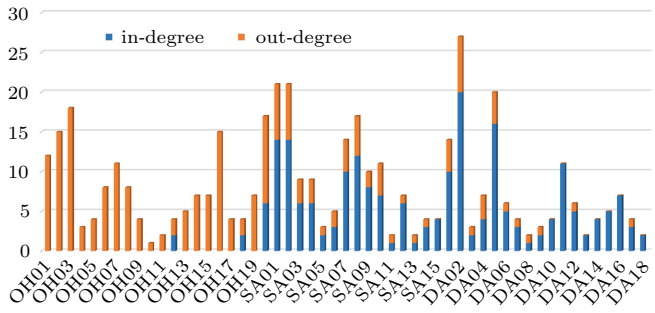


Fig. 4. Values of in-degree, out-degree, and total degree.

3.2.3. Node strength

In a weighted network, node strength represents not only the number of nodes to which a corresponding node is connected but also the weight of each edge. It is typical to measure the importance of nodes in the network. Since DWHN is a directed network, there are three different node strengths of each node: in-strength, out-strength, and total strength. A higher node strength illustrates a greater connectivity. The top 15 hazards of DWHN, ranked by the value of total strength, are presented in Fig. 5. Apparently, "collapse of soil" (DA02), "road collapse" (DA05), and "collapse of support structure" (DA01) are more important than other derivative accidents in DWHN. Meanwhile, "collapse of soil" (DA02) has maximum in-strength and total strength with the value of 55 and 67. Hence, "collapse of soil" (DA02) plays a dominant role in DWHN. For secondary accidents, "pipeline rupture" (SA08), "water seepage" (SA01), and "water burst" (SA02) occupy the top three with the total strength of 50, 47, and 44, respectively. With a value of 54, "inadequate supervision and management" (OH03) has the highest out-strength while its value of in-strength is zero, making it more arduous to be controlled. Furthermore, the average node strength of DWHN is 16.23, indicating that each hazard averagely connects to others more than 16 times in the network.

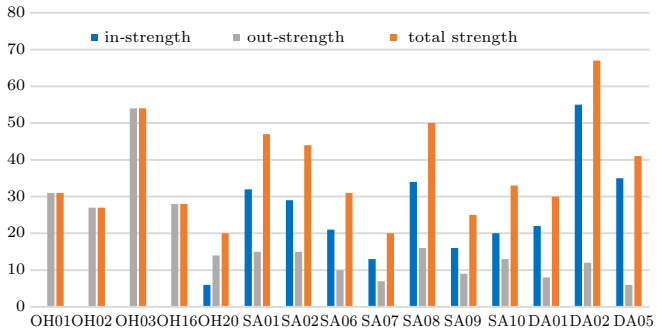


Fig. 5. Values of in-strength and out-strength for the top 15 nodes in total strength.

3.2.4. Average path length and diameter

Average path length is the average number of steps for shortest paths taken over all pairs of hazards in the network. The shorter the average path length, the higher the transmission efficiency of hazards. For DWHN of the subway construction, the average path length is 2.414, indicating that it only takes two steps to make one hazard connected to the other on average. That is to say, the relationships between different hazards are relatively tight and thus it is easy for hazards to cause accidents in DWHN. Diameter is defined as the longest shortest path of the network. The diameter of DWHN is 7. Taking a corresponding path for example, there are 7 steps between "unclear survey of underground pipelines" (OH04) and "fire" (DA16), in detail, "unclear survey of underground pipelines" (OH04) can cause "water seepage" (SA01),

"water seepage" (SA01) triggers "soil swelling" (SA10), "soil swelling" (SA10) gives rise to "collapse of soil" (DA02), "collapse of soil" (DA02) leads to "pipeline rupture" (SA08), "pipeline rupture" (SA08) generates " explosion" (DA17), and then results in "fire" (DA16).

3.2.5. Weighted clustering coefficient

The clustering coefficient of a hazard describes the connectivity with its neighboring hazards in the network, which ranges from 0 to 1. Since the DWHN is a weighted network, the weight of edges is taken into consideration to calculate the clustering coefficient. If a node has a higher weighted clustering coefficient, it is more closely related to its neighbors in the subway construction. Figure 6 depicts the weighted clustering coefficient of nodes in DWHN. Seven nodes, "unclear survey of underground pipelines" (OH04), "improper control of earth pressure" (OH11), "gas leakage" (SA13), "machinery damage" (SA15), "collapse of tunnel face" (DA08), "secondary collapse" (DA09), "vehicle injury" (DA13), have the weighted clustering coefficient of 1, demonstrating that these nodes have high degree of coupling with their neighbors. The network weighted clustering coefficient is the average value of all nodes in the network. The value of DWHN is 0.456, which is higher than the average unweighted one with the value of 0.218, indicating that the relationship among hazards and accidents become aggregative based on the weighted impact.

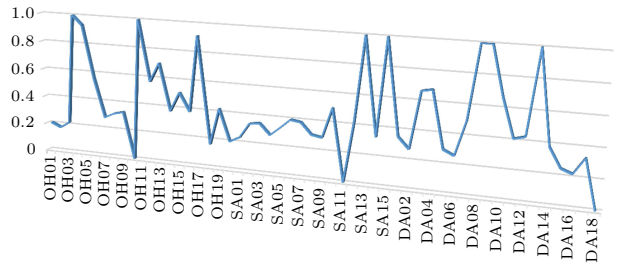


Fig. 6. Values of weighted clustering coefficient.

3.2.6. Betweenness centrality

Betweenness centrality is used to analyze which hazards are intermediary factors in DWHN of the subway construction. A hazard with larger betweenness centrality has a greater impact on the transfer of nodes through the network. The betweenness centrality of 29 nodes in DWHN is zero, meaning that these nodes do not play the role of intermediary based on shortest paths between other hazards in the network. Figure 7 presents another 24 nodes whose values are greater than zero. "Pipeline rupture" (SA08) is the most important mediator hazard with the largest betweenness centrality of 0.2, which indicates that many hazards and accidents have relationships with "pipeline rupture" (SA08), which make it serve as a bridge in DWHN. Therefore, "pipeline rupture" (SA08) has become the core in DWHN of the subway construction, followed by "collapse of soil" (DA02), "water seepage" (SA01), and "road collapse" (DA05) with the value of 0.16, 0.13, and 0.11. That is to say, 60% of the shortest paths go through these four hazards in the DWHN of the subway construction. The removal and control of these nodes can reduce the connectivity between other hazards in DWHN, which is an effective way to prevent and mitigate the occurrence of accidents in the subway construction.

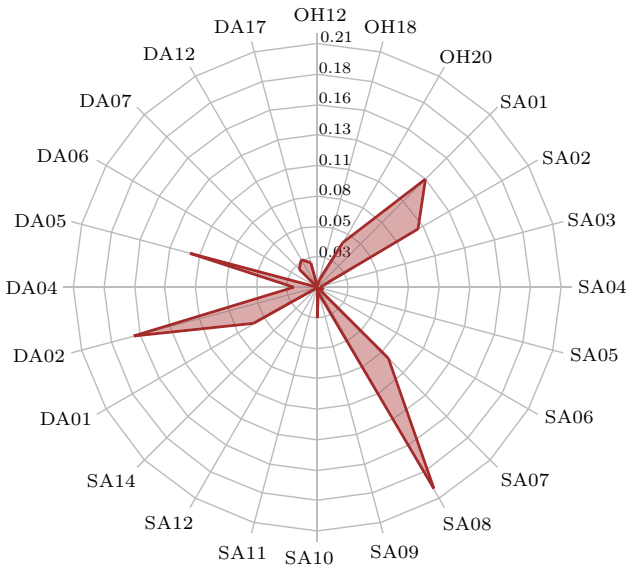


Fig. 7. Values of betweenness centrality.

3.3. Real network property

In this section, two real network properties of small-world and scale-free are used to characterize topological features of DWHN in the subway construction.

3.3.1. The small-world property

The characteristics of small average path length and large clustering coefficient at the same time imply that the network meets the property of small-world. If DWHN satisfies these two rules, we can say that the network possesses the small world property. Most nodes in a small-world network can be affected by every other through a small number of steps. As can be seen from section 3.2, the average path length of DWHN is 2.414 and the weighted clustering coefficient of DWHN is 0.456. DWHN exhibits both small average path length and large clustering coefficient at the same time, confirming that DWHN possesses the property of small-world. This means that most nodes in DWHN are not neighbors with each another, but most hazards can have relations with every other only by a small number of steps. That is to say, hazards in DWHN have better connectivity and will transmit very widely and quickly in the subway construction. Two levels of secondary accidents and derivative accidents are easy to be

generated owing to its rapid propagation. This makes it more challenging to prevent the spreading of accidents in DWHN.

3.3.2. The scale-free property

Degree distribution is adopted to analyze the scale-free property of the network. If a network whose degree distribution satisfies the power-law distribution, it has the characteristic of the scale-free. In the scale-free network, the degree distribution is heterogeneous that a large number of nodes have a few connections while a few nodes have relationships with many other nodes. The cumulative degree distribution is used to measure the scale-free feature of the network since the size of DWHN is too small. Thus, the cumulative degree distribution of DWHN in log–log coordinate is calculated. As presented in Fig. 8, DWHN follows a power-law distribution with the function of $P(K) \sim 2.6878k^{-1.095}$ ($R^2 = 0.7864$), meaning that the DWHN has the typical property of scale-free network with the $\gamma = 1.095$ to a certain extent. That is to say, hazards in the DWHN prefer to have relationships with the core nodes. Moreover, the property of scale-free makes DWHN more robust to random attacks, while vulnerable to target attacks. Controlling or removing these nodes with higher degree, strength and betweenness centrality can increase the average path length and destroy the connectivity of DWHN. It will have a great significance to mitigate and prevent the cascading effects in the subway construction.

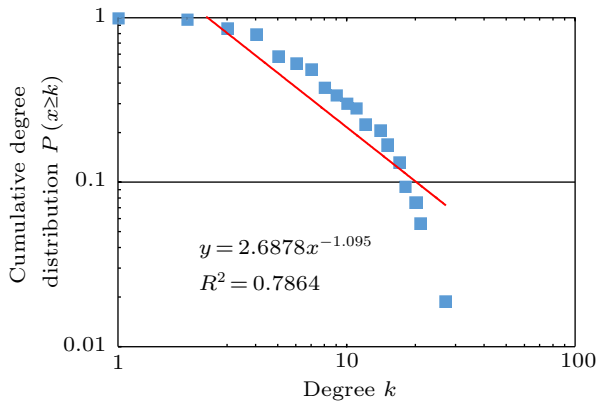


Fig. 8. Cumulative degree distribution of DWHN.

4. Conclusion

This paper has provided a new perspective to analyze topological features and evolution of accidents in the subway construction. We identified hazards and built a system of three-level hazards and accidents of the subway construction. Based on the complex network theory, we constructed a directed and weighted hazard network (DWHN) and employed the characteristics of the network in the subway construction. The main conclusions are as follows.

First, 140 event chains are explored on the basis of 162 collected accidents in the subway construction. 53 hazards which divided into three levels including original hazards, secondary accidents and derivative accidents and 213 relationships among these different factors are identified.

Second, the complex network theory is adopted to construct the directed and weighted hazard network (DWHN) of the subway construction, composed of 53 nodes and 213 edges. The nodes are hazards, and the edges are the complex interrelations of these factors. Indicators for analyzing directed weighted network including network size and density, node degree, node strength, average path length and diameter, weighted clustering coefficient, and betweenness centrality are employed to capture the complex features of DWHN.

Meanwhile, the average path length of DWHN is 2.414 and the weighted clustering coefficient of DWHN is 0.456. With both small average path length and large clustering coefficient at the same time, the DWHN has the property of small-world. This demonstrates that hazards will spread widely and quickly in the network. Secondary accidents and derivative accidents are easy to be generated for its rapid transmission.

In addition, the cumulative degree distribution of DWHN obeys a power law distribution, meaning that it is a scale-free network. The scale-free property makes DWHN vulnerable to target attacks. Precaution hazards with higher degree, strength, and betweenness centrality can enormously increase the average path length and destroy the connectivity of DWHN to prevent the spreading of accidents in the subway construction.

Appendix A

Table A1. Event chains in cases of subway construction accidents.

Case No.	Event chains
1	EM13, OH07, OH03, OH02 → SA01 → SA03 → SA14 → SA07 → DA04 → SA05
2	OH07, OH03, OH08, OH02, OH01 → DA01, DA06 → DA11
3	OH17, OH19, OH06 → SA10 → DA02
4	OH17, OH14, OH19, OH06 → SA10 → SA07 → DA02, DA04 → DA01
5	OH13, OH03 → SA08 → SA01 → SA05 → SA07 → DA05
6	OH02, OH03 → SA08 → SA02 → SA10 → SA12 → DA01 → DA02
7	OH15, OH06 → SA01 → SA10 → DA02 → DA05
8	OH10, OH08, OH13 → SA01→ OH12 → DA05
9	OH03, OH01 → SA06 → DA14
10	OH06 → SA01 → OH12 → DA05 → DA07
11	OH13, OH04 → SA01→ DA02 → DA04
12	OH08 → SA11 → DA11
13	OH13, OH04 → SA01 → SA10 → DA02 → SA08, SA15
14	OH13, OH04 → SA01 → SA02 → DA08 → DA05
15	OH07, OH03, OH02, OH09, OH01 → OH20 → DA10
16	OH20 → DA17
17	OH15, OH05 → DA02
18	OH17 → DA02
19	OH13, OH04 → SA01 → SA10 → DA02 → SA08 → DA17 → DA16

Table A1. Continued.

Case No.	Event chains
20	OH16, OH02, OH03, OH01, OH05 → DA02 → DA09
21	OH17, OH19 → SA10 → DA02
22	OH15, OH06, OH05, OH03 → SA01 → SA10 → DA02 → DA05
23	OH16 → SA02, SA03 → DA05 → SA15
24	OH16 → SA02 → DA02 → DA05
25	OH02, OH01 → DA03 → DA11
26	OH02, OH03, OH08, OH01 → DA02 → DA05
27	OH20 → DA16
28	OH02, OH01 → DA10
29	OH16 → DA18
30	OH02, OH03, OH08 → SA12 → DA01 → DA11
31	OH02, OH03, OH01 → SA06 → DA12
32	OH15, OH14, OH06 → SA09 → DA05
33	OH07, OH08, OH03, OH02 → SA02 → SA14
34	OH09, OH02, OH03 → DA14
35	OH16, OH19, OH03 → SA02 → DA08 → DA05
45	OH07, OH03, OH08 → DA01
46	OH16, OH03, OH05, OH06 → DA05 → DA04 → DA09 → SA08 → SA13
47	OH16, OH03 → DA02
50	OH02, OH03 → DA01
51	OH16, OH19 → SA10 → DA02
53	OH08 → SA12 → DA01 → DA11
54	OH06 → OH20 → SA07, SA02
55	OH19, OH08 → DA01 → DA12
57	OH16, OH01, OH02, OH20 → DA15
58	OH02, OH03 → DA14
59	OH13 → SA02 → DA02
60	OH02, OH09, OH03, OH01 → DA11
61	OH03, OH01 → SA06 → DA12
62	OH16, OH05 → DA01 → DA02 → SA15
63	OH08 → SA09 → DA05
65	OH16, OH08 → SA01 → SA02
66	OH02, OH01, OH03 → SA06 → DA12
67	OH15, OH14, OH06 → SA02, SA03 → SA07 → DA04
71	OH13, OH04 → SA08 → SA01 → SA10 → DA05
73	OH16, OH14, OH03, OH09, OH01 → DA02
76	OH02, OH01, OH03 → DA16
77	OH20, OH03 → DA07 → DA10
78	OH02, OH03, OH01 → DA16
79	OH02, OH03, OH01 → DA06 → DA11
80	OH13, OH04, OH03 → SA08 → SA02 → SA15
81	OH13, OH04, OH06 → SA08 → SA13 → DA17
82	OH03 → DA02
84	OH13, OH04 → SA08 → SA02 → SA07
88	OH13, OH04 → DA02
89	OH02, OH03 → DA02 → DA11
90	OH01, OH03 → SA06 → DA12
94	OH01, OH03 → SA06 → DA12
95	OH16, OH01 → DA11
98	OH16, OH13, OH04 → SA08 → SA02 → DA05
100	OH01 → SA06 → DA12
101	OH20 → DA12
104	OH01, OH03 → DA12 → DA13
105	OH20 → DA10
106	OH02, OH03, OH01 → SA06 → DA12
108	OH16, OH03, OH01 → DA02
110	OH13 → SA08 → SA01 → SA03 → DA05
111	OH02 → SA06 → DA12

Table A1. Continued.

Case No.	Event chains
114	OH19, OH16, OH03, OH01 → SA04 → DA02
116	OH02, OH03, OH01 → DA01
120	OH02, OH03 → DA06 → DA11
122	OH17 → DA02
123	OH12, OH16 → SA02 → DA05 → SA08
124	OH07, OH01, OH03 → DA16
125	OH07, OH01, OH03 → DA16
126	OH07, OH03, OH08, OH19, OH16 → DA02
127	OH11 → SA09 → DA05
128	OH11 → SA07 → SA08 → SA01 → SA09 → DA05
129	OH16, OH07 → SA09 → DA05
130	OH16 → DA18
131	OH11 → SA09 → DA05
132	OH11 → SA09 → SA07 → DA04
133	DA01 → DA11
135	OH19, OH17 → SA10 → DA02
136	OH20 → DA10
137	OH15, OH14, OH03 → SA02, SA03, SA04 → DA05 → SA14
138	OH16 → DA18
139	OH03 → DA13
140	OH13, OH07, OH03 → SA08 → SA13
141	OH13, OH03, OH07 → SA08 → SA02 → DA02
142	OH07 → OH12 → DA05
143	OH17, OH15, OH03, OH08 → SA01 → SA10 → SA07
144	OH15, OH14 → SA02
145	OH16 → DA04, SA07
146	OH14, OH16 → SA07
147	OH17, OH15 → DA05 → DA04
149	SA10 → DA05
150	OH07, OH03 → SA08 → SA02
151	OH07, OH03 → SA08 → SA13
152	OH16, OH14, OH15 → SA09 → DA05
153	OH16, OH14, OH15 → SA09 → DA05
154	OH02, OH01, OH07, OH03 → DA02
155	OH16, OH15 → DA02 → SA15
156	DA01 → DA05 → DA04 → SA08
157	OH13 → OH18 → DA18
158	OH20, OH18 → DA16
159	OH07, OH19 → SA12 → DA01 → DA11
160	OH20, OH03, OH01 → DA11
161	OH01, OH03 → SA06 → DA14
162	OH19, OH20 → DA15

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