

Article

Inter-Organizational Partnering Strategies in Disaster Response: A Complex Network Perspective

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Abstract: Establishing appropriate inter-organizational partnership in disaster response is of great help to the improvement of disaster relief performance. However, the selection of proper disaster response organizations for government agencies to build partnerships among the numerous relief organizations remains to be addressed. To fill the gap, this paper adopted a complex network modeling method to explain the formation mechanism of inter-organizational partnership in disaster response. Then, based on a numerical simulation method, the paper compared different inter-organizational partnering strategies, and explored the optimal inter-organizational partnering strategy in the disaster response process. Results demonstrate that the optimal partnering strategy is contingent on disaster response conditions, with accurate disaster information and abundant relief materials to choose the material difference principle, and vague disaster information to choose the organizational influence principle. At the same time, frequent information communication and material cooperation allocation can be transformed into low-frequency information communication and government-led material allocation. This study provides practical guidance for disaster relief organizations to choose inter-organizational partnering strategies, and enriches the disaster organization management theory.

Keywords: disaster response; inter-organizational partnering strategy; partnering principle; partnering scope; complex network



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1. Introduction

With the changes in human behavior and natural environment in the process of economic and social development, the world is facing an unprecedented ‘dangerous situation’. The Global Assessment Report issued by the United Nations pointed out that under the impact of disasters, the social and economic progress achieved by the world will fall short by 2030, and disasters will occur in every corner of the world at a frequency of 1.5 per day [1]. Due to the increasing correlation and dependence between different economic and social subsystems, the impact of disaster events is becoming more and more severe. The complexity of disaster response stems from the rapid influx of massive relief organizations, under extremely tight time and resource constraints [2]. The response organizations can include government departments, non-governmental organizations (NGO), volunteer groups, and even the public and the media [3,4].

In the disaster response process, the government, as the main participant relief process, needs to cooperate with large numbers of response organizations. In order to make up for the lack of disaster relief capabilities of a single organization, the government will screen relief organizations with a certain partnering principle [5], and select corresponding organizations to establish partnership [6]. Response organizations chosen by the government will cooperate and exchange tangible and intangible resources with the government. Tangible resources can be emergency supplies, funds, vehicles, or other shared equipment, while intangible resources mostly refer to disaster information and disaster relief knowledge [7]. It is necessary to determine the appropriate partnering scope with the partner organizations.

Existing studies have pointed out the roles and functions of disaster relief organizations, clarified the importance of joint disaster relief, and made a preliminary exploration of

the promoting and hindering factors of joint response [8]. However, how the government can develop appropriate inter-organizational partnering strategies that can realize the effective integration of relief organizations' resources and capabilities in disaster response remains to be resolved in practice and theory. Therefore, the paper focused on the development of inter-organizational partnering strategies for the government agencies in disaster response, trying to answer the question of what partnering strategies should the government agencies adopt to establish partnerships with other disaster response organizations, under different disaster conditions.

The structure of this paper is as follows. Section 2 conducts a literature review, analyzing the partnering principle and partnering scope; Section 3 models the inter-organizational partnership formation process in disaster response; Section 4 simulates the disaster response model of different partnering strategies of response organizations; Section 5 discusses the disaster–environmental contingency inter-organizational partnering strategies; Section 6 concludes the study.

2. Literature Review

2.1. Partnering Principles in Disaster Response Organizing

Organizational influence is a key factor when partnerships with disaster response organizations are established [9]. Response organizations tend to establish cooperative relationships with central organizations with greater influence, which is called the influence-centered principle. In complex network research, the center of influence strategy, also known as the preferential attachment effect, refers to the tendency that more popular organizations with more existing cooperative relationships will obtain more cooperation over time [10]. Partnering with high-impact organizations can bring many positive effects, which are beneficial to the basic factors such as cost-effectiveness of the organization operation, material flow, and information flow. More influential organizations often have more credibility, leadership, professional skills, and resource reserves [11]. Therefore, establishing cooperative relationships with high-impact organizations is given priority, and organizational influence orientation is also one of the main principles for government agencies to establish cooperative relationships.

The rapid and sudden characteristics of disaster pose a great challenge to the emergency material reserves of government agencies. Government agencies usually do not have sufficient types of material reserves, and some types of materials are not found to be in shortage until the disaster develops to a certain stage [12]. From the perspective of relief reserves and supplies, the government is also actively seeking to establish cooperative relationships with other response organizations. Some relief organizations may be lacking in the number of resources, but may reserve non-common resources. Larger emergency relief organizations can often provide more resources due to their well-established supply chains and greater warehousing inputs [13–15]. Therefore, when establishing cooperative relationships with emergency relief organizations, government agencies will consider the types and quantities of supplies. The material difference is also an important principle for the government to establish partnerships with disaster relief organizations.

The occurrence of disasters often has impacts on local communication infrastructure and network facilities. It is difficult for any organization to make accurate judgments on the disaster-affected areas [16]. At the same time, emergency relief has extremely high requirements on timeliness and accuracy of information [17]. A few seconds may mean important losses of people's lives and property. After a disaster occurs, government agencies that cannot fully grasp disaster information will seek disaster information sources from other disaster relief organizations. Some local disaster relief organizations that have local information would be chosen [18]. Information accuracy becomes a key principle to establish disaster cooperation.

2.2. Partnering Scopes of Disaster Response Organizations

Disaster relief material and information cooperation is the most important and typical way of cooperation between partner organizations in disaster response [19]. In disaster relief, the allocation of materials is the key to the successful completion of disaster relief. The government and other disaster relief organizations can cooperate on material collection and inventory, material classification and distribution, material transportation, material management, and supervision in material allocation [20,21]. For example, in terms of material classification and distribution, the government can organize professionals to classify the collected materials and then distribute them according to the actual needs of the disaster area, while other disaster relief organizations can also send professionals to participate in the sorting and distribution of supplies. In short, through the cooperation of the government and other disaster relief organizations, the allocation of materials can be more efficient and orderly. Urgently needed materials can be sent to disaster areas in the shortest time to provide urgent rescue for the residents in disaster areas.

The transmission and sharing of information is another crucial task, and accurate disaster information plays a key role in the effect of emergency disaster relief [22,23]. Especially at the beginning of unconventional emergencies, the demand for information is enormous, which leads to cooperation on information sharing. Governments and other disaster relief organizations can cooperate on disaster relief information collection, aggregation, and release [24,25]. On the one hand, the government can collect disaster information through various channels, including investigating the situation of the disaster area and collecting the needs of the victims [26]. Disaster relief organizations can conduct information collection and aggregation in their own field, and share this information with the government and other disaster relief organizations [27]. On the other hand, the government can release the latest disaster information, rescue progress, response measures and other information on official media, and provide necessary information support to others. Disaster relief organizations can publish the latest disaster information on their official media, and provide necessary information support to the government [28].

Through the cooperation between the government and other disaster relief organizations in disaster relief information, it is possible to understand the disaster situation more efficiently and accurately. Additionally, grasping the progress of rescue and adjusting the response measures can be conducted in a timely manner [29]. However, excessive information exchange and repeated information sharing may also waste the time of repeated communication, and even make the implementation of emergency relief activities improper [30,31]. Therefore, when government agencies establish cooperation with disaster relief organizations, they can selectively exchange disaster information with some organizations, instead of communicating information with all cooperative organizations. After the occurrence of unconventional emergencies, the sharply increased demand for materials makes the financing of emergency materials the most important task. More accurate disaster demand information is an important basis for the distribution of emergency materials. All in all, for different emergency relief organizations, it is necessary to selectively carry out the cooperative supply of emergency supplies or the sharing of disaster information, that is, to choose the optimal organizational cooperation scope for materials and information resources, rather than a generalized all-round cooperation.

Existing studies have carried out some research on organizational partnerships in disaster response. However, there is limited research on the formulation of organizational partnership strategies for more efficient disaster response. In order to further improve and supplement existing research, we conduct research on partner strategies in disaster response, compare and analyze the partnering principles and partnering scopes when disaster relief organizations choose partners, and give suggestions on partner strategies under different disaster conditions.

3. Methodology

In this research, we first defined the inter-organizational partnering strategies in disaster response from the perspective of partnering principles and partnering scopes. Then we used a complex network modeling approach to describe different inter-organizational partnering strategies in disaster response. Based on the numerical simulation method, the information cooperation process, material cooperation process and distribution decision-making process under different emergency conditions are simulated. Finally, the optimal inter-organizational partnering strategies under different disaster conditions are compared, analyzed, and discussed.

3.1. Construction of Disaster Response Network Structure

According to previous research, we deconstruct organizational partnering strategies from two aspects: organizational partnership principles and organizational partnering scopes. Specifically, the principles of organizational partnership include the principle of organizational influence, the principle of material difference, and the principle of information accuracy. The organizational cooperation scopes include government agency-led material cooperation, NGO-led material cooperation, and information cooperation.

Immediately after a disaster occurs, an emergency demand network centered on the affected area emerges [32]. Among them, the nodes in the emergency demand network represent the disaster-affected area unit. Each node is the smallest emergency demand unit that divides the disaster-affected area according to administrative jurisdiction or geographical location. The weight of the emergency demand node means the demand for emergency resources in the represented area. The demand is often different with the severity of the disaster in the area, the population size in the area, and the damage to the infrastructure. The edge in the emergency demand network represents the connection in the disaster-stricken area, which is determined according to the geographical adjacency of the disaster-stricken units and the damage of the transportation network. When a disaster occurs, the transportation infrastructure in the disaster-stricken area is often affected, and the network structure originally connected by geographically adjacent locations is destroyed [33]. From the perspective of complex network theory, it destroys the regular grid network that is originally geographically adjacent [34]. Specifically, the evolution process of an emergency demand network is divided into two stages: generation and destruction. In the generation stage, the disaster-affected area is evenly divided into m regional nodes. For each node, edges with the nearest 2–4 neighbors are randomly added to form a regular network with m nodes. In the destruction stage, according to the degree of damage γ , a certain proportion of edges in the network are randomly removed with the probability of $p \propto \gamma$. Each edge in the network has a probability of p to be removed. Finally, the emergency demand network Net_D is formed.

Facing the emerging emergency demand network in the disaster area, government agencies, as the core organization of emergency response, would appear first and carry out emergency relief tasks [5]. Government agencies often have a small number of important institutions that play a leading role, and other coordinating government organizations cooperate with them to actively complete disaster relief. This is consistent with the scale-free characteristics in complex networks. Therefore, the formation of the emergency response organization network of government agencies follows the following three stages: (1) the initialization phase, that is when a small-scale regular network with n_0 nodes is generated; (2) the growth phase, that is when a new node is introduced into the network and connected to the existing g nodes in the network, where $1 < g < n_0$. In order to describe the scale-free characteristics of the government emergency response network, the rule of priority connection is adopted. When a new node is introduced, the node i with degree k_i is connected with the probability $p \propto k_i$; (3) the repeating stage, that is, repeating the growth stage of the network, introduces new nodes until the total number of nodes in the network reaches n_1 the number of government agencies participating in disaster relief, forming a government agency emergency response network Net_G .

Subsequently, NGOs enter in an orderly manner to participate in the rescue [3]. The structure generation process of the NGO emergency response network is similar to the emergency response network of government agencies. It follows the process of initialization, growth, and repetition, forming the NGO emergency response network Net_N . According to the difference in the government's strategy for choosing cooperative NGOs, the principles of connection between Net_G and Net_N are different. When government agencies select cooperative NGOs based on the principle of organizational influence, NGOs with a large node degree have a greater probability of being selected. When government agencies select partnering NGOs based on the principle of material differences, NGOs with greater complementarity in supplies are given priority. When the accuracy of information is the principle of cooperation, local NGOs with more accurate information are more likely to be selected for cooperation. After completing the connection between Net_G and Net_N according to the differences in partnering strategies, the emergency response organization network is constructed.

3.2. Disaster Response Network Operation for Emergency Relief

After the construction of the disaster response network is completed, the disaster relief organizations will carry out emergency relief activities in accordance with their cooperation strategies. The first step in disaster relief activities is to communicate and exchange information. The disaster information matrices of government agencies and NGOs are M_{gov} and M_{ngo} , respectively, both of which are matrices of $m \times d_{type}$ dimension, where m is the number of disaster-stricken nodes, d_{type} is the type of emergency supplies. Each element in the matrix represents the emergency material demand information of the corresponding disaster-affected node held by government agencies or NGO organizations. Figure 1 shows the flow of disaster relief activities.

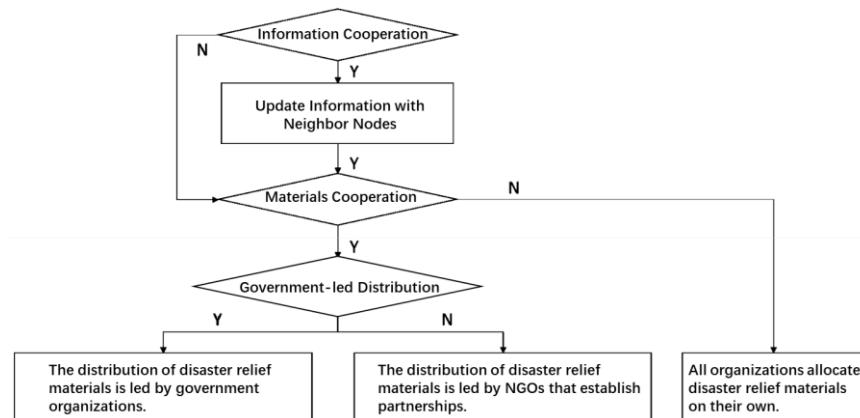


Figure 1. Flow of disaster relief activities.

Organizations that choose information cooperation communicate with partners and update their own disaster information, while organizations that choose not to cooperate will skip this process and do not update the disaster information. When updating the disaster information, the information cooperation organization updates the organization's disaster information matrix with Equation (1):

$$M' = \frac{M + \sum M_{neighbor}}{1 + N_{neighbor}} \quad (1)$$

where M is the initial information matrix of the organization, $M_{neighbor}$ is the information matrix of information cooperation neighbor nodes, and $N_{neighbor}$ is the number of information cooperation neighbor nodes.

After completing the update of the disaster information, the distribution of relief supplies begin. Government organizations and NGOs have different material distribution

principles. For government organizations, in pursuit of maximizing social welfare and fairness, emergency supplies are distributed in equal proportions based on updated disaster information. For NGOs, for the sake of reputation and survival, they would give priority to satisfying the nearest disaster-stricken nodes with lower distribution costs, and then send the remaining materials to other disaster-stricken nodes. In the specific distribution of materials, according to different partnering strategies, it can be categorized into three situations. They are (1) an individual distribution operation without material cooperation, that is, all disaster relief organizations allocate their own emergency resources on their own, and do not interfere with each other's material distribution; (2) material cooperation led by the government, that is, government agencies use the resource inventory of cooperative NGOs together, and allocate resources in proportion to the disaster situation; cooperative NGOs serve as resource pools to cooperate with the government's resource allocation decisions; other NGOs that do not participate in cooperation still follow their own allocation; and (3) material cooperation led by NGOs, that is, the cooperative NGO organization integrate the emergency material inventory of government agencies, and give priority to meeting the material needs of disaster-stricken nodes with lower transportation costs; government agencies cooperate with the material allocation decisions of cooperative NGOs to complete the distribution of emergency materials; NGOs that do not participate in the cooperation distribute on their own.

3.3. Evaluation of Emergency Relief Process

The evaluation of emergency relief activities is then analyzed from three aspects: effectiveness, efficiency, and fairness. Effectiveness and efficiency are the basic criteria for measuring logistics activities, that is, to use the highest efficiency to deliver the most resources to the demand nodes. In addition to effectiveness and efficiency, emergency disaster relief must adhere to the basic principles of humanitarianism and carry out disaster relief activities in a neutral and impartial manner. Therefore, the fairness of material distribution also needs to be taken into consideration. The effectiveness of a system usually refers to the degree to which requirements are met, or the level of service provided. In network research, the effect of resource allocation is generally measured from the perspective of changes in node weights in the network. In this study, we mainly measure the resource allocation effect of the network from the degree of demand satisfaction of emergency nodes. At the same time, in order to exclude outliers and reflect the satisfaction degree of most demand nodes, we use the non-parametric outlier detection method to calculate the interquartile range of the satisfaction degree of all demand nodes. The quartile multiplier value $k = 1.5$. The effect of the corresponding node is calculated according to Equation (2):

$$Ieffe_{IQR} = \frac{\sum \min(a_k, w_k) / w_k}{m_{IQR}} \quad (2)$$

where a_k and w_k , respectively, represent the amount of resources actually received and the amount of resources actually needed by the affected node k , m_{IQR} is the number of nodes that pass the outlier detection.

Efficiency was first proposed by scholars of classical economic theory and interpreted as the efficiency of resource allocation, that is, the operating conditions that meet human needs as much as possible under the constraints of resources and technical conditions. In fact, efficiency is about the ratio of inputs to outputs. The efficiency of this study refers to the extent to which the actual task or target completion is close to the optimal completion under the given resource constraints, which is measured by Equation (3):

$$Ieffi_{IQR} = \frac{Ieffe_{IQR}}{(\sum s_i + \sum s_j) / \sum w_k} \quad (3)$$

Fairness in emergency relief usually refers to making the disaster-stricken points have equal rescue opportunities, so that the difference between the satisfaction levels

of the disaster-stricken points is the smallest. Therefore, in this study, we first selected the coefficient of difference index in statistics to measure the fairness of emergency relief. Subsequently, in order to further characterize the unfairness of the affected network, we counted the proportion of nodes whose demand satisfaction exceeds the ratio of total supply to total demand.

4. Simulation Analysis and Results

4.1. Parameter Settings

Based on the ratio of military emergency relief network nodes in the U.S. Ultralog program [35,36], we set the ratio of disaster response organizations (including government agencies and NGOs) to the number of disaster-stricken nodes as 1:5, where $m = 500$, $n_1 = 25$, $n_2 = 75$. On average, each disaster response organization node is responsible for the resource supply of five demand nodes. Due to the randomness and unpredictability of emergency resource demand caused by unconventional emergencies, it is assumed that the number of demanded nodes is a group of numbers that obey random distribution. In terms of emergency supplies, on the one hand, the total ratio of government agencies and non-governmental organizations in empirical research related to disaster management is about 1:3 [17,20,37]; on the other hand, due to the limited management resources of government agencies, the number of NGOs that can develop cooperative relationships is limited by their cooperation capabilities. Taking these two points into consideration, the number is set according to the ratio of 1:3. Government organizations and NGOs are independent of each other in the preparation process of emergency resources, so it is assumed that the supply quantity of emergency response organizations is a set of numbers conforming to a normal distribution.

In order to reflect the types of different NGO organizations in the cooperation strategy, the parameter p_{lcl} of NGO localization rate is introduced, which means the proportion of local organizations in all NGOs. Generally, about 15% of local organizations participate in disaster response NGOs [38], so we set $p_{lcl} = 0.15$. There are differences in disaster relief coverage between local and non-local NGOs. Assuming the disaster area coverage of local NGOs as 10% means that local NGOs can connect up to one-tenth of the disaster-stricken nodes and distribute materials. The coverage of international NGOs is 50% [38]. In order to further refine the emergency conditions of disasters and respond to the government's information accuracy cooperation principle, the parameter γ_{infor} is introduced to describe the degree of information scarcity of disasters. The details of the simulation parameters are tabulated in Table 1.

Table 1. Basic information of parameters.

Parameter	Explanation
N_d	Number of affected regions
M	Types of items required in disaster areas
$Dmd_{i,j}$	Demand of material j of affected region i
N_{gov}	Number of government disaster relief organizations
$Sup_{gov_{i,j}}$	Relief materials from government organizations
N_{ngo}	Total number of NGOs
p_{lcl}	Localization proportion of NGOs
N_{ngo_lcl}	Total number of local NGOs
N_{ngo_nlcl}	Total number of non local/international NGOs
$Sup_{ngo_{i,j}}$	Relief materials from NGOs
$coop_info$	Information cooperation scope
$coop_mat$	Material cooperation scope
$coop_mat_lead$	Material distribution leader

4.2. Optimal Partnering Strategy Analysis

Figures 2–5 show the simulation results of the optimal partnering strategy under different disaster conditions. The vertical axis represents the accuracy of the information.

The closer to the origin, the higher the ambiguity of the information. When the information level is 0, it means that the disaster information is completely lacking, and only fuzzy judgment can be made by experience and historical data. When the information level is 1, it means that the disaster information is complete. The axis of abscissa represents the level of materials. The closer to the far point, the less the total amount of resources that disaster relief organizations can provide. When the material level is 0, it means that the material is completely lacking. When the material level is 1, it means that the total supply of materials provided by the disaster relief organization is equal to the total demand of the disaster area. When the material level exceeds 1, it means that the total supply of materials is excessive.

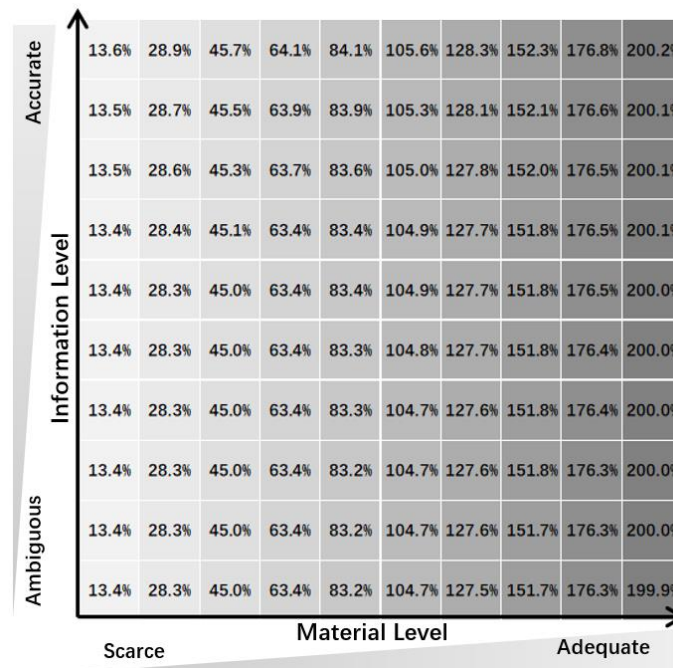


Figure 2. Best disaster relief effect under different disaster conditions.

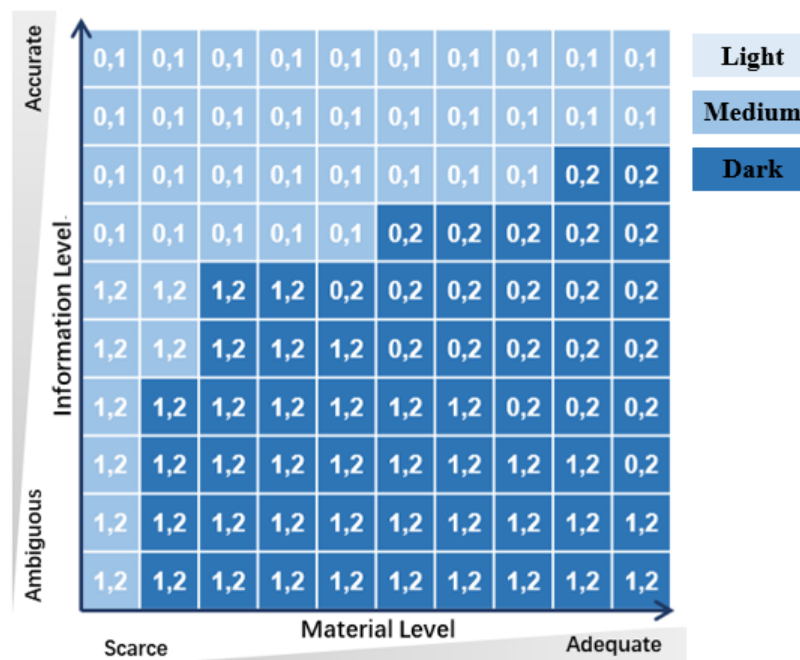


Figure 3. Optimal partnering principle under different disaster conditions.

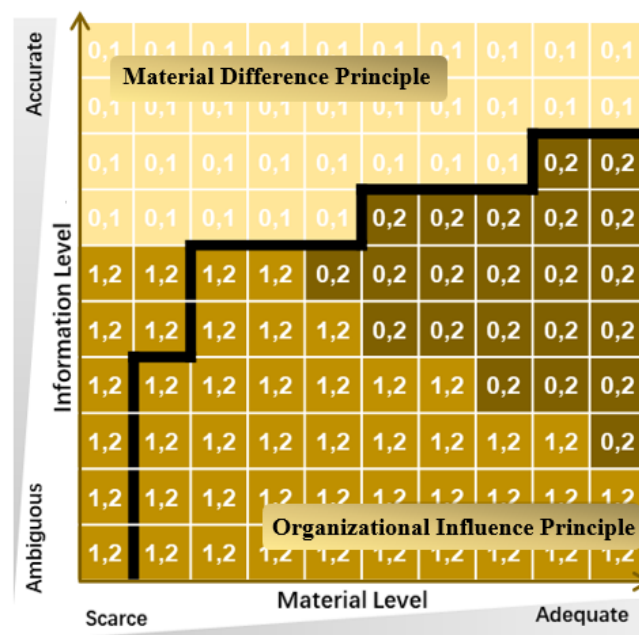


Figure 4. Optimal partnering scope under different disaster conditions.

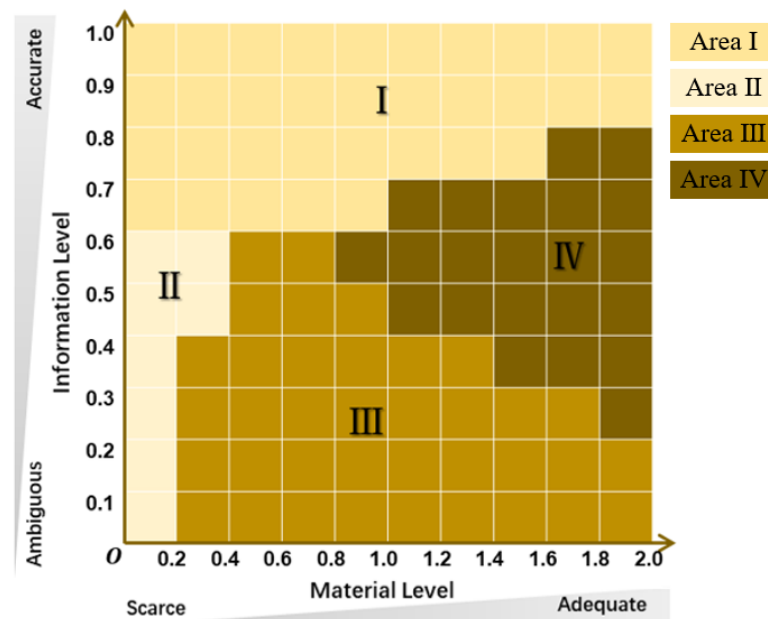


Figure 5. Best partnering strategy under different disaster conditions.

Figure 2 illustrates the best disaster relief effect under the disaster conditions of different material levels and information levels. The number on each grid represents the average satisfaction degree of the affected node under the condition of the information level and material level. The depth of the background color represents the degree of satisfaction of the affected point. It can be seen that with the change in material level and information level, the satisfaction degree of the disaster-affected point changes. The change in the material level plays a decisive role in the satisfaction of the disaster-stricken point. Observing along the horizontal axis, it can be found that as the total amount of materials that the disaster relief organization can provide increases, the satisfaction of the disaster-affected point gradually increases. Overall, the trend is consistent with the proportion of materials that disaster relief organizations can provide. However, except for the condition of extreme abundance of materials, the degree of satisfaction of disaster-affected points

in other cases is lower than the ratio of material supply. This is because according to Equation (2), for a single disaster-affected node, the part that exceeds its actual material demand is regarded as excess material supply and is excluded from calculation. The change in the information level only slightly affects the satisfaction of the affected points. Along the vertical axis, when the information gradually transitions from fuzzy to precise, the degree of satisfaction of the affected points increases slightly. It can be seen that when the government's information level is extremely low, there is no obvious deterioration of the disaster relief situation, which is due to the improvement in the government's grasp of information through appropriate partnering strategies and cooperation scopes.

Figure 3 shows the optimal cooperation principle under the disaster conditions of different material levels and information levels. Among them, the background color represents the principle of cooperation, and the blue from dark to light represents the principle of organizational influence (dark blue), the principle of material difference (medium blue), and the principle of information accuracy (light blue). It can be seen from Figure 3 that when the material level is relatively scarce, establishing a cooperative relationship based on the principle of material difference has a better disaster relief effect. When the material level is gradually increased, establishing a cooperative relationship with organizations with high organizational influence can bring better disaster relief results. This is due to the lack of material conditions, which make government agencies urgently need differentiated resources to better carry out emergency relief work. However, when the material level is improved, it should choose to cooperate with organizations with greater organizational influence, and the material gap at this time is made up by material cooperation.

From the dimension of information level, the transition from the principle of material difference to the principle of organizational influence would be delayed with the improvement in information level. When the information ambiguity is high, government agencies turn to organizations with high organizational influence for cooperation at a lower material level. While the accuracy of information increases, the government would change the cooperation principle to a higher material level until the accuracy is very high and only adopts the material difference principle. This is because, on the one hand, high information accuracy enables the government to better grasp its lack of materials, enabling government agencies to screen cooperative organizations that can make up for the supply gap in a more precise manner. On the other hand, high organizational influence means that the NGO has more partners, and the NGO will have higher information accuracy after updating the information. As a result, this advantage is diminished as government agencies themselves become more informed.

At the same time, when government agencies establish disaster relief cooperation based on the principle of best cooperation, they mainly adopt the principle of material difference and organizational influence. The principle of information accuracy will not be mainly adopted. This is due to the fact that government agencies can compensate for this principle by adjusting the way information is cooperated. For example, after establishing cooperation through the principle of material difference, the accuracy of information can be improved by strengthening the information exchange with the cooperative organization, without giving up more important differentiated material resources.

Figure 4 illustrates the optimal partnering scope under the disaster conditions of different material levels and information levels. (a, b) in the box represent information and material cooperation scopes. For a, 0 and 1 represent no information cooperation and information cooperation, respectively. For b, 0, 1, and 2 represent no material cooperation, material cooperation led by government agencies, and material cooperation led by NGOs. It can be seen from Figure 4 that there are mainly three situations for the optimal cooperation mode under different disaster conditions. They are (0, 1) indicating that the information is not cooperative and the government leads the material cooperation, (0, 2) indicating that information is not cooperative and NGOs lead material cooperation, and (1, 2) indicating information cooperation and NGO-led material cooperation. From the perspective of information cooperation, when the information level is low, the best

cooperation mode of government agencies is $a = 1$, which means information cooperation. With the gradual improvement in the level of disaster information, the situation of information non-cooperation gradually appears. This is because with the improvement in the government's information level, it cannot rely on the information provided by cooperative organizations, so it chooses the way of information non-cooperation.

At the same time, as the materials become more abundant, the situation that government agencies choose not to cooperate with information would appear sooner. That is, as the material level γ_{mat} increases, the government will choose not to cooperate with information when the accuracy of information is worse. For example, when the material level is only 0.1, the government agencies choose not to cooperate with information when the information level γ_{infor} is 0.6; when the material level γ_{mat} is 1.4, the government agency chooses information non-cooperation when the information level γ_{infor} is 0.4, and when the material level γ_{mat} is 2, the information level γ_{infor} that government agencies choose not to cooperate with information is reduced to 0.2. This is because, with the gradual abundance of materials, the demand for materials received by the disaster-stricken areas has exceeded the demand. At this time, even if accurate disaster information is not available, a large amount of even redundant resources can be sent to each disaster-stricken point to meet the emergency needs. Therefore, government agencies choose not to cooperate with information, and this trend would become more obvious as the supplies gradually become abundant.

From the perspective of material partnering, no matter what the situation is, there is no case of material non-cooperation with $b = 0$. The difference in material cooperation scopes lies in whether the leading party is a government agency ($b = 1$) or an NGO ($b = 2$). When the information level of government agencies is at a low level, the optimal value of b is always 2, which means it is better for NGOs to allocate material cooperation. When the level of information gradually increases, the best allocator for disaster relief supplies is in a mixed state. At this time, the allocator is determined by the level of supplies. Government agencies dominate when the level of supplies is low, and NGOs dominate when the level of supplies is high. As the level of information improves further, it is better for government agencies to lead the collaborative distribution of emergency supplies.

It is easy to understand that when the ambiguity of government information is high, NGOs would lead the allocation, and when the accuracy of government information is improved, government agencies will lead the allocation. When the accuracy of the government's information is relatively high but has not yet reached 1, there is a situation where the government takes the lead when supplies are scarce and NGOs take the lead when supplies are plentiful. For example, in a row where γ_{infor} is 0.8, when γ_{mat} exceeds 1.6, the distribution led by the government becomes dominated by NGOs. This is due to the difference in allocation principles between government agencies and NGOs. The government adheres to the principle of distribution according to the proportion of the demand of the disaster-stricken point, so that when the material level is low, more disaster-stricken points can obtain resources. On the other hand, NGOs distribute one by one, and can only get better results when the materials are more abundant. This also explains the shift in dominance between government agencies and NGOs when information levels are different. With the continuous improvement in the government's information level, this dominant shift will gradually be delayed. The government can complete the distribution of materials well by relying on its own information and resources. At this time, the distribution of materials led by NGOs requires extremely rich materials.

Integrating the analysis results of cooperation principles and cooperation scopes, we can obtain the best cooperation strategies corresponding to the four regions shown in Figure 5.

Area I represents a state with a high level of information. The best strategy I at this time is to select partners based on the principle of material difference, and carry out information non-cooperation and government-led material distribution. Area II corresponds to the state of extremely low material level and low information level. At this time, the best strategy II is

to select partners based on material differences and carry out information cooperation and NGO-led material distribution. Area III represents a lower level of information. Except for the state of extremely low material level at this time, the corresponding optimal strategy III should establish cooperation between information and materials based on the principle of organizational influence, and the distribution should be led by NGOs. Area IV corresponds to the situation where the material level is high and the information level is medium. The best strategy IV is to select partners based on the principle of organizational influence and distribute materials led by NGOs.

5. Discussion

During the disaster response process, different types of disaster relief organizations have their own advantages [39], such as the organizational influence formed in the long-term development of the organization, or adequate regional emergency material reserves, or accurate information from local sources. These aspects of advantages are highly important in the disaster relief process [40]. Therefore, in order to carry out disaster relief activities smoothly, the government agencies need to choose disaster response partnership carefully. Contingency theory states that prudent, adaptive, and situational workarounds are required to address organizational challenges [41]. Similarly, when the government formulates organizational relationship strategies, it needs to consider not only the current disaster conditions, but also its own internal capabilities. The government should select disaster relief organizations with different resource advantages to carry out disaster relief activities together.

Specifically, in the emergency stage of disasters with rapid disaster conditions and a lack of supplies, government agencies should give priority to solving the problem of lack of emergency resources. Sufficient emergency supplies are the basis for the smooth development of disaster relief activities [38]. Disaster relief organizations should be screened based on the principle of material differences. Then, based on the level of disaster information, government agencies should determine whether to carry out information cooperation, and choose the leading party for material distribution decisions. Information sharing and communication and coordination are the basis of relationship building among emergency response organizations [22,23]. It is found that information cooperation should be facilitated when the information is vague, and material cooperation with other social disaster relief organizations should be emphasized. When the information is more accurate, the investment in information cooperation can be appropriately reduced, and more of the leading power of materials should be in the hands of government agencies.

With the gradual slowdown of the disaster situation and the gradual abundance of material supplies, the choice of high-efficiency partnering strategies for government agencies still varies with the level of internal disaster information. When the government has a clear understanding of the situation in the disaster-stricken area, it should choose partnerships based on the principle of material differences, and put more emphasis on giving full play to the coordination and leadership role of government agencies. When the disaster information is not fully grasped, it is necessary to screen disaster relief organizations based on the principle of organizational influence, and establish information cooperation with high-influence organizations. In addition, power should be moderately delegated on the basis of full cooperation, and the distribution of emergency supplies should be jointly decided.

Establishing a stable partnership is the basis for effective coordinated action among emergency response organizations [42]. For disaster relief organizations that specialize in emergency supplies or high impact, in the severe stage of disasters, the information cooperation relationship between disaster demand information and supply information should always be maintained. At the same time, such disaster relief organizations should carry out their own decision making and material distribution appropriately. With the gradual relief of the disaster situation, the frequency of information communication can be appropriately reduced. The disaster relief organization's independent decision-making

power for disaster relief can be recovered. For disaster relief organizations with obvious advantages in disaster information, since most of these organizations are local organizations, they have incomparable advantages in collecting real-time event development trends and the needs of disaster-stricken people. Therefore, it is possible to properly establish information communication channels with such organizations and weaken the cooperation demand for emergency supplies. Differential relationship strategies are also required for typical emergency organizational roles. Specifically, for material suppliers, we should simply establish a material cooperation relationship, and allocate more information cooperation inputs to other disaster relief organizations. For material distributors, due to the needs of some of their material distribution functions, information cooperation should be established at the same time when the disaster is severe. For information channel partners, they mostly establish cooperative relationships based on organizational influence, which can have the functions of collecting and widely disseminating disaster information.

6. Conclusions

In this study, we conducted an in-depth analysis of the disaster relief cooperation process from organizational partner principles, and organizational cooperation scopes. A complex organization network model for disaster response organizations was established, and on the basis of the model, simulations of information cooperation, material cooperation, and distribution decisions in the disaster relief process under different emergency conditions were carried out. Based on the analysis of disaster relief performance evaluation, we then discussed the optimal organizational partnering strategy for environmental contingency, the best cooperation scope under the established partner principle, and the optimal partnering strategy for typical partnering roles.

We found that the partnering strategies applicable to different disaster conditions are context-dependent in the selection of organizational partners for disaster response. In the stage of a disaster outbreak where materials are extremely scarce, the principle of material difference is the primary principle for the government to choose partners. While as the material reserves are gradually able to cover emergency needs, the government should give priority to large-scale NGOs with high organizational influence to establish cooperation. Therefore, when specifically determining the principle of partnership, the government chooses the principle of material difference at a low level of material supply. Under the condition of abundant material resources, if the information is accurate, the principle of material difference should be chosen; otherwise, the principle of organizational influence should be chosen.

As for cooperation in information resources, as the government's ability to grasp disaster information improves or materials can fully meet all emergency needs, information cooperation becomes an unnecessary option, and additional communication will substantially increase communication costs but will hardly improve the disaster relief effect. At the same time, for the partnering relationships established with different partnership principles and typical disaster relief roles, the material and information cooperation scopes under different disaster conditions are also different, which is determined by the matching between organizational advantages and disaster response tasks. More specifically, for the scope of cooperation in information, when there is sufficient information available, non-cooperation in information can be selected, and in other cases, information should be shared all the time. For the scope of material cooperation, in most cases, the allocation of materials should be led by NGOs. Only when the government has sufficient control over the disaster situation can the material distribution be led by the government.

This study contributes to the related body of knowledge by unveiling the choice of organizational strategies for disaster response from the perspective of organizational structure and environmental contingency. For the theoretical contributions of this paper, first, this paper reveals the formation process and mechanism of the relationship between disaster relief organizations from the perspective of complex network modeling, which provides an explanation for in-depth understanding of the cooperation structure of disaster

relief organizations. Second, the analysis of disaster relief activities on the disaster relief network expands the research scope of network science theory in the field of disaster management. Third, by discovering that the organizational structure effects depend on internal and external environmental conditions such as disaster conditions, information conditions, and disaster relief organization's own capabilities, it enriches the organizational management theory of disaster response. For the managerial implications of this paper, this study provides references for how disaster response organizations choose partners in the disaster relief process. Disaster response organizations should first consider the current disaster conditions and choose partners on the basis of evaluating their own resource capabilities. Moreover, the selection process of partners is dynamic, and it is adaptable to the development of and changes in the disaster situation, and the partnering strategy is adjusted accordingly as the disaster situation changes. Nevertheless, this research has the following limitations. First, the paper mainly considered government agencies and NGOs, without considering other disaster relief participating organizations. In addition, we did not consider the national attributes of disaster relief organizations in our research, as multinational organizations may lead to more organizational coordination issues. Future research could include more types of disaster relief organizations and further enrich the attributes of disaster relief organization.

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