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Invulnerability Analysis of Traffic Network in Tourist Attraction Under Unexpected Emergency Events Based on Cascading Failure

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ABSTRACT This study aims to analyze the cascading failure process of traffic network in tourist attraction under unexpected emergency events, and discuss the measures to improve traffic network invulnerability. For that purpose, taking tourist attraction as the research object, the topology model of traffic network in tourist attraction is established based on Space L method. After different types of emergency events are simulated as different attack strategies, we discuss the spatial and temporal distribution characteristics and evolution process of tourism emergency events. The cascading failure model of traffic network based on load-capacity is constructed, then the main factors affecting the scale of dynamic cascading failures are given and their sensitivity are analyzed. Taking the Summer Palace in Beijing as an example, the invulnerability analysis of the traffic network is carried out and the node protection strategies with different network load are proposed. The study reveals that (a) the traffic network of the Summer Palace has a typical network characteristics of small world; (b) network load, node capacity, node attack strategy, adjacent nodes relationship, load distribution rule significantly affect the scale of cascading failure of the traffic network in tourist attraction, (c) when the network load coefficient $\delta < 0.7$, the cascading failure rate (CFR) can be effectively controlled within 0.2 to avoid large-scale cascading failure; (d) the scale of cascading failure can be effectively reduced by 22.14%, 40.91%, and 63.66%, after increasing the capacity of the nodes which are the top 5%, 10%, and 20% in the ranking of CFR, respectively.

INDEX TERMS Transportation, traffic network in tourist attraction, cascading failure, load-capacity model, emergency event, attack strategy.

I. INTRODUCTION

A. BACKGROUND

With the development of social economy, people have more and more leisure time to travel. Large tourist flow has become a problem that tourist attractions (especially some famous tourist attractions) have to face. In 2018, the total number of tourists in the world reached 12.10 billion, making tourism an important indicator to measure modern living standards [1]. Large tourist flow has gradually become a common and normal phenomenon, and the imbalance between supply and demand is deepening with the acceleration of market growth. Especially during the height of tourist season, the uneven distribution of tourists in tourist attractions leads to the congestion of hot scenic spots and paths, and the low value of tourism experience [2]. Short-term highly aggregated tourist crowds caused by various tourism emergency events, such as natural disasters, traffic accidents, and tourist group accidents, not only causes the decline of tourists' satisfaction, but also induces safety accidents, which puts pressure on the management of tourist attraction [3].

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Due to large regional differences, low level of information construction and many other uncertain factors, it is difficult to ensure the travel safety of tourists [4]. There is a lot of space for improvement in service and management in response to emergency events, and the timeliness and effectiveness of the implementation of tourism safety service measures need to be strengthened [5]. For example, many tourist attractions have carried out intervention measures, such as access control diversion, time-sharing diversion, and location-specific restriction, in combination with the layout of scenic spots, the scale of tourists and the existing tourism management experience. Relevant studies show that controlling the total number of tourists in tourist attractions can reduce the possibility of emergency events occurring through various measures of diversion and flow restriction.

The occurrence of tourism emergency event has the characteristics of concealment, suddenness, linkage, complexity and persistence [6]. There were 197 safety emergency events occurred in Chinese tourist attractions in 2017 [7], which distributed in 28 provinces and cities resulted in a total of 89 deaths. Many emergency events are mainly traffic accidents and natural disasters, and the temporal distribution is significantly positively correlated with the height of tourist season. Cultural landscape tourist attractions have the highest emergency risk, followed by water scenery tourist attractions and ancient architecture tourist attractions [8]. In general, emergency events may occur in every tourist attraction, while some famous tourist attractions have higher possibilities. Its background, cause and process are very complex, which puts forward high requirements for their prevention, early warning and emergency treatment. Scholars have analyzed the occurrence, development, evolution, and extinction process of tourism emergency events, and found that the occurrence probability, evolution process and damage degree to tourist attraction are closely related to the natural environment conditions, traffic conditions, safety management level, emergency response mechanism, personnel quality and tourists' safety awareness [9].

The traffic system of large tourist attractions can be abstracted into a complex network composed of scenic spots and paths. The spatial features and geographic topological relations can be analyzed by network analysis tools based on graph theory [10]. The traffic network in tourist attraction is relative closed and stable. If some scenic spots and paths are attacked by large holiday tourist flows or damaged by sudden natural disasters, the transportation function of network will be greatly affected. Even the traffic network of entire area can be paralyzed, resulting in cascading failure [11].

Cascading failures are common in many real networks, the manifestation patterns of which are distinct in different network structure, type, load scale, attack strategies, and distribution rules. When a small number of nodes are destroyed, chain reaction can be caused and the destroyed nodes will continuously transfer the load to other nodes in the network, causing extensive network damage or even collapse [12]. For example, the Bund stampede of Shanghai in 2015. Due to the impact of holiday tourist flow on well-known scenic spots, the number of tourists exceeds the carrying capacity of some scenic spots and paths, causing excessive crowding and trampling. In 2017, some scenic spots and paths were damaged after an earthquake, which made nearly 50,000 tourists trapped in Jiuzhaigou Scenic Area.

According to the complex network theory, the above emergency events can be simulated as two kinds of attacks on the traffic network in tourist attraction [13]. One is random attack (RA), which means that the attack will occur randomly in any scenic spot. The emergency events such as natural disasters, traffic accidents and mass tourist group accidents can be regarded as RA [14]. The other is selective attack (SA), which means that the attack will occur in a particular scenic spot according to certain strategies [15]. Emergency events such as tourism safety accidents and public health accidents can be regarded as SA. Tourism is more sensitive to emergency events in the era of Internet and mass tourism [16]. If the management of tourist attraction fails to deal with the emergency events timely and the disposal is not appropriate, it will not only cause greater losses to the lives and property of tourists, but also cause serious damage to the normal order, which seriously affect the local tourism brand and image [17]. It is very important for the tourism traffic system has the ability to deal with disturbances such as large tourist flow impact and short-term highly aggregated tourist crowds, and for the management to have the ability to take measures timely to recover and improve the invulnerability of network from those adverse events. To eliminate congestion and ensure the safety of tourist attractions, many tourist attractions have carried out intervention measures considering the layout of scenic spots, the scale of tourists and the existing tourism management experience. Relevant studies show that controlling the total number of tourists in tourist attractions can play a role and reduce the possibility of emergency events occurring.

B. RESEARCH MOTIVATION

The tourists' travel is a continuous activity composed of a series of activities. People's travel behavior becomes increasingly complex, showing the diversity of demand characteristics. Safe, reliable and stable traffic network is an important guarantee for the sustainable operation and development of tourist attractions. Higher requirements for safe traffic network under tourism emergency events have been put forward. Therefore, it is of great significance to analyze the topological characteristics of the traffic network and calculate quantitatively its invulnerability under emergency events to ensure the stable operation of the traffic network in tourist attraction. The following questions are proposed:

- How to construct the traffic network in tourist attraction and evaluate its network characteristics?
- Different tourism emergency events have distinct spatiotemporal scale and evolution process, and how much is the effect of them on invulnerability of cascading failure?

- What are the main factors that affect the scale of cascading failure of traffic network in tourist attraction and their sensitivity? What measures can be taken to reduce the scale and improve the invulnerability of network?

The essence of the above problems is to capture the propagation process and influence mechanism of cascading failure of traffic network in tourist attraction under emergency events. Therefore, it is necessary to clarify the traffic network construction model, the form and space-time characteristics of tourism emergency events, and the cascading failure model and simulation of the network.

The rest of the paper is organized as follows. Section 2 summarizes relevant literature on tourism emergency events, network construction of the tourist attraction, and invulnerability of cascading failure. Section 3 proposes the model construction of this study and the concept of related topological characteristics are introduced. The evolution mechanism of the occurrence, development, evolution and extinction of tourism emergency event is described in Section 4. And Section 5 discusses and analyzes the cascading failure process, evaluation indexes and influencing factors based on the load-capacity model. In Section 6, taking the Summer Palace in Beijing as an example, data set is established by means of questionnaire survey, thermal map analysis and ArcGIS to evaluate the cascading failure of the network, and the methods to improve the invulnerability are given. Conclusions and suggestions for future research and some proposals for sustainable development of traffic network in tourist attraction are given in Section 7.

II. LITERATURE REVIEW

A. TRAFFIC NETWORK IN TOURIST ATTRACTION AND EMERGENCY EVENTS

With the rapid development of the tourism industry and the improvement of the traffic facilities in tourist attractions, the connections between the scenic spots are becoming closer, and tour routes show networking characteristics. Based on the complex network theory, the world tourism destination network, domestic tourism network, Fujian province tourism network and Huangshan city tourism network were constructed respectively in macro and medium levels [18]–[21]. The results showed that the tourism network above the provincial area has scale-free characteristics, while the tourism network of Huangshan city has small-world characteristics.

There are many studies focused on the optimization of tour routes, traffic system and tourism structure, which are feasible in application with the aid of graph theory. Hsi [22] carries out a network analysis of Nantou city's self-driving tour destinations and put forward suggestions on tourism facilities and services. Han *et al.* [23] introduced the application of graph theory in shortening time and improving satisfactions in tour routes design and constructed a simple coloring model based on design principles. Zhu and Wu [24] put forward the concept of the network space structure of the tourism system and the application of the fractal theory in the aspects of scenic spots, tour routes and tourism traffic, and conducted an empirical study on the tourism network of Beijing.

The rapid development of regional tourism industry is bound to be supported by traffic system. A reasonable layout of tourism traffic network can quickly aggregate and diverted tourist flows and improve tourism satisfactions. GIS and network analysis method were used to discuss the spatial concentration of tourism network by Sang *et al.* [25], and it was verified that the shortest distance friction factor in the spatial flow model would affect the spatial flow efficiency of tourist flow. The correlation analysis on traffic infrastructure, tourist behavior, destination attraction and tourist flow indicates that reasonable traffic network layout can effectively improve the distribution efficiency of tourist flow [26]. Claire *et al.* [27] discussed the movement mode of tourist flow based on the distance attenuation model, and found that the level of tourism traffic network has a significant impact on the tourist flow efficiency.

Tourism emergency events are divided into five categories: natural disasters, tourism accidents, safety accidents, tourist group accidents and public health accidents. Tourism emergency events have specific spatial and temporal characteristics. The origin factors are complex such as personal factors, environmental factors, facilities and equipment factors [28]. In order to systematically evaluate the potential risks in a certain region, it is important to identify the spatial and temporal distribution characteristics. The study on the temporal and spatial distribution of tourism emergency events and their influencing factors has become a hot issue concerned by scholars.

- The time factor is significantly correlated with the occurrence of tourism emergency events. The tourism emergency events usually occur more frequently during the height of tourist season.
- The impact of spatial factors on tourism emergency events is mainly reflected in regional spatial differences, types of tourism activities and tourism subjects. Studies have shown that traffic safety accidents and water recreation events account for the majority of emergency events (accounting for 20% and 41% respectively) in national parks in the United States [29].

B. INVULNERABILITY OF CASCADING FAILURE

The study of dynamic invulnerability is inseparable from cascading failure theory. Scholars have proposed the Load-Capacity (LC) model [30], Binary model [31], Coupled Mapping Lattice (CML) Model [11], and disaster spread dynamic model [32]. Many cascading failures of real traffic networks are analyzed by the load-capacity model. Some improvements have been made considering the characteristics of traffic network. For example, Wu *et al.* [33] established the cascading failure model under different removal conditions in urban traffic network. Zheng *et al.* [34] believes that traffic overload tends to increase the traffic time without damaging the structural connectivity of the network. A cascading failure model with automatic updating of the edge capacity is proposed. The sensitivity of node degree under attack conditions was simulated. Xie *et al.* [35] hold the view that the dynamic characteristics of the network have a great impact on the network's invulnerability, so it should be fully considered in the design of network element attack or protection strategies.

In addition to the construction of cascading failure model, these influencing factors, including network structures, network loads, attack strategies, evaluation indexes and other aspects are widely concerned. Bao *et al.* [36], Xia and Hill [37], Duenas and Vemuru [38], Asha and Newth [39] analyzed the effects of network load distribution, network topology, node betweenness, node capacity tolerance coefficient on cascading failure. It is found that attack strategies, travel network structure, tour choice behavior are all important influence sources of network cascading failure scale [40]. The network invulnerability decreased with the increase of load coefficient and increased with the increase of capacity [41].

C. THE MAIN CONTRIBUTION

The existing literatures provided us with tourism emergency events definition, evolution mechanism analysis, traffic network construction in tourist attraction, attack strategy formulation, and cascading failure simulation. However, there are still some aspects can be improved.

(1) There is a lack of in-depth exploration of the interaction and evolution mechanism among the forms of tourism emergency events, attack strategies and network cascading failure process.

(2) The tourism traffic networks are built mainly from the macro-level to medium-level. The failure scenarios and network attack strategies of the cascading failure of traffic network in tourist attraction need to be further discussed in micro-level. The communication carrier of crowded condition in tourism network – each scenic spot has distinct individual difference. Its attribute is not only related to network topology characteristics, but also affected by subjective indexes such as tourists' congestion perception and residence time.

(3) The traditional mathematical model of cascading failure based on load-capacity is not appropriate to describe that process of the traffic network in tourist attraction in micro-level. Different tourism demands, node capacities, node loads, failure load redistribution rules need to be further considered, to build a cascading failure model appropriate for tourism traffic network.

Therefore, it is necessary to study the traffic network construction model, the form and space-time characteristics of tourism emergency events, and the cascading failure model and simulation of the network. In light of the above demonstration, the contributions of this study is three-fold.

(1) All kinds of tourism emergency events and attack strategies were summarized and discussed, and the evolution mechanism of cascading failure in tourist attraction were analyzed and divided into four stages including occurrence, development, evolution and extinction.

(2) The graph theory is extensively applied to the network modeling of tourist attraction in micro-level based on the traffic network topological characteristics and tourists' behavior.

(3) A cascading failure model appropriate for tourism traffic network was built considering different tourism demands, node capacities, node loads, failure load redistribution rules and other factors. Some methods that can improve network's invulnerability was proposed.

The methodology is shown in Figure 1 for the above problems. This paper takes tourist attraction as the research object and builds a traffic network topology model based on Space L method [42]. The spatial and temporal distribution patterns and rules of tourism emergency events were studied, and the cascading failure model of traffic network in tourist attraction based on load-capacity is constructed. The main factors affecting the scale of network dynamic cascading failures and their sensitivities are analyzed. Taking the Summer Palace in Beijing as an example, the research on the invulnerability analysis of traffic network in tourist attraction under unexpected emergency events based on cascading failure was carried out.

The research can provide theoretical basis and data support for the identification of key nodes of the traffic network in tourist attraction, the improvement of the network cascading failure invulnerability and the tourist experience.

III. MODEL CONSTRUCTION

A. CONSTRUCTION OF TRAFFIC NETWORK IN TOURIST ATTRACTION

Scenic spots and paths are the basic elements of the traffic network in tourist attraction. The path runs through the scenic spots and has comprehensive functions of traffic, sightseeing, space division and connecting. It is of great significance to understand the essential characteristics to explore the internal topology of the network.

The traffic system of large tourist attraction can be abstracted into a network composed of scenic spots and paths. The simple assumptions are as follows.

(1) Nodes in the network include scenic spots, intersections and open spaces where high aggregated tourist crowds. Any two nodes can reach each other. The basic network can be abstracted into a closed undirected network.

(2) The link is abstracted as a straight line and the length is expressed by distance measured on the map.

Based on Space L method, the network established in this paper is $G = (N,P)$, where $N(G) = \{1, 2, 3, \ldots, N\}$, N is the set of nodes and $|N|$ is the total number of nodes in the network. $P(G) = \left\{p_{ij} \middle| v_i, v_j \in V(G), i, j \in N\right\}$, P is the

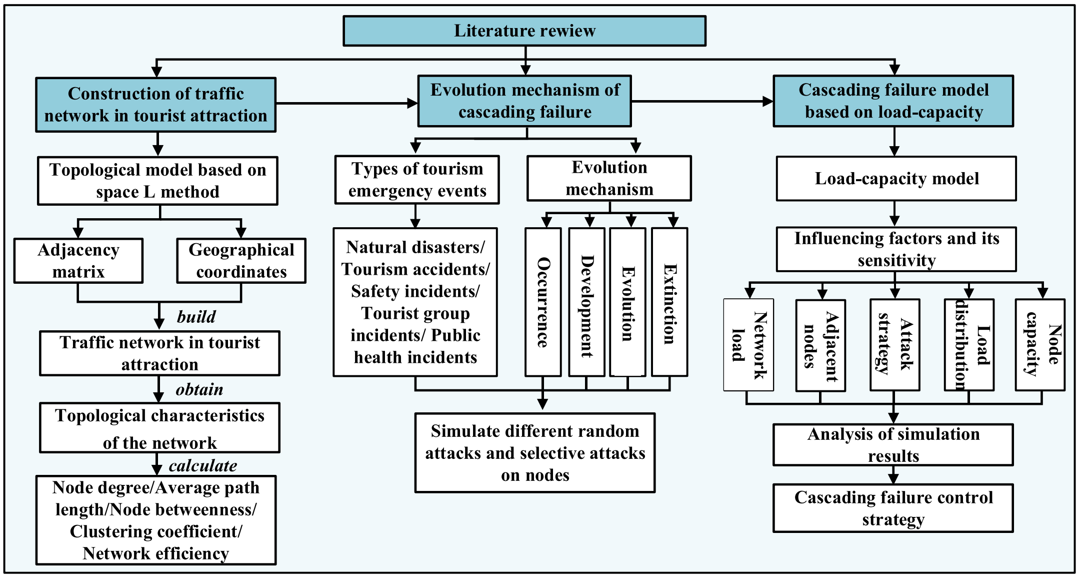

FIGURE 1. Overview of methodological framework.

set of edges in the network. The data of network topology structure is displayed in the form of adjacency matrix.

B. TOPOLOGICAL CHARACTERISTICS OF THE NETWORK

It is necessary to find some geometric quantities that can effectively describe its structural characteristics. There are some commonly used statistical indicators including: node degree values, average path length, node betweenness, clustering coefficient, and network efficiency (Eqs.(1)-(6)). These indicators can describe the structural characteristics of different aspects of complex networks, and can comprehensively represent the inherent characteristics.

$$k_i = \sum\nolimits_{j \in N} a_{ij}, \tag{1}$$

$$L = \frac{2}{|N|(|\mathrm{N}|-1)} \sum\nolimits_{i \geq j} d_{ij}, \tag{2}$$

$$B_i = \sum\nolimits_{k,j \in N, k \neq j} \frac{n_{kj}(\mathrm{i})}{n_{kj}}, \tag{3}$$

$$C_i = \frac{\mathrm{E}_i}{\mathrm{C}_{\mathrm{k}_i}^2} = \frac{2\mathrm{E}_i}{\mathrm{k}_i(\mathrm{k}_i-1)}, \tag{4}$$

$$C = \frac{1}{|\mathrm{N}|} \sum\nolimits_{I=1}^{N} C_I = \frac{1}{|\mathrm{N}|} \sum\nolimits_{I=1}^{|N|} \frac{2\mathrm{E_i}}{\mathrm{N}_i(\mathrm{N}_i-1)}, \tag{5}$$

$$E = \frac{1}{|N|(|\mathrm{N}|-1)} \sum\nolimits_{I \geq J}^{|N|} \frac{1}{d_{ij}}, \tag{6}$$

where a_{ij} represents adjacency matrix of the network; if there is a direct edge between node i and node j, $a_{ij} = 1$, otherwise, $a_{ij} = 0$; $|N|$ is the number of nodes in the network; d_{ij} is the shortest link between v_i and v_j; n_{kj} is the number of all shortest links between v_k and v_j, and $n_{kj}(i)$ the number of shortest links passing through v_i between v_k and v_j.

IV. EVOLUTION PROCESS OF CASCADING FAILURE

A. EVOLUTION MECHANISM UNDER EMERGENCY EVENTS

Based on the Crisis and Disaster Stage Theory [43], [44], the cascading failure process of tourism emergency events has a unique evolutionary rule in four different stages: occurrence, development, evolution and extinction, as shown in Figure 2.

- Occurrence stage. Due to the interaction of different types and intensities of factors, the hazard sources of tourism emergency events are formed [45]. Emergency events occur at certain nodes, and the nodes fail after malignant development to a certain extent.
- Development stage. The load of failure node is transferred to the adjacent nodes since the source isn't effectively controlled. Under the action of internal and external factors, the emergency event continues to develop, causing greater damage or loss to the tourist attraction, and even cascading failure occurs.
- Evolution stage. As the number of failure nodes increases, cascading failure evolves further in terms of spatial scope and intensity, mainly including four forms: propagation, transformation, derivation and coupling.
- Extinction stage. The diffusion power of cascading failure gradually declines under the influence of external environment and manual intervention. Cascading failures is under control and the propagation is stopped.

B. PROPAGATION PROCEDURE OF CASCADING FAILURE

The transfer of failure loads in the network is based on the connection between nodes [46], [47]. According to existing literature, propagation procedure of cascading failure is shown as the following four stages.

(1) Normal stage. Tourist is loaded on each node optionally and the number of tourists for each node does not exceed

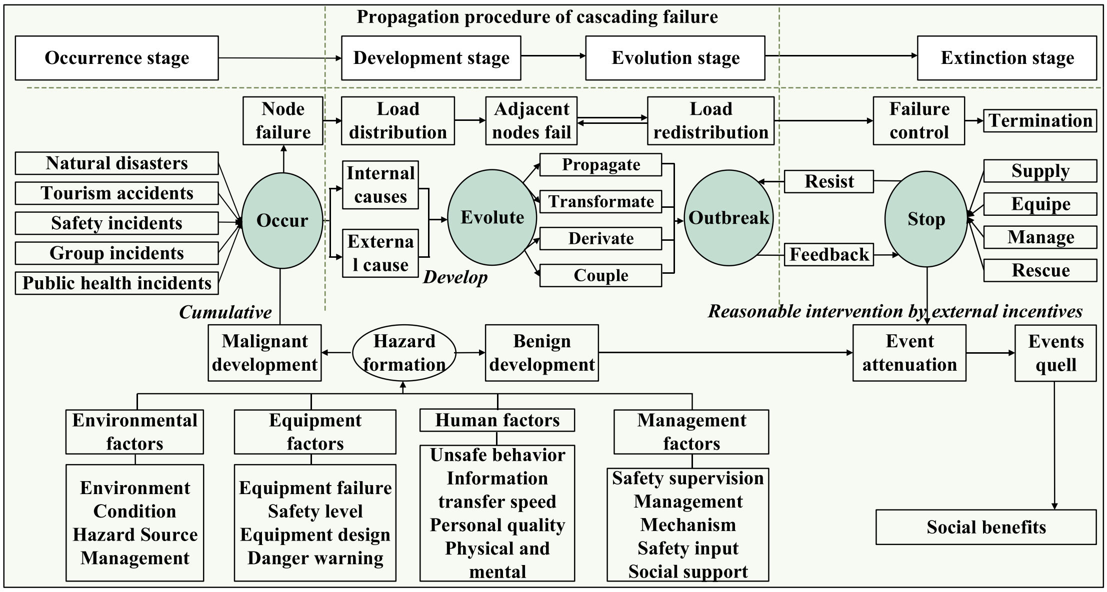

FIGURE 2. Evolution mechanism of cascading failure of emergency events in tourist attractions.

its maximum capacity before the nodes are attacked. The network runs normally as shown in Figure 3(a).

(2) Attack node.

The load on each node exceeds its maximum capacity after a node attacked. The original connectivity and traffic function cannot be maintained, and the node fails as shown in Figure 3(b).

(3) Cascading failure propagation

Assuming that the initial load of failure node v_i is L_i and the load capacity is C_i, when v_i fails, the load on v_i transfer to adjacent nodes v_{b1}, v_{b2}, v_{b3}, which will cause load pressure on adjacent nodes as shown in Figure 3(c)(Occurrence stage). If the adjacent node such as v_{b3}, the load on v_{b3} does not exceed its maximum capacity limit. That is $\Delta L_{i\to b3} + L_{b3} < C_{b3}$, then the node remains in a ''normal'' state, where $\Delta L_{i\to j}$ is the failure load assigned to adjacent node v_j. Conversely, the node fails when $\Delta L_{i\to b3} + L_{b3} > C_{b3}$, as shown in Figure 3(d)(Development stage). Due to the propagation and diffusion mechanism of cascading failure, the failure node carries out the redistribution process of new tourist load, as shown in Figure 3(e) (Evolution stage).

(4) Cascading failure termination.

All nodes in the network fail, called cascading collapse state. Or the network rebalancing causes its ability of evacuation and the small propagation range. Cascading failure propagation of the network is terminated in both cases, as shown in Figure 3(f).

V. CASCADING FAILURE MODEL BASED ON LOAD-CAPACITY

In the application of load-capacity model, scholars have made different algorithms in cascading failure model based on the actual research network. There are some comparisons to the basic definitions in the algorithms of cascading failure as follows.

Previous definitions of network node load can be divided into the following categories. (a) All nodes in the network bear the same load. This is quite different from the actual network load and less practicability. (b) It is defined as node betweenness. This definition method is reasonable but has high computational complexity. (c) It is defined as the function of node degree. This definition is more reasonable and the calculation is simpler than (b). (d) It is defined as the product of the value of node degree and the value of adjacent node degree.

Secondly, there are several definitions of node capacity. (a) It is subject to a certain statistical distribution, which is quite different from most networks in reality. (b) It is proportional to the initial load of nodes, and this definition is widely adopted. (c) There is a non-linear relationship between node capacity and initial load of nodes, and this definition method considers that some nodes with small capacity in the network tend to have large remaining capacity.

Finally, there are four main methods for load redistribution after node failure. (a) The load on the failure node is evenly redistributed to adjacent nodes. (b) Redistribute according to the shortest path in the network. (c) Redistribute the load of the failure node according to a certain local preferential probability. (d) Redistribute according to the remaining capacities of the adjacent nodes, which is practical to a certain extent.

A. MODEL VARIABLES DEFINITION

The capacity of most existing systems of traffic network is considered as a constant. Effective load redistribution strategy can improve the ability to resist cascading failure without

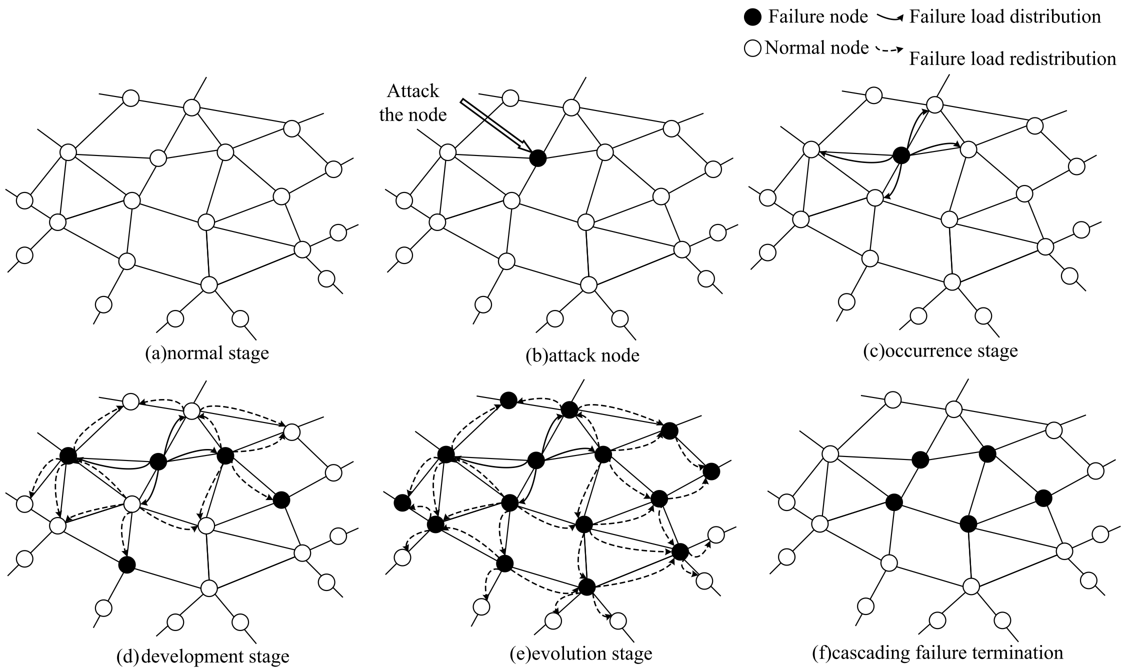

FIGURE 3. Propagation procedure of cascading failure.

changing the physical characteristics of the existing network. Before making the rules, the definition of the capacity and load of nodes should be given firstly.

1) NODE CAPACITY

Tourist attractions have a limited capacity of tourists. Node capacity is the maximum number of tourists as shown in Eq.(7):

$$C_i = \frac{\sum X_i}{Y_i}, \tag{7}$$

where X_i: effective accessible area of the i^{th}scenic spot; Y_i: basic space standard for the tourist unit area of the i^{th} scenic spot.

2) NODE LOAD

The number of tourists of v_i at time t is taken as node load L_i(t), and all nodes maintain normal state at initial time. That is, $L_i(0) = \delta C_i$, and $0 \leq \delta \leq 1$, δ is the load coefficient of the node.

B. TRAFFIC REDISTRIBUTION RULES FOR FAILURE NODES

Therefore, according to the node capacity and initial load defined in the previous section, the load of failure node v_i will be transferred to adjacent node v_j according to the proportion function P_j in Eq.(8) (solid arrow in Figure 4).

$$P_j = \frac{[C_j - L_j(\mathrm{t})]d_{ij}}{\sum_{v_n \in \Gamma_i} [C_n - L_n(\mathrm{t})]d_{in}} \tag{8}$$

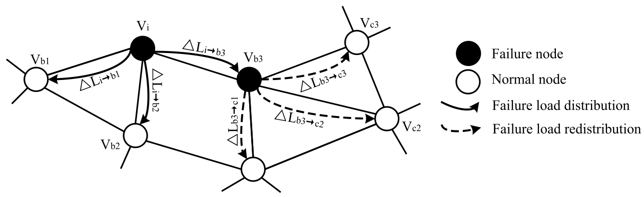

FIGURE 4. Load redistribution process after a node failed.

Based on failure redistribution rules, any adjacent node v_j gets the failure load $\Delta L_{i\to j}$ as shown in Eq.(9).

$$\Delta L_{i\to j} = L_i P_j \tag{9}$$

A failure propagation function is defined to describe the dynamic propagation mechanism, as shown in Eq.(10).

$$L_j(\mathrm{t}+1) = L_j(\mathrm{t}) + L_i \frac{[C_j - L_j(\mathrm{t})]d_{ij}}{\sum_{v_n \in \Gamma_i} [C_n - L_n(\mathrm{t})]d_{in}} > C_j \tag{10}$$

If Eq.(10) can be satisfied, a new redistribution of the failure load will be triggered (dotted arrow in Figure 4).

C. EVALUATION INDEX AND ALGORITHM

The effect on cascading failure of the network is measured uniformly by the evaluation index of Cascading Failure Rate (CFR), as shown in Eq.(11).

$$\mathrm{CFR} = \sum_{v_i \in V} CFR_i / |\mathrm{N}|(|N| - 1), \tag{11}$$

where CFR_i is the number of failure nodes caused by v_i, which satisfies $0 \leq CFR_i \leq |\mathrm{N}| - 1$.

The algorithm is designed as follows and as shown in Figure 5.

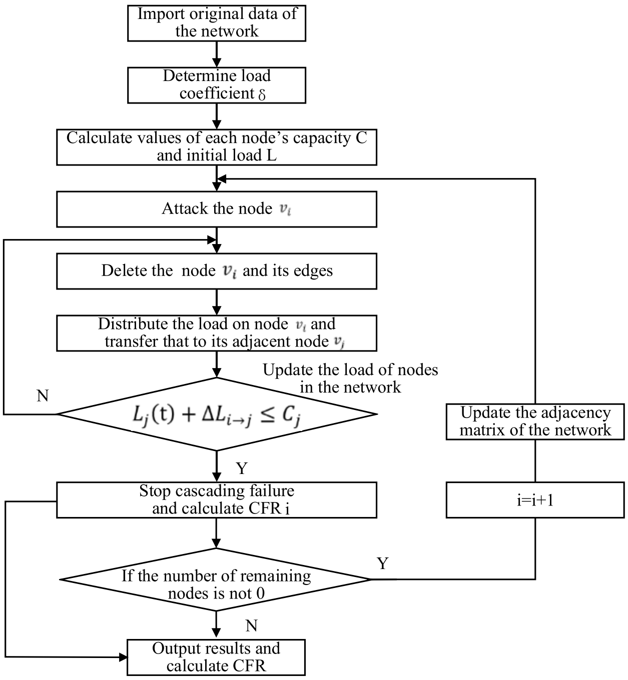

FIGURE 5. Simulation process of cascading failure model based on load-capacity.

Step 0: Import the adjacency matrix and original data of the network.

Step 1: Determine values of each node's capacity C and initial load L. All nodes maintain normal state at first.

Step 2: Attack the i^{th} scenic spot (node v_i), $i = 1, 2, \ldots$, N.

Step 3: Find the adjacent nodes of the failure node v_i, and delete node v_i and its edges.

Step 4: Distribute the load on failure node v_i according to the redistribution rule and proportion P_j.

Step 5: Update the load of nodes in the network. Determine the load condition of each adjacent node. If the node load exceeds the node capacity, $L_j(t+1) = L_j(t) + \Delta L_{i\to j} > C_j$, the node fails and goes to *Step 4*; If the loads of all adjacent nodes do not exceed their capacities, go to *Step 6*.

Step 6: Stop cascading failure and calculate the number of failure nodes in the network (CFR_i).

Step 7: If the number of remaining nodes in the network is 0, the loop ends; otherwise, update the adjacency matrix and go to *Step 3*.

Step 8: Output results and calculate the cascading failure rate CFR.

D. ANALYSIS OF INFLUENCING FACTORS

According to variables definition and cascading failure process of the model, the main factors include: network load, attack strategy, node load, failure load distribution rules, and node capacity.

The research scheme will be designed from five aspects in this section. The sensitivities of different network loads, attack strategies and initial node loads to the cascading failure process are analyzed, and the relationship between changing the load distribution rules and increasing node capacity to improve the invulnerability is discussed. Simulation experiments are carried out with the help of Eclipse integrated development environment.

- Simulation of different network load on cascading failure. That is to discuss the sensitivity of changing the load coefficient value ($\delta = 0.1, 0.2 \ldots, 1.0$) to network cascading failures.
- Simulation of different attack strategies on cascading failure.

The four types of node attack strategies, random attack (RA), and selective attack including Initial Degree (ID), Congestion Degree (CD), and Hot Degree (HD) are applied to simulate various emergency events that may happen to traffic networks in tourist attractions. One node is randomly removed, removed with the highest node degree, the congestion perception of tourists, and the degree of heat based on the different ways of attack. The number of failure nodes CFR_i caused by this node will be calculated, and then the average cascading failure rate CFR will be calculated under different network load until 20% of the nodes are selected.

- Simulation of adjacent nodes on cascading failure

The research on invulnerability of network under different coupling parameter α values, is to discuss the sensitivity of failure nodes' self-load to cascading failure, considering the influence of adjacent nodes. At this time, the initial load of any node v_i is shown in Eq.(12).

$$L_i^{'(t)} = \begin{cases} \alpha L_i(0) + (1-\alpha)\dfrac{\sum_{v_j\in\Gamma_i} L_j(0)}{k_i}, & L_i'(t) < C_i \\ C_i - 1, & L_i'(t) \ge C_i, \end{cases} \qquad (12)$$

where k_i is the degree of any node v_i. Γ_i is the set of adjacent nodes of nodes $v_i.\alpha = 0.5, 0.6, 0.7, 0.8, 0.9, 1.0$, $v_i, v_j \in$ V (G). Parameter α is used to adjust the influence weight of node v_i on its own load, and 1-α adjusts the influence degree of adjacent nodes on its load accordingly.

- Simulation of redistribution rules on cascading failure

Under the influence of adjacent nodes, failure loads were calculated according to Eq.(9) based on node residual capacity and Eq.(14) based on node capacity respectively. The influence of different redistribution rules on cascading failure of the network are compared.

$$\Delta L'_{i\to j} = L_i \frac{C_j d_{ij}}{\sum_{v_n\in\Gamma_i} C_n d_{in}}. \qquad (13)$$

- Simulation of increasing node capacity on cascading failure

C_i' is the node capacity after the capacitance increase, coefficient of capacity expansion $\beta = 0.1, 0.2, 0.3, \ldots, 1.0$, as shown in Eq.(14), the influence of coefficient of capacity expansion β on the improvement of cascading failure invulnerability under different load coefficients ($\delta = 0.2, 0.4, 0.6, 0.8$) are discussed.

$$C_i' = (1+\beta)L_i(0), \quad \beta \ge 0. \qquad (14)$$

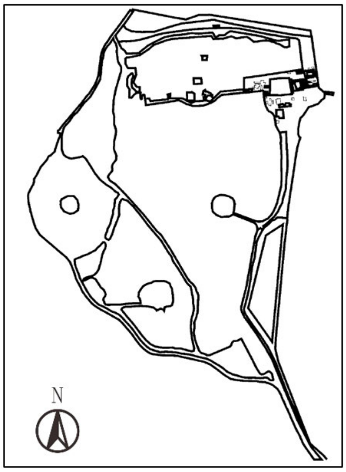

FIGURE 6. The Summer Palace.

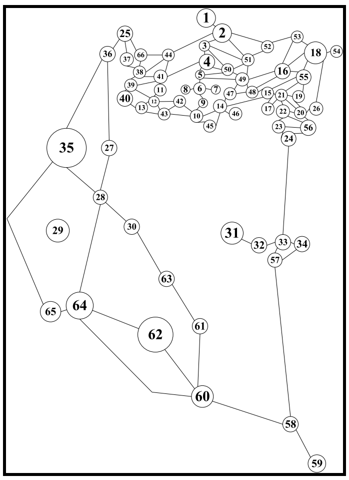

FIGURE 7. Topological graph of traffic network in Summer Palace.

VI. CASE STUDY

A. DATA DESCRIPTION

Located in the western suburbs of Beijing, Figure 6 shows the Summer Palace is a 5A level tourist attraction covering an area of 290.13 ha. It has high popularity with a wide range of tourists, and natural, humanistic, religious attributes.

The traffic network of the Summer Palace is constructed based on Space L method as shown in Figure 7. Based on ArcGIS and survey data, the capacity C_i of each node can be calculated according to Eq.(8). The maximum instantaneous capacity of the Summer Palace is 80,000 people.

Based on ArcGIS, questionnaires, and Baidu thermal map, the data set is established. The spatial geographic information of scenic spots, tourist experience data, and heat change are obtained.

B. TOURISM EXPERIENCE SURVEY

The research team has conducted a continuous survey on the tourist routes and congestion perceptions in the Summer Palace since 2013. Figure 8 shows the congestion perception of tourists in each scenic spot. Tourist congestion

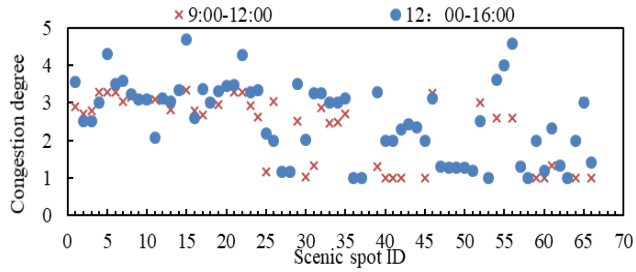

FIGURE 8. Tourist congestion perception of each scenic spot.

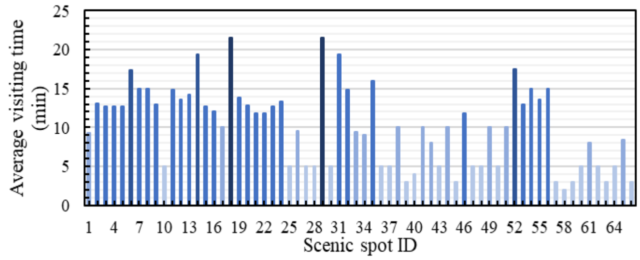

FIGURE 9. Tourists' average visiting time.

TABLE 1. Thermal map classification of scenic spot.

Color	Sample	Hot value	Heat region	Implication	Population density
Purple		1	Low heat region	Sparsely populated	<5 per·hm-2
Blue		2		Very comfortable	5-10 per·hm-2
Green		3	Heat region	Comfortable	10-20 per·hm-2
Yellow		4		General	20-40 per·hm-2
Orange		5	High heat region	Crowded	40-60 per·hm-2
Red		6		Very crowded	>60 per·hm-2

perception of each scenic spot was obtained by on-site survey in June 21-22, 2016, and congestion degree 5 means the scenic spot is very crowded while 1 means not crowded.

Average congestion perception degree of tourists in the afternoon (12:00-16:00) is 2.56, which is significantly higher than that (average congestion is 2.20) in the morning in Figure 8. The tourist congestion perception in Wenchang courtyard (scenic spot NO.56) increases the most, from 2.59 to 4.59 with a growth rate of 77.22%, while there was no difference in 22 scenic spots, such as the Long corridor (scenic spot NO.14) and Renshou temple (scenic spot NO.20).

The tourists' average visiting time and distribution in each scenic spot are shown in Figure 9, which shows tourists spend up to 15 minutes at 92% of the scenic spots in the Summer Palace. The average visiting time is 11-15 minutes.

C. THERMAL MAP OF THE SUMMER PALACE

The distribution characteristics of tourists' activities in each scenic spot were analyzed based on Baidu thermal map. Referring to the official legend [48], color value and brightness jointly represent the population and hot value as shown in Table 1.

Figure 10 shows part of the thermal map of the Summer Palace during the opening hours (7:00-19:00) on October 1, 2018 (The first day of National Day holidays, sunny day).

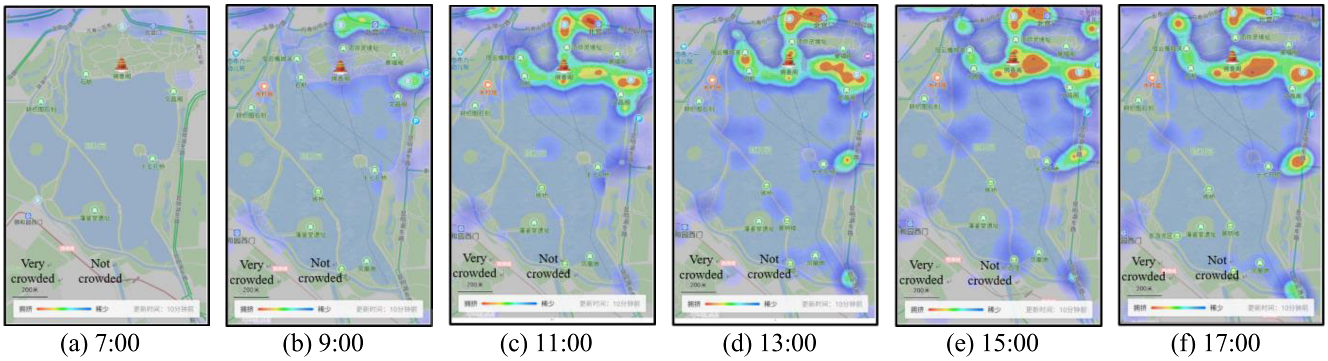

FIGURE 10. Thermal map of Summer Palace in Beijing (source: Baidu thermal map).

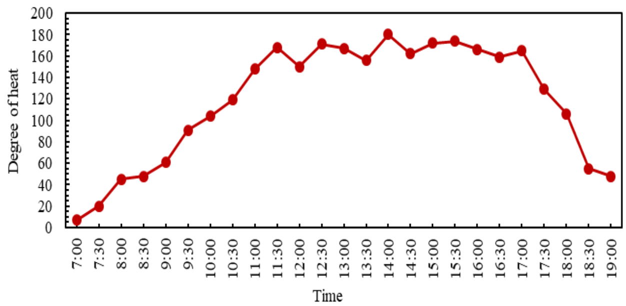

FIGURE 11. Degree of heat in the Summer Palace at different times (7:00-19:00).

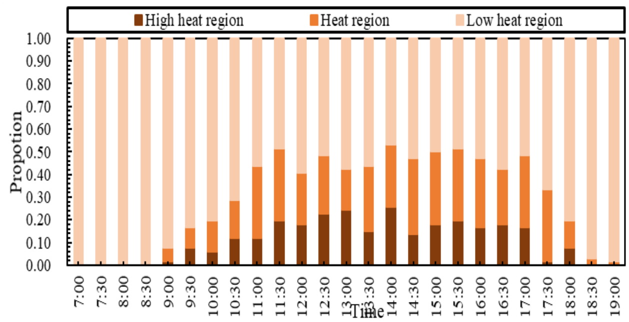

FIGURE 12. Heat region of the Summer Palace at different times (7:00-19:00).

In ArcGIS, the grid calculator is used to calculate the average degree of heat at each time of the day. Thus, it depicts the spatial and temporal trajectory and aggregation trend of tourist flow inside the Summer Palace during holidays:

$$\bar{H} = \sum H_T/25, \tag{15}$$

where $\bar{H}$ is the average degree of heat during the opening hours of the Summer Palace; H_T is the degree of heat at time T, T = 7:00, 7:30, 8:00, ..., 19:00.

The spatial distribution of the heat region is unbalanced. High heat region is highly concentrated in the vicinity of Beigong Gate, Wanshou Mountain and Donggong Gate. The schedule of tourist arrivals shows clear volatility. High heat region rises sharply from 7:00 to 11:00 as shown in Figure 11. It reaches a peak at 11:30 and forms a stable period of about 5.5h to 17:00, after which a significant decline occurs. The proportion of high heat region is different from that of heat region in Figure 12, indicating there are relatively limited places for tourists to gather in the Summer Palace.

D. TOPOLOGICAL CHARACTERISTICS OF THE SUMMER PALACE

The small world nature means that the network has topological features [49] as shown by the Eqs.(16)-(17). Based on the Dijskra algorithm, the topological characteristics of the Summer Palace network are calculated as follows.

$$C \gg C_{rand} \sim < k > /N \tag{16}$$

$$L \gg L_{rand} \sim lnN/\ln < k > \tag{17}$$

TABLE 2. Calculation results of the topological characteristics of the network.

Network characteristics	Results
Node degree <k>	3.2576
Average path length <L>	5.8346
Node betweeness <B>	0.0151
Node clustering coefficient <C>	0.5178
Network efficiency < E >	0.2423
Average path length corresponding to random network $<L_{rand}>$	3.547576
Average clustering coefficient corresponding to random network $<C_{rand}>$	0.049357

The Table 2 shows the average node degree value of the network is 3.258, indicating that each scenic spot in the Summer Palace is connected to 3-4 scenic spots on average. The clustering coefficients of nodes in the network are distributed between 0.256 and 1. The average is 0.5178, which is much larger than that of the corresponding random network and shows the network has close connectivity. It can be seen that there is a linear positive correlation between the node degree value and node betweenness as shown in Figure 13. The distance between two nodes is the number of edges connecting the shortest links of them in Figure 14. The smaller the distance, the tighter the network. The average path length of the network is 5.8346, and about 81.9% of nodes can reach any other node by 2-9 links. The statistical results show that the Summer Palace network has typical small world network

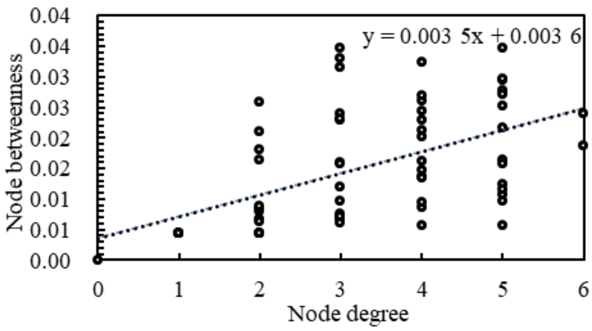

FIGURE 13. Relationship between node degree and betweenness.

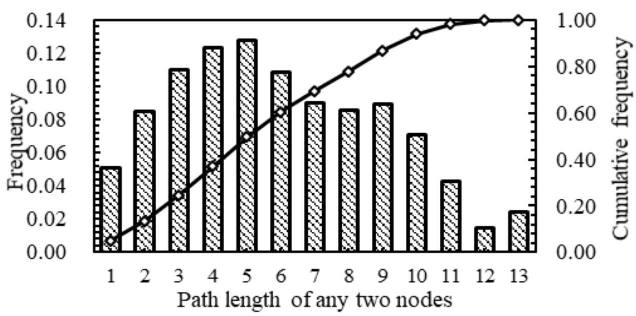

FIGURE 14. Distribution of the path length.

characteristics for its small average path length and large clustering coefficient.

E. CASCADING FAILURE INVULNERABILITY ASSESSMENT FOR THE SUMMER PALACE

The sensitivity of different network loads, attack strategies and initial node loads to the cascading failure process will be analyzed, and the relationship between changing the load distribution rules and increasing node capacity to improve the invulnerability will be discussed in this chapter.

1) SENSITIVE ANALYSIS OF DIFFERENT NETWORK LOAD ON CASCADING FAILURE

The cascading failure simulation results of the Summer Palace under different network loads are shown in Figure 15. When the load coefficient δ is 1, there will be about 80,000 tourists in the Summer Palace. Some conclusions can be obtained as follows.

- With the increase of the load coefficient δ, the cascading failure rate CFR increases gradually, and their relation can be fitted as an exponential function with the fitting degree of 0.9764.
- The first derivative is calculated for the simulation results, and it is found that CF increased the most by 109% when the load coefficient δ increases from 0.7 to 0.8.

Therefore, measures should be taken to control the number of tourists before reaching 70% of the capacity, which can directly avoid large-scale cascading failure.

According to the results in Figure 15, the number of failure node caused by node attack is ranked in Figure 16, which

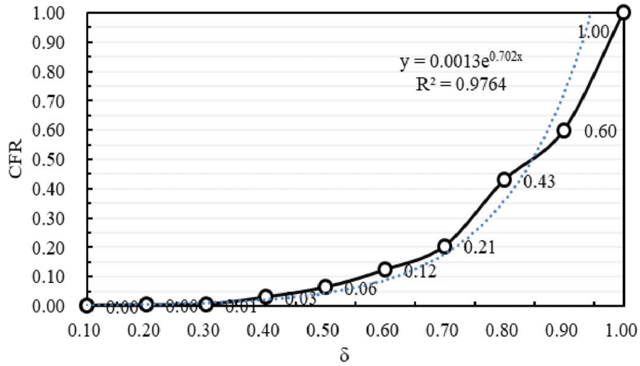

FIGURE 15. Effect of different load coefficient cascading failure.

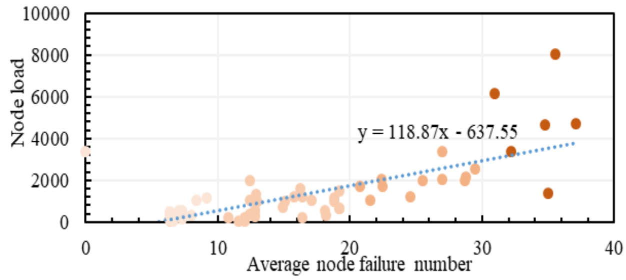

FIGURE 16. Relationship between average node failure number and the load of nodes.

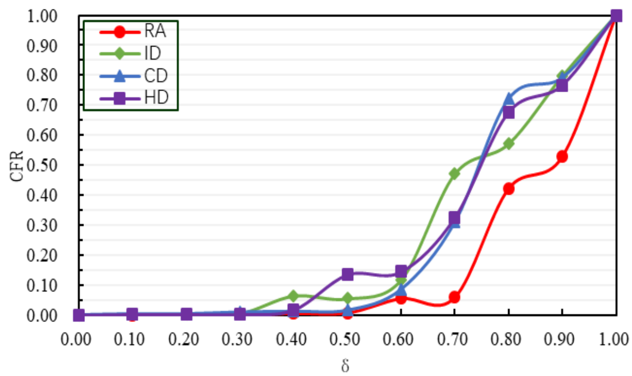

FIGURE 17. Effect of different attack strategies on cascading failure of tourist attractions.

shows the number is positively correlated with the node load within a certain range.

2) SENSITIVE ANALYSIS OF DIFFERENT NODE ATTACK STRATEGIES ON CASCADING FAILURE

The simulation results of the network under four types of node attack strategies, random attack (RA), and selective attack including Initial Degree (ID), Congestion Degree (CD), and Hot Degree (HD) are shown in Figure 17.

- When $\delta \leq 0.3$, CFR ≤ 0.01 which shows no matter what kind of attack strategy, it has little effect on the cascading failure of the network.
- While $\delta = 1.0$ (node load reaches node capacity), CFR $= 1.0$. Any failure node will result in all nodes fail and the network breakdown.

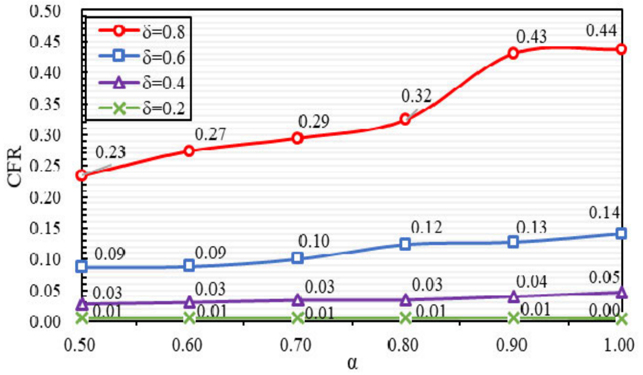

FIGURE 18. Effect of different coefficient α on cascading failure of tourist attractions.

- The CFR caused by selective attack (ID/CD/HD) is higher than that of random attack (RA), which indicates invulnerability of the network under random attack is higher than that under selective attack in tourist attraction.

When $\delta \in [0, 0.4] \cup [0.6, 1.0]$, the trend of curve CD is consistent with that of curve HD. The difference value of node failure efficiency under different loads is less than 0.06. It indicates that the network cascading failure results obtained by these two attack strategies are similar, and the node importance is parallel based on tourists' congestion perception survey and Baidu thermal map.

3) SENSITIVE ANALYSIS OF ADJACENT NODES ON CASCADING FAILURE

Considering the influence of adjacent nodes on the initial load of nodes, the cascading failure simulation results of the network under different values of parameter $\alpha(\alpha = 0.5, 0.6, 0.7, 0.8, 0.9, 1.0)$ are shown in Figure 18.

- When the network load coefficient δ is 0.2, 0.4, and 0.6, the curve fluctuates little and the parameter α has little influence on the cascading failure rate CFR.
- When $\delta = 0.8$, as parameter α increases from 0.5 to 1.0, CFR increases from 0.23 to 0.44, increasing by 91.30% in the network.

As the initial load of the node is less affected by the adjacent node, that is the degree of connection between failure node and its adjacent nodes decreases, which will have a significant negative impact on cascading failure scale.

F. METHODS TO IMPROVE THE NETWORK INVULNERABILITY OF CASCADING FAILURE

In order to prevent and control the happen and development of cascading failures, it is necessary to accelerate the construction of intelligent tourist attraction, release information to change the rules of load distribution, tap the potential capacity of scenic spots and protect some nodes.

1) METHOD 1: CHANGE THE LOAD REDISTRIBUTION RULES

Comparing the effects of different failure load redistribution rules (Eq.(9) and Eq.(13) on cascading failure invulnerability of networks, the results are shown in Figure 19. G(A) and G(B) represent the results of allocation according to the remaining capacity or the capacity of nodes.

- G(A) and G(B) increase monotonously. The influence of adjacent nodes on the initial load of nodes becomes smaller with the increase of parameter α, and closer of the two approaches.
- Whatever α is, there is always G(A) < G(B). It shows that the allocation according to the remaining capacity of the node can reasonably utilize the capacity of the node and avoid more failure nodes.
- When $\delta \leq 0.5$, the difference between G(A) and G(B) is less than 0.05. After $\delta > 0.5$, the difference of cascading failure scale between the two groups began to increase significantly. For example, when $\alpha = 0.50$, $\delta = 0.8$, the cascading failure rate of G(A) is 0.234, which is about 74.7% lower than that of G(B) distributed by node capacity (CFR = 0.570).

2) METHOD 2: PROTECT NODES AND INCREASE THEIR CAPACITIES

a: INCREASE THE CAPACITIES OF ALL NODES

The cascading failure simulation results of the Summer Palace in different coefficient β ($\beta = 0.1, 0.2, 0.3\ldots, 1.0$) are shown in Figure 20, after improving the capacity of all nodes.

- With the increase of coefficient β, the node capacity improves and the cascading failure rate CFR decreases, indicating that can effectively reduce the damage degree of the whole network.
- When $\delta = 0.4$, CFR ≤ 0.04, which shows increasing the capacity of all nodes does not make much sense for improving invulnerability of the network;
- When $\delta = 0.6, 0.8, 1.0$, the initial values of 0.124,0.429 and 1.0 are all significantly lower than 0.1 after increasing node capacity. The decrease speed increases with the increase of the network load coefficient δ. For example, $CFR_{(\delta=0.6,\beta=0.1)} = 0.092$, $CFR_{(\delta=0.8,\beta=0.5)} = 0.089$, $CFR_{(\delta=1.0,\beta=0.9)} = 0.076$.

b: INCREASE THE CAPACITIES OF KEY NODES

Due to the construction cost of the traffic network in tourist attraction, the β value cannot be arbitrarily increased, and it is impossible to arbitrarily expand the capacity of all nodes. It is practicable to implement specific protection for key nodes to save the construction cost. Therefore, the key threshold that makes the network reach the best invulnerability and the least total cost in the case of cascading failure, has become the measurement index that we pursue.

The capacities of the top 5%, 10%, and 20% nodes in Figure 17 are increased respectively. The experimental statistical results are shown in Figure 21, while $\beta = 0.2, 0.4, 0.6, 0.8$.

G(A0), G(A5), G(A10) and G(A20) represent unprotected network, 5% protected network (3 nodes), 10% protected network (6 nodes), and 20% protected network (12 nodes) respectively.

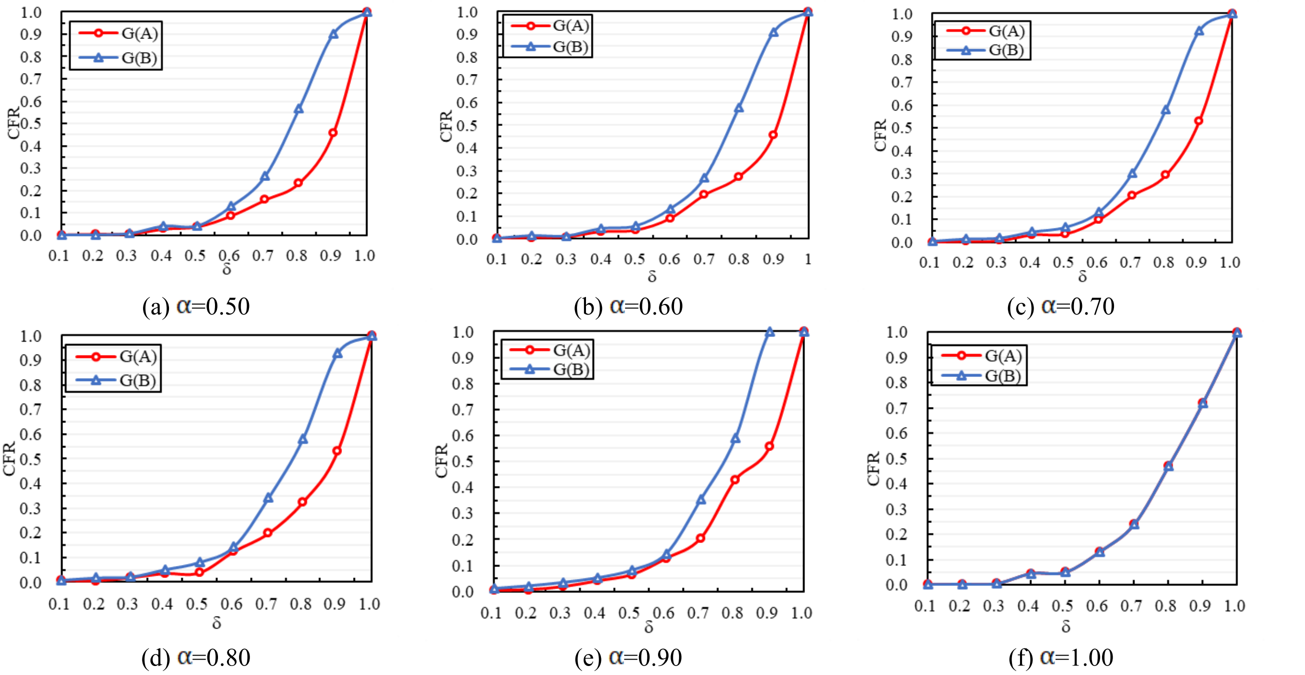

FIGURE 19. Effect of different load redistribution strategies on cascading failure.

TABLE 3. Effect on node protection enforcement strategy.

Coefficient δ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Number of tourists (ten thousand)	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0
Node protection rate(%)	-	-	-	-	-	5	10	20	20	20
Coefficient β	-	-	-	-	-	0.2	0.4	0.6	0.6	0.8
CFR_{before}	0.003	0.004	0.006	0.031	0.064	0.124	0.205	0.429	0.600	1.000
CFR_{after}	-	-	-	-	-	0.096	0.121	0.170	0.257	0.363
$\frac{CFR_{before} - CFR_{after})}{CFR_{before}}$	-	-	-	-	-	22.140	40.910	60.410	57.230	63.660

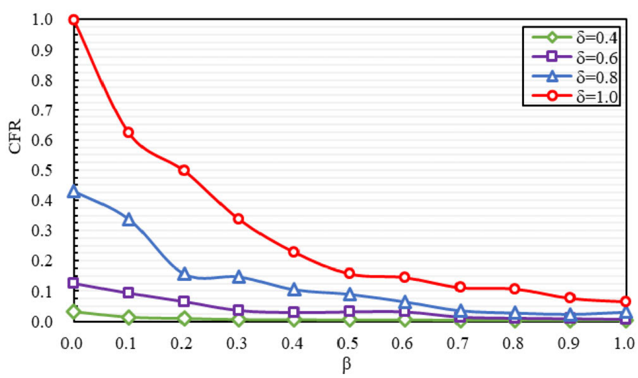

FIGURE 20. Effect of increasing node capacity on cascading failure of tourist attractions.

• When $\delta \leq 0.5$, CF ≤ 0.1, no matter how much β value increases and how many nodes are protected, CFR decreases from 0.064 to 0.022 at most. There is no need to increase the capacities of key nodes;

• With the increase in δ value and β value, CFR shows a large gap, and it makes more sense to improve some capacities of key nodes. When $\delta = 0.8$, $\beta = 0.6$, the cascading failure rates decrease from 0.429 to 0.392, 0.292, and 0.170 respectively, compared with the unprotected network when protecting 5%, 10%, and 20% nodes. It indicates that the application of specific protection to key nodes of the network can significantly reduce the cascading failure rate and improve the cascading failure invulnerability of the network.

The first derivative of each point in Figure 21 is calculated to give the strategy implementation effect under different number of tourists in the Summer Palace, as shown in Table 3. The cascading failure scale can be effectively reduced by 22.14%, 40.91%, and 63.66% after increasing the capacities of the top 5%, 10%, and 20% nodes respectively.

• When $\delta \leq 0.5$, the protection of key nodes will not be implemented until the number of tourists in tourist attraction reaches 50% of the node capacity;

• When $0.5 < \delta \leq 0.6$, it means the number of tourists in tourist attraction reaches between 50% and 60% of the node capacity. The cascading failure rate decreases to 9.6% by making the capacities of top 5% nodes increase 0.2 times ($\beta = 0.2$);

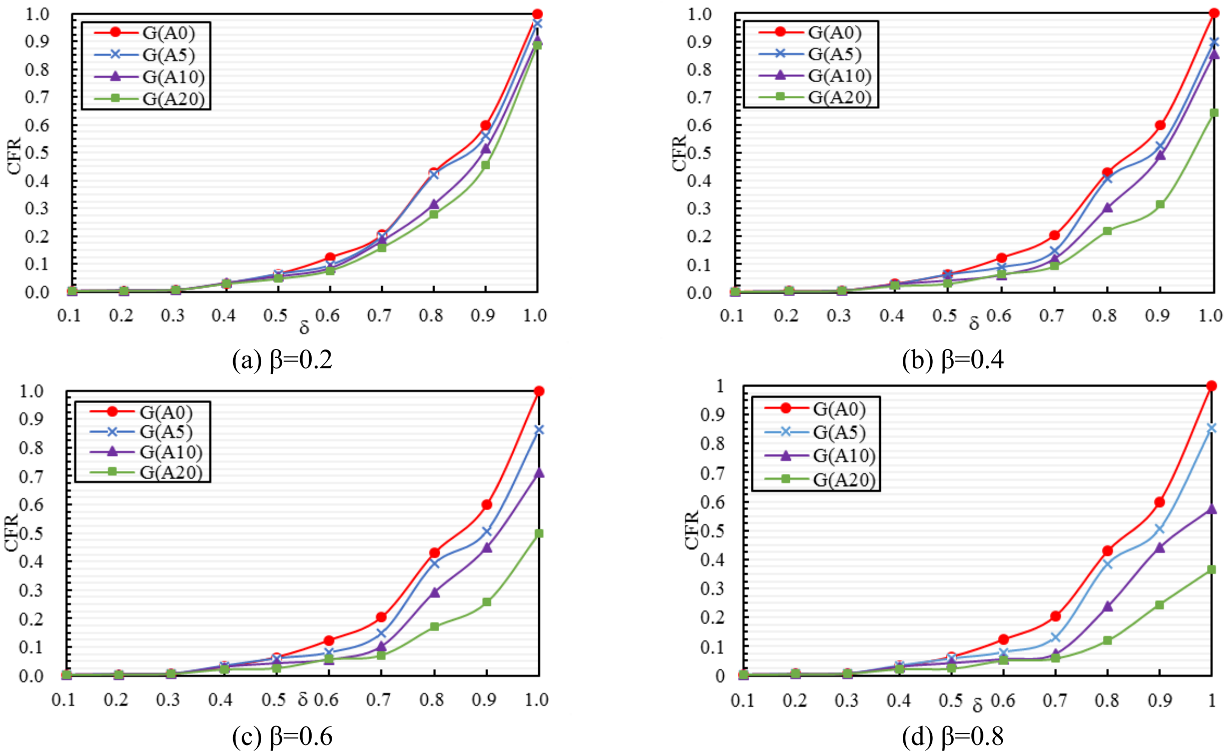

FIGURE 21. Cascading failure resistance of networks under different node protection strategies.

- When $0.6 < \delta < 0.8$, it means the number of tourists in tourist attraction reaches between 60% and 80% of the node capacity. CFR decreases by 40.91% making the capacities of top 10% nodes increase 0.4 times ($\beta = 0.4$);
- When $0.8 \leq \delta \leq 1.0$, it means the number of tourists in tourist attraction reaches between 80% and 100% of the bearing capacity. The node failure rate decreases by 60.410% making the capacities of top 20% nodes increase 0.6 or 0.8 times ($\beta = 0.6$ or $\beta = 0.8$);

VII. DISCUSSIONS AND CONCLUSIONS

To ensure the balanced spatio-temporal distribution of tourists in the tourist attraction, prevent and control the occurrence of cascading failure, and ensure the safe, sustainable and reliable operation of the network, it is necessary to study the invulnerability of cascading failure of the traffic network under emergency events. Based on Space L method, the topology model of traffic network in tourist attraction was established taking tourist attraction as the research object. The spatial and temporal distribution characteristics and rules of tourism emergency events were discussed, and the cascading failure model of traffic network based on load-capacity was constructed. The main factors affecting the scale of dynamic cascading failures and their sensitivity were analyzed.

Taking the Summer Palace tourist attraction in Beijing as an example, the invulnerability analysis of traffic network in tourist attraction under unexpected emergency events based on cascading failure were carried out.

- The study found that the traffic network of the Summer Palace has a typical network characteristics of small world. Simulation results show that network load, node capacity, node attack strategy and other factors significantly affect the cascading failure scale of traffic network in tourist attraction.
- When the load coefficient $\delta \leq 0.3$ CFR ≤ 0.01, and it shows the attack has little effect on the cascading failure of the network. The first derivative was calculated for the simulation results. And CFR increased the most by 109% when the load coefficient δ increases from 0.7 to 0.8 in the Summer Palace. Measures should be taken to control the number of tourists before reaching 70% of the node capacity, which can directly avoid large-scale cascading failure. As the degree of connection between failure node and its adjacent nodes reduced, the attack has a significant negative impact on cascading failure scale.
- When $\delta \leq 0.5$, the protection of key nodes will not be implemented until the number of tourists in tourist attraction reaches 50% of the node capacity. The invulnerability of traffic network can be improved significantly by changing redistribution rules of failure load and increasing node capacity. The cascading failure scale can be effectively reduced by 22.14%, 40.91%, and 63.66% after increasing the capacities of the top 5%, 10%, and 20% nodes respectively.

The conclusions provide reasonable suggestions for emergency events management and control strategy of the traffic network. Meanwhile they also have certain reference significance for the tour route planning of the network and the reasonable reconstruction and expansion in tourist attractions. Overall, it is beneficial to improve the safety and connectivity reliability of the network and ensure the stable operation of the traffic system.

Due to individual and group differences of tourists and the influence of different tourism environments, the decision-making behavior mechanism of tourists in emergency events is complex. The next step is to further elaborate and study the decision-making behavior of tourists under emergency events and its influencing factors. The survey should select more different tourist attractions and time periods to enrich the survey data and analyze results in a diversified way. Corresponding management and control strategies for preventing, controlling and terminating cascading failure need to be discussed.

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REFERENCES

[1] Y.-S. Wang, H.-T. Li, C.-R. Li, and D.-Z. Zhang, "Factors affecting hotels' adoption of mobile reservation systems: A technology-organization-environment framework," *Tourism Manage.*, vol. 53, pp. 163–172, Apr. 2016.

[2] B. Wang, C. Shao, and X. Ji, "Dynamic analysis of holiday travel behaviour with integrated multimodal travel information usage: A life-oriented approach," *Transp. Res. A, Policy Pract.*, vol. 104, pp. 255–280, Oct. 2017.

[3] X. Wu, H. Guan, Y. Han, and J. Ma, "A tour route planning model for tourism experience utility maximization," *Adv. Mech. Eng.*, vol. 9, no. 10, pp. 1–8, 2017.

[4] J. Jun, "Understanding the variability of speed distributions under mixed traffic conditions caused by holiday traffic," *Transp. Res. C, Emerg. Technol.*, vol. 18, no. 4, pp. 599–610, Aug. 2010.

[5] W.-M. Gai, Y. Du, and Y.-F. Deng, "Evacuation risk assessment of regional evacuation for major accidents and its application in emergency planning: A case study," *Saf. Sci.*, vol. 106, pp. 203–218, Jul. 2018.

[6] V. Van Can, "Estimation of travel mode choice for domestic tourists to Nha Trang using the multinomial probit model," *Transp. Res. A, Policy Pract.*, vol. 49, pp. 149–159, Mar. 2013.

[7] C. Pi and X. Zheng, "Focus on safety and risk, building and sharing a tourism security network-an analysis and prospect of China's tourism security situation in 2017-2018," *J. Huaqiao Univ. Philosophy Social Sci.*, vol. 2, pp. 60–71, 2018.

[8] Y. Han, G. Yang, and X. Wu, "Tour routes optimization design considering tourists," *J. Beijing Univ. Technol.*, vol. 44, no. 12, pp. 1537–1546, 2018.

[9] G. Qumsieh Mussalam and K. Tajeddini, "Tourism in Switzerland: How perceptions of place attributes for short and long holiday can influence destination choice," *J. Hospitality Tourism Manage.*, vol. 26, pp. 18–26, Mar. 2016.

[10] X. Li, J. Kurths, C. Gao, J. Zhang, Z. Wang, and Z. Zhang, "A hybrid algorithm for estimating origin-destination flows," *IEEE Access*, vol. 6, pp. 677–687, 2018.

[11] X. F. Wang and J. Xu, "Cascading failures in coupled map lattices," *Phys. Rev. E, Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.*, vol. 70, no. 5, 2004, Art. no. 056113.

[12] F.-H. Tseng, J.-H. Hsueh, C.-W. Tseng, Y.-T. Yang, H.-C. Chao, and L.-D. Chou, "Congestion prediction with big data for real-time highway traffic," *IEEE Access*, vol. 6, pp. 57311–57323, 2018.

[13] M. Li, I. Koutsopoulos, and R. Poovendran, "Optimal jamming attack strategies and network defense policies in wireless sensor networks," *IEEE Trans. Mobile Comput.*, vol. 9, no. 8, pp. 1119–1133, Aug. 2010.

[14] P. Zhang, H. Yue, P. Wang, C. Shao, and X. Zhang, "Modeling the enveloping macroscopic fundamental diagram based on the traffic assignment with deterministic user equilibrium," *IEEE Access*, vol. 7, pp. 69776–69794, 2019.

[15] Y. Qiu and L. Tian, "Self-organized criticality in a scale-free network with random and intentional attack," *Acta Scientiarum Naturalium Universitatis Nankaiensis*, vol. 43, no. 2, pp. 27–33, 2010.

[16] A. L. Hughes and L. Palen, "Twitter adoption and use in mass convergence and emergency events," *Int. J. Emergency Manage.*, vol. 6, nos. 3–4, p. 248, 2009.

[17] N. M. Girdler and D. G. Smith, "Prevalence of emergency events in British dental practice and emergency management skills of British dentists," *Resuscitation*, vol. 41, no. 2, pp. 159–167, 1999.

[18] J. I. L. Miguéns and J. F. F. Mendes, "Travel and tourism: Into a complex network," *Phys. A, Stat. Mech. Appl.*, vol. 387, no. 12, pp. 2963–2971, May 2008.

[19] H. Chang, Y. He, and Y. Zhang, "A collaboration network description on the Chinese travel route system," *Sci. Technol. Rev.*, vol. 24, no. 9, pp. 84–87, 2006.

[20] L. Tang, J. Wei, and M. Zhao, "Features of regional travel itineraries complex networks: Taking Fujian province as an example," *Tourism Tribune*, vol. 29, no. 6, pp. 57–66, 2014.

[21] Y. Zhang, J. Cao, and L. Qi, "Research on structural characteristic of destination's virtual network: The city of Huangshan as a case study," *Acta Sci. Naturalium Univ. Pekinensis*, vol. 49, no. 6, pp. 1098–1104, 2013.

[22] H.-Y. Shih, "Network characteristics of drive tourism destinations: An application of network analysis in tourism," *Tourism Manage.*, vol. 27, no. 5, pp. 1029–1039. 2006.

[23] Y. Han, H. Guan, and J. Duan, "Tour route multiobjective optimization design based on the tourist satisfaction," *Discrete Dyn. Nature Soc.*, vol. 2014, Jan. 2014, Art. no. 603494. doi: 10.1155/2014/603494.

[24] X. Zhu and E. Wu, "Scientific prospect of fractal theory applied to the network space of tourism system," *Prog. Geography*, vol. 26, no. 1, pp. 133–142, 2007.

[25] S.-H. Lee, J.-Y. Choi, S.-H. Yoo, and Y.-G. Oh, "Evaluating spatial centrality for integrated tourism management in rural areas using GIS and network analysis," *Tourism Manage.*, vol. 34, no. 1, pp. 14–24, Feb. 2013.

[26] B. Prideaux, "The role of the transport system in destination development," *Tourism Manage.*, vol. 21, no. 1, pp. 53–63, 2000.

[27] C. B. Smallwood, L. E. Beckley, and S. A. Moore, "An analysis of visitor movement patterns using travel networks in a large marine park, north-western Australia," *Tourism Manage.*, vol. 33, no. 3, pp. 517–528, 2012.

[28] C. Xie, "Study on the safety risks of outward bound sports based on aggregation and optimal scaling analysis," *Tourism Tribune*, vol. 26, no. 5, pp. 47–52, 2011.

[29] T. W. Heggie, T. M. Heggie, C. Kliewer, "Recreational travel fatalities in US national parks," *J. Travel Med.*, vol. 15, no. 6, pp. 404–411, 2008.

[30] L. Nie, Y. Li, and X. Kong, "Spatio-temporal network traffic estimation and anomaly detection based on convolutional neural network in vehicular ad-hoc Networks," *IEEE Access*, vol. 6, pp. 40168–40176, 2018.

[31] D. J. Watts, "A simple model of global cascades on random networks," *Proc. Nat. Acad. Sci. USA*, vol. 99, no. 9, pp. 5766–5771, 2002.

[32] L. Buzna, K. Peters, and D. Helbing, "Modelling the dynamics of disaster spreading in networks," *Phys. A, Stat. Mech. Its Appl.*, vol. 363, no. 1, pp. 132–140, 2006.

[33] J. J. Wu, Z. Y. Gao, and H. J. Sun, "Effects of the cascading failures on scale-free traffic networks," *Phys. A, Stat. Mech. Appl.*, vol. 378, no. 2, pp. 505–511, 2007.

[34] J. F. Zheng, Z.-Y. Gao, and X.-M. Zhao, "Modeling cascading failures in congested complex networks," *Phys. A, Stat. Mech. Appl.*, vol. 385, no. 2, pp. 700–706, Nov. 2007.

[35] F. Xie, S. Chen, and D. Chen, "Cascade-based attack vulnerability in complex networks," *J. Tsinghua Univ. Sci. Technol.*, vol. 51, no. 10, pp. 1252–1257, 2011.

[36] Z. J. Bao, Y. J. Cao, L. J. Ding, Z. X. Han, and G. Z. Wang, "Dynamics of load entropy during cascading failure propagation in scale-free networks," *Phys. Lett. A*, vol. 372, no. 36, pp. 5778–5782, 2008.

[37] F. Xia, J. Fan, and D. Hill, "Cascading failure in Watts—Strogatz small-world networks," *Phys. A, Stat. Mech. Appl.*, vol. 389, no. 6, pp. 1281–1285, 2010.

[38] L. Dueñas-Osorio and S. M. Vemuru, "Cascading failures in complex infrastructure systems," *Struct. Saf.*, vol. 31, no. 2, pp. 157–167, Mar. 2009.

[39] J. Ash and D. Newth, "Optimizing complex networks for resilience against cascading failure," *Phys. A, Stat. Mech. Appl.*, vol. 380, pp. 673–683, Jul. 2007.

[40] Z. Wang, X. Chen, and C. Li, "Identifying influence sources of cascading failure for road traffic network," *China J. Highway Transp.*, vol. 28, no. 10, pp. 98–104, 2015.
[41] H. Qi, "Graphical solution for arterial road traffic flow model considering spillover," *IEEE Access*, vol. 6, pp. 6755–6764, 2017.
[42] D.-M. Zhang, F. Du, H. Huang, F. Zhang, B. M. Ayyub, and M. Beer, "Resiliency assessment of urban rail transit networks: Shanghai metro as an example," *Saf. Sci.*, vol. 106, pp. 230–243, Jul. 2018.
[43] B. A. Turner, "The organizational and interorganizational development of disasters," *Administ. Sci. Quart.*, vol. 21, no. 3, pp. 378–397, 1976.
[44] B. T. Burkholder and M. J. Toole, "Evolution of complex disasters," *Lancet*, vol. 346, no. 8981, pp. 1012–1015, 1995.
[45] I. M. Shaluf, F.-R. Ahmadun, and S. Mustapha, "Technological disaster's criteria and models," *Disaster Prevention Manage.*, vol. 12, no. 4, pp. 305–311, 2003.
[46] J. Wang, Y.-H. Liu, Y. Jiao, and H.-Y. Hu, "Cascading dynamics in congested complex networks," *Eur. Phys. J. B*, vol. 67, no. 1, pp. 95–100, 2009.
[47] J.-W. Wang and L.-L. Rong, "Robustness of the western United States power grid under edge attack strategies due to cascading failures," *Saf. Sci.*, vol. 49, no. 6, pp. 807–812, 2011.
[48] X. Tan, D. Huang, and X. Zhao, "Jobs housing balance based on Baidu thermodynamic diagram," *J. Beijing Normal Univ. Natural Sci.*, vol. 52, no. 5, pp. 622–627, 2016.
[49] Q. Xu, Z. Zu, Z. Xu, W. Zhang, and T. Zheng "Space P-based empirical research on public transport complex networks in 330 cities of China," *J. Transp. Syst. Eng. Inf. Technol.*, vol. 13, no. 1, pp. 193–198, 2013.

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