Hindawi
Journal of Advanced Transportation
Volume 2020, Article ID 3976910, 9 pages
https://doi.org/10.1155/2020/3976910

Research Article

Simulation Study on Cascading Failure of Multimodal Transport Network

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Received 29 November 2019; Revised 3 November 2020; Accepted 16 November 2020; Published 1 December 2020

Academic Editor: Xingju Wang

Cascading failure in multimodal transport network may cause huge economic loss and social impact, which has gradually attracted public attention. In view of the coupling effect of nodes in multimodal transport network and the higher complexity of cascading failure process, the concepts of node correlation degree and node cooperation degree are proposed to characterize the characteristics of the network, and a logit model is introduced to calculate the initial load of nodes. In the case of ignoring network interruption, we propose two load redistribution methods: local allocation and global-local allocation. Taking the multimodal transport network in Sichuan–Tibet region of China as an example, the cascading failure effect of multimodal transport network in Sichuan–Tibet region is quantified by sensitivity analysis. The results show that when the load of the multimodal transport network in Sichuan–Tibet region exceeds the maximum capacity but does not exceed 150%~170% of the network capacity, the network can still operate normally. In addition, the nodes in the multimodal transport network should have 0.3~0.5 scalable space. In the cascading failure control method, load redistribution based on global-local allocation can minimize the impact of node overload.

1. Introduction

Cascading failure theory was first studied by Motter and Lai [1], and the classical ML model was proposed. Most of the existing researches are based on this. At present, the cascading failure theory is mainly used in power [2, 3], traffic [4, 5], and information network [6]. In the past few decades, scholars and researchers have done a lot of research on the cascading failure and its control methods in the network. Peng [5] built a cascade model on the urban road traffic network based on the disaster spreading dynamics. Considering the influence of self-healing ability of nodes and delay time factor on the disaster spreading mechanism, taking the number of collapse nodes and the repair rate of nodes as evaluation factors, the influence of different parameter values on the network was studied; Liu et al. [7] studied the cascading failure model in the traffic network under the emergency and determined the initial load by the incremental loading method under the multipath probability. Considering the influence of road resistance on the driver's decision, the redistribution strategy of the load based on the foreground theory can be determined. In the case of node failure, Zhong and Shuai [8] established a cascading failure model of transport network of dangerous goods under the continuous attack. Taking the node survival rate and the number of relative secondary joint failures as the evaluation factors, the node load was spread by means of average distribution, and the impact of different parameters on the network invulnerability was analyzed. Zhang et al. [9] analyzed the effects of different parameters on cascading failure process; Qian [10] studied the effects of network time delay and self-healing on cascading failure process. Hao et al. [11] and Peng et al. [12] studied the scale-free networks (BA networks), small world networks (NW networks), and random networks (ER networks) and proposed to weaken the cascading failure in the network by controlling the node weighting and initial load. Hong et al. [13] studied the inhibition effect of multiple recovery strategies on the cascading failure in interdependent network. On the whole, the shortcomings of the existing studies are as follows: first, existing researches have simplified the idealization of the network, ignoring some of the attributes in the real network; second, the complex coupling relationship between nodes of multimodal transport network is ignored in the existing research.

It can be seen that the relevant researches focus on: first, the determination of initial load and update mechanism; second, the research of load redistribution after node failure; and third, the influence of different factors on cascading failure effect. In this paper, the relationships between nodes of multimodal transport network are redefined and applied to the cascading failure model. According to the characteristics of the network, the corresponding initial load distribution mode and load redistribution mode are proposed, which can provide a theoretical basis for effectively controlling the evolution process of cascading failure in multimodal transport network.

The structure of this paper is as follows: Section 2 introduces the definitions, including node relevance and node collaboration; in Section 3, the cascading failure model is established; in Section 4, the empirical analysis of the multimodal transport network in Sichuan–Tibet region of China is performed; and Section 5 summarizes the work of this paper.

2. Definitions

2.1. Node Relevance. In a multimodal transport network, there are multiple connection modes between nodes, and different node connections will affect the carrying capacity and load propagation speed of the network. Therefore, the calculation of the node relevance in the network is the premise of cascading failure modeling. According to the connection mode of organizational elements, the relationships between nodes of multimodal transport network can be divided into five types [14]. First, direct subordination: the nodes are directly connected, and the downstream nodes are subordinate to the upstream nodes. Second, indirect subordination: the nodes are connected indirectly, and the downstream nodes are subordinate to the upstream nodes. Third, direct control relationship: the nodes are directly connected, and the upstream node controls the downstream node. Fourth, indirect control relationship: the nodes are connected indirectly, and the upstream node controls the downstream node. Fifth, parallel relationship: the nodes are in parallel state, and there is no subordinate and control relationship.

Through the two steps of determining the node order of different connection modes and the calculation of relative importance contrast matrix, the relevance between nodes can be calculated: first, determine the node order under different connection modes. In a multimodal transport network, the number of nodes $X = \{x_1, x_2, \ldots, x_n\}$ is determined in a certain order of location. Second, determine a comparison matrix of the relative importance of nodes x_i and x_j. On the basis of determining the order relation, experts judge the importance degree between two adjacent nodes and obtain the importance degree matrix between nodes in the network. The numerical description of connection strength is shown in Table 1.

In the process of network failure and load redistribution, the load tends to flow in the direction of high node correlation.

2.2. Node Collaboration. The concept of node collaboration is often used in command and control network to measure the effect of collaborating between two or more nodes in order to complete one task [6]. In the multimodal transport network, the node collaboration K_{ij}^{w} is used to measure the effect of the two nodes collaborating with each other in order to complete the transport task using the w_{th} transport mode. In this paper, transport cost c_{ij}^{w}, transport time t_{ij}^{w}, and transport reliability r_{ij}^{w} are used to measure the node collaboration. The higher the node collaboration, the better the transport effect. When the two nodes are transfer nodes, the w_{th} transportation mode represents the way of goods outflow.

Let f_{ij}^{w} be the traffic volume for completing a transport task, l_{ij}^{w} be the transport operation between two nodes, o_{ij}^{w} be the unit operation cost, and u_{ij}^{w} be the unit operation time; then the transport cost c_{ij}^{w} and the transport time t_{ij}^{w} are shown as follows:

$$c_{ij}^{w} = f_{ij}^{w} \cdot l_{ij}^{w} \cdot o_{ij}^{w}, \tag{1}$$

$$t_{ij}^{w} = f_{ij}^{w} \cdot l_{ij}^{w} \cdot u_{ij}^{w}. \tag{2}$$

Among them, $c_{ij}^{w} > 0$, and $t_{ij}^{w} > 0$. Let $d(s)$ be a function of transport failure rate, which indicates the times of damage or failure of transport in unit time, and then the transport reliability r_{ij}^{w} is

$$r_{ij}^{w} = 1 - e^{-\int_0^{t_{ij}^{w}} d(s)\mathrm{d}s}, \tag{3}$$

where $r_{ij}^{w} \in (0, 1]$ and $\mathrm{d}(s) \geq 0$.

Due to the nonuniform dimension of cost, time, and reliability, the standard deviation method is adopted to standardize the cost and time, so that they are distributed between [0, 1]. The conversion formula is shown as follows:

$$x^{*} = \frac{x - \min}{\max - \min}, \tag{4}$$

where maxis the maximum value in the data set, min is the minimum value in the data set, andmax − min is the range. The normalized values of transit cost c_{ij}^{w} and transit time t_{ij}^{w} are recorded as c_{ij}^{w*} and t_{ij}^{w*}, and the subjective weighting method is used for weight distribution. The collaboration of transport nodes can be obtained as shown below, $K_{ij}^{w} \in (-(1/2), (1/2)]$:

Table 1: Numerical description of connection strength.

Significance	Same importance	Slightly important	More important	Obviously important	Very important	Extremely important
Numerical value	0.50	0.60	0.70	0.80	0.90	1.0

$$K_{ij}^{w} = -\frac{1}{4}c_{ij}^{w*} - \frac{1}{4}t_{ij}^{w*} + \frac{1}{2}r_{ij}^{w}. \tag{5}$$

By considering the influence of transport cost, transport time, and transport reliability, this paper establishes a node collaboration model.

3. Cascading Failure Model

In the cascading failure model, according to the different risk sources of cascading failure, it can be divided into node failure mode [15], edge failure mode [16], and node-edge mixed failure mode [17]. In the multimodal transport network, three failure modes coexist, but due to the limitation of space, this paper only discusses the cascading failure effect based on node failure [18].

3.1. Initial Load of Node. At present, the existing method of determining the initial load considers that the larger the capacity of the node is, the higher the initial load is. This paper considers that in the multimodal transport network, the initial load will be affected by the node collaboration, and the goods will tend to flow in the direction of high node collaboration, but with the continuous accumulation of goods, the node collaboration will also change. In this paper, a logit model is introduced to calculate the selection probability of the w_{th} transport mode between nodes i and j at time T, as shown below:

$$P_{ij}^{w}(T) = \frac{\exp\left(K_{ij}^{w}\right)}{\sum_{w}\exp\left(K_{ij}^{w}\right)}. \tag{6}$$

When the load of the network in a stable state is called the initial load in the network as $L(0)$, then the initial load $L_i(0)$ of node i is shown as follows, where ξ is a constant:

$$L_i(0) = \sum_{w}\sum_{j} P_{ij}^{w}L(0) + \xi. \tag{7}$$

The initial load $L_{ij}^{w}(0)$ of the w_{th} transport mode between nodes i and j is shown as follows, where δ is a constant:

$$L_{ij}^{w}(0) = P_{ij}^{w}L(0) + \delta. \tag{8}$$

3.2. Load Capacity. Suppose that the maximum load capacity of the connection edge of the w_{th} transport mode between nodes i and j in the network is C_{ij}^{w}, the maximum load capacity of node i is C_i; $\alpha > 0$ and $\varphi > 0$ are the tolerance factors of the edge and node, respectively, and then,

$$\begin{aligned} C_{ij}^{w} &= (1+\alpha)L_{ij}^{w}(0), \\ C_i &= (1+\varphi)L_i(0). \end{aligned} \tag{9}$$

Among them, the algebraic relationship between C_i and C_{ij}^{w} is $C_i \geq \sum_{w}\sum_{j}C_{ij}^{w}$.

3.3. Load Redistribution. In multimodal transport network $G = (V, E)$, the set of nodes is $V = \{v_1, v_2, \cdots, v_n\}$. After the state of node v_i changes from "normal" to "overload" due to the influence of internal and external factors, the load that exceeds the maximum load capacity on the node will propagate to other nodes in certain rules. This paper discusses two load redistribution methods: load redistribution method based on local distribution and load redistribution method based on global-local distribution.

3.3.1. Load Redistribution Method Based on Local Distribution. The basic idea of local distribution is as follows: considering the influence of the node collaboration and node relevance with the adjacent nodes, node v_i in overload state will give additional load to the adjacent "normal" nodes, and the load of the adjacent "normal" nodes is

$$L_j(t+1) = L_j(t) + \frac{\sum_{w}\beta_{ij}^{w}K_{ij}^{w}}{\sum_{j}\sum_{w}\beta_{ij}^{w}K_{ij}^{w}}\left(L_i(t) - C_i\right). \tag{10}$$

3.3.2. Load Redistribution Method Based on Global-Local Distribution. The basic idea of global-local distribution is as follows: on the basis of considering node state, node collaboration, and node relevance, supplemented by the remaining capacity factor of adjacent "normal" nodes, the load is redistributed with the goal of network balance. In this way, the load of adjacent "normal" nodes is as follows:

$$\begin{aligned} L_j(t+1) = L_j(t) &+ \frac{\left(C_j - L_j(t)\right)\cdot\left(L_i(t) - C_i\right)}{\lambda_1\sum_{j}\left(C_j - L_j(t)\right)} \\ &+ \frac{\left(L_i(t) - C_i\right)\sum_{w}\beta_{ij}^{w}K_{ij}^{w}}{\lambda_2\sum_{j}\sum_{w}\beta_{ij}^{w}K_{ij}^{w}}. \end{aligned} \tag{11}$$

Among them, $0 < \lambda_1, \lambda_2 < 1$, and $\lambda_1 + \lambda_2 = 1$.

When the load exceeds the maximum load C_j of node v_j, the excess part will continue to propagate to the adjacent nodes of v_j until the load of all nodes in the network is within the maximum load, and the cascading failure ends.

3.4. Measures of Cascading Failure Effect. In this paper, the proportion of abnormal nodes and average network efficiency are used to measure the cascading failure effect in multimodal transport network.

3.4.1. The Proportion of Abnormal Nodes. Suppose that the total number of nodes in the multimodal transport network is N, in which the total number of nodes in abnormal state is N_f and the proportion of nodes in abnormal state is R_f. The higher the proportion is, the stronger the cascading failure in the multimodal transport network is, and vice versa:

$$R_f = \frac{N_f}{N}. \tag{12}$$

3.4.2. Average Network Efficiency. The average network efficiency E is used to measure the connectivity in multimodal transport network. When nodes are abnormal, the higher the average network efficiency is, the weaker the cascading failure in the network is. Otherwise, the stronger the cascading failure is.

In this paper, overload function [19] $F_i(t)$ is used to express the difficulty of load passing through nodes:

$$F_i(t) = \begin{cases} 1, L_i(t) \le L_i(0), \\ 1 + \dfrac{L_i(t) - L_i(0)}{C_i - L_i(0)}(N-1), L_i(0) \le L_i(t) \le C_i, \\ N, L_i(t) > C_i, \\ N^2, \text{failure}. \end{cases} \tag{13}$$

Let d_{ij} represent the path with the highest load trafficability between node v_i and node v_j, and $P(i, j, w)$represents the set of all paths between node v_i and node v_j; then, the average network efficiency is as shown as follows:

$$d_{ij} = \min\left\{\sum_p F_p(t), p \in P(i, j)\right\}, \tag{14}$$

$$E = \frac{1}{N(N-1)} \sum_{i \ne j} \frac{1}{d_{ij}}. \tag{15}$$

4. Case Study

Taking the multimodal transport network in Sichuan–Tibet region as an example, this paper selects the hubs of Sichuan–Tibet railway, Sichuan–Tibet highway, and aviation as network nodes, and extracts 23 transport mode intersections in turn as 1–23 nodes in the multimodal transport network. The corresponding network structure is shown in Figure 1.

4.1. Node Relevance and Collaboration. According to the correlation between 23 nodes, the relevance between nodes is calculated under different connection modes. Among the adjacent nodes, according to the distribution of node order, the relationship of the direct control between the upstream node and the downstream node has the same relevance with the relationship of the direct subordinate between the downstream node and the upstream node. But the connection strength between the two nodes will change with the change of the upstream and downstream relationship. In general, the node relevance is 0.5. In this paper, only nongeneral node relationships are represented as shown in Table 2.

The node collaboration is affected by the transport cost, transport time, and transport reliability. At present, the multimodal transport network in Sichuan–Tibet region has not been built yet, and there is no adequate data. Therefore, the Delphi method is adopted in this paper to get the estimated data of the transport cost and transport time of the multimodal transport network by visiting the relevant staff in Sichuan–Tibet region. Then, through the analysis of the external environment of the node and the use of G1 method, the relevant data of transport reliability are obtained. According to the calculation formula in Section 2.1, the node collaboration under different transport modes can be obtained, as shown in Tables 3–5.

4.2. Numerical Analysis. In the multimodal transport network, the load will only propagate to the adjacent nodes, so only the nodes with direct and parallel relationships are calculated and analyzed. This paper sets Chengdu as the upstream direction and Lhasa as the downstream direction for the following simulation. Based on the local distribution and the global-local distribution methods, the cascading failure effect of multimodal transport network is analyzed by using MATLAB and Origin software. If the initial load in the network is $L(0)$, then the initial load $L_i(0)$ of each node can be obtained according to the calculation steps and order in Sections 2.1 and 3.1. Set the maximum tolerance factor of the node $\alpha = \{0.1, 0.3, 0.5, 0.7, 0.9\}$ and the overload load proportion η as, respectively, 10%, 30%, 50%, 70%, and 90% of the initial load of the corresponding node:

1. Considering the maximum tolerance factor of the node changes, the overload load proportion is 50%. Under the local distribution method, the effects on the proportion of abnormal nodes and average network efficiency of the network are shown in Tables 6 and 7.
2. Considering the maximum tolerance factor of the node changes, the overload load proportion is 50%. Under the global-local distribution method, the effects on the proportion of abnormal nodes and average network efficiency of the network are shown in Tables 8 and 9.
3. Considering the overload load proportion changes, the tolerance factor is 50%. Under the local distribution method, the effects on the proportion of abnormal nodes and average network efficiency of the network are shown in Tables 10 and 11.
4. Considering the overload load proportion changes, the tolerance factor is 50%. Under the global-local distribution method, the effects on the proportion of

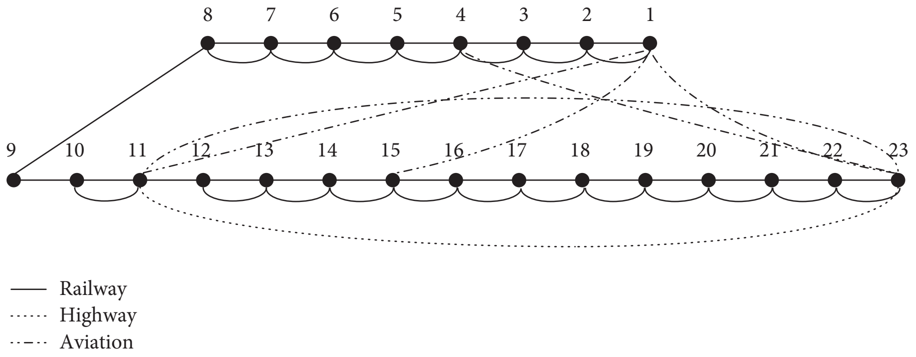

Figure 1: Multimodal transport network map in Sichuan–Tibet region.

Table 2: Relevance of nodes.

Node number	1	2	4	5	11	15	23
1	—	Direct control, 0.8	—	—	Direct control, 0.7	Direct control, 0.7	Direct control, 0.6
2	Direct subordinate, 0.8	—	—	—	Parallel	Parallel	Parallel
4	—	—	—	Direct control, 0.6	—	—	Direct control, 0.6
5	—	—	Direct subordinate, 0.6	—	—	—	Parallel
11	Direct subordinate, 0.7	Parallel	—	—	—	Parallel	Direct control, 0.6
15	Direct subordinate, 0.7	Parallel	—	—		—	Parallel
23	Direct subordinate, 0.6	Parallel	Direct subordinate, 0.6	Parallel	Direct subordinate, 0.6	Parallel	—

Table 3: Collaboration degree of railway transportation nodes.

Number	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Collaboration	0.885	0.836	0.793	0.72	0.625	0.639	0.606	0.619
Number	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
Collaboration	0.612	0.632	0.632	0.636	0.621	0.545	0.519	0.71
Number	17-18	18-19	19-20	20-21	21-22	22-23		
Collaboration	0.685	0.616	0.632	0.635	0.673	0.656		

Table 4: Collaboration degree of highway transportation nodes.

Number	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Collaboration	0.842	0.875	0.525	0.477	0.414	0.424	0.402
Number	10-11	12-13	13-14	14-15	15-16	16-17	17-18
Collaboration	0.42	0.378	0.366	0.319	0.301	0.412	0.398
Number	18-19	19-20	20-21	21-22	22-23	11-23	
Collaboration	0.412	0.423	0.425	0.451	0.44	0.579	

Table 5: Collaboration degree of airline transportation nodes.

Number	1–11	1–15	1–23	4–23	11–23
Collaboration	0.614	0.592	0.522	0.612	0.572

Table 6: The proportion of abnormal nodes (a).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.420	0.240	0.100	0.100	0.100
0.200	0.770	0.530	0.350	0.200	0.200
0.300	0.980	0.850	0.690	0.460	0.300
0.400	1.000	1.000	0.930	0.710	0.580
0.500	1.000	1.000	1.000	0.920	0.790
0.600	1.000	1.000	1.000	1.000	0.930
0.700	1.000	1.000	1.000	1.000	1.000
0.800	1.000	1.000	1.000	1.000	1.000
0.900	1.000	1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000	1.000	1.000

Table 7: Average network efficiency (a).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.045	0.067	0.098	0.098	0.098
0.200	0.021	0.038	0.063	0.098	0.098
0.300	0.004	0.018	0.036	0.070	0.098
0.400	0.000	0.000	0.019	0.034	0.069
0.500	0.000	0.000	0.000	0.016	0.036
0.600	0.000	0.000	0.000	0.000	0.013
0.700	0.000	0.000	0.000	0.000	0.000
0.800	0.000	0.000	0.000	0.000	0.000
0.900	0.000	0.000	0.000	0.000	0.000
1.000	0.000	0.000	0.000	0.000	0.000

Table 8: The proportion of abnormal nodes (b).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.320	0.180	0.100	0.100	0.100
0.200	0.670	0.330	0.250	0.200	0.200
0.300	0.930	0.750	0.390	0.360	0.300
0.400	1.000	0.920	0.680	0.580	0.480
0.500	1.000	1.000	0.910	0.770	0.620
0.600	1.000	1.000	1.000	0.970	0.790
0.700	1.000	1.000	1.000	1.000	0.930
0.800	1.000	1.000	1.000	1.000	1.000
0.900	1.000	1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000	1.000	1.000

abnormal nodes and average network efficiency of the network are shown in Tables 12 and 13.

The results of numerical analysis can be obtained as follows:

(1) When the overload load proportion gradually increases between 10% and 90%, the speed of risk propagation in the multimodal transport network will increase, but it will not affect the final state of the

Table 9: Average network efficiency (b).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.065	0.087	0.098	0.098	0.098
0.200	0.041	0.058	0.081	0.098	0.098
0.300	0.014	0.038	0.057	0.079	0.098
0.400	0.000	0.013	0.039	0.054	0.080
0.500	0.000	0.000	0.016	0.036	0.057
0.600	0.000	0.000	0.000	0.017	0.033
0.700	0.000	0.000	0.000	0.000	0.019
0.800	0.000	0.000	0.000	0.000	0.000
0.900	0.000	0.000	0.000	0.000	0.000
1.000	0.000	0.000	0.000	0.000	0.000

Table 10: The proportion of abnormal nodes (c).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.100	0.100	0.100	0.210	0.290
0.200	0.200	0.200	0.350	0.590	0.680
0.300	0.300	0.410	0.690	0.880	1.000
0.400	0.520	0.620	0.930	1.000	1.000
0.500	0.740	0.910	1.000	1.000	1.000
0.600	0.920	1.000	1.000	1.000	1.000
0.700	1.000	1.000	1.000	1.000	1.000
0.800	1.000	1.000	1.000	1.000	1.000
0.900	1.000	1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000	1.000	1.000

Table 11: Average network efficiency (c).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.098	0.098	0.098	0.079	0.063
0.200	0.098	0.098	0.063	0.047	0.024
0.300	0.098	0.065	0.036	0.200	0.000
0.400	0.071	0.032	0.019	0.000	0.000
0.500	0.034	0.018	0.000	0.000	0.000
0.600	0.015	0.000	0.000	0.000	0.000
0.700	0.000	0.000	0.000	0.000	0.000
0.800	0.000	0.000	0.000	0.000	0.000
0.900	0.000	0.000	0.000	0.000	0.000
1.000	0.000	0.000	0.000	0.000	0.000

network. Among them, when $\eta = 10\%$, the risk propagation speed is the slowest in multimodal transport networks. When $\eta = 90\%$, the risk propagation speed is the fastest in the network. As the proportion of overloaded nodes in the network increases, the network will eventually collapse. According to the results of the Delphi method, the proportion of overloaded nodes in the multimodal transport network of Sichuan–Tibet region is not expected to be 0.4, so the overload load proportion that can be carried is between 50% and 70%.

(2) When the tolerance factor α increases gradually from 0.1 to 0.9, the cascading failure speed in the multimodal transport network will also slow down, but with the increase of the proportion of overloaded nodes, the network will eventually collapse completely. Among them, when $\alpha = 0.1$, the cascading failure speed of multimodal transport network is the fastest, and when $\alpha = 0.9$, the speed is the slowest. Therefore, according to the results of the Delphi method, the tolerance factor in the network can be set between 0.3 and 0.5.

Table 12: The proportion of abnormal nodes (d).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.100	0.100	0.100	0.260	0.350
0.200	0.200	0.200	0.250	0.480	0.670
0.300	0.300	0.390	0.430	0.760	0.890
0.400	0.470	0.580	0.680	0.920	1.000
0.500	0.620	0.730	0.910	1.000	1.000
0.600	0.790	0.900	1.000	1.000	1.000
0.700	0.960	1.000	1.000	1.000	1.000
0.800	1.000	1.000	1.000	1.000	1.000
0.900	1.000	1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000	1.000	1.000

Table 13: Average network efficiency (d).

The proportion of overloaded nodes	The tolerance factor				
	$\alpha = 0.1$	$\alpha = 0.3$	$\alpha = 0.5$	$\alpha = 0.7$	$\alpha = 0.9$
0.100	0.098	0.098	0.098	0.082	0.073
0.200	0.098	0.098	0.081	0.059	0.045
0.300	0.098	0.079	0.057	0.036	0.022
0.400	0.079	0.058	0.039	0.017	0.000
0.500	0.053	0.031	0.016	0.000	0.000
0.600	0.036	0.020	0.000	0.000	0.000
0.700	0.017	0.000	0.000	0.000	0.000
0.800	0.000	0.000	0.000	0.000	0.000
0.900	0.000	0.000	0.000	0.000	0.000
1.000	0.000	0.000	0.000	0.000	0.000

(3) When the load in the network is redistributed by the local distribution method and the global-local distribution method, respectively, it can be seen that when the proportion of overloaded nodes is within 0.3, the effect of the two distribution methods is not much different. When the proportion of overloaded nodes is more than 0.3, the global-local distribution method can make the cascading failure speed in the network slower. Therefore, in multimodal transport network of Sichuan–Tibet region, the method of global-local distribution should be used for load redistribution.

5. Conclusion

According to the characteristics of node coupling in multimodal transport network, the concept of node degree is replaced by node relevance and node collaboration, and it is applied in the cascading failure model. The logit model is introduced into the model to calculate the initial load of nodes in the network. Based on the overload state of nodes, two load redistribution methods are proposed: local distribution and global-local distribution. Taking the proportion of abnormal nodes and average network efficiency as the measured index of the cascading failure results, the paper analyzes the cascading failure evolution process of the multimodal transport network in Sichuan and Tibet regions. The results show that when the proportion of overloaded nodes of the multimodal transport network in Sichuan and Tibet is less than 0.4, the overload load proportion that the network can carry is 50%~70%. When the tolerance factor in the network is set between 0.3 and 0.5, the global-local redistribution method can more effectively control the network cascading failure process. In other words, when the load of the multimodal transport network in Sichuan–Tibet region exceeds the maximum capacity but does not exceed 150%~170% of the network capacity, the network can still operate normally. In addition, the nodes in the multimodal transport network should have 0.3~0.5 scalable space. In the cascading failure control method, load redistribution based on global-local allocation can minimize the impact of node overload.

Data Availability

The corresponding data of multimodal transport network in Sichuan–Tibet region in the manuscript are obtained by interviewing related department and simulation of MATLAB software, and all data are available.

Conflicts of Interest

The authors declare there are no conflicts of interest.

Authors' Contributions

All authors have contributed to the creation of this manuscript for important intellectual content and read and approved the final manuscript.

Acknowledgments

The project was supported by National Key R&D Plan in China (2018YFB1601400).

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