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Research on the Construction of a Natural Hazard Emergency Relief Alliance Based on the Public Participation Degree

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Abstract: At present, in light of new situations and the new task of natural hazard response, effective public participation in emergency relief has become an urgent task that can reduce economic losses and casualties. The purpose of this paper is to construct a natural hazard emergency relief alliance and analyze the mechanisms and dynamics of public participation. In this study, methods based on a multi-agent system were adopted, and we used different participants as heterogeneous agents with different attitudes and resources. Using four different processes, namely participation proposals, negotiation interval, negotiation decision-making function, and participation strategy, we comprehensively construct an emergency relief alliance for natural hazards. In addition, the dynamic public interaction process is analyzed and a construction algorithm is given. The experimental results show that the proposed method has better performance in alliance formation efficiency, negotiation efficiency, and agent utility. The research results illustrate that the public's attitudes and resources influence the construction of emergency relief alliances; a greater degree of public participation contributes to a more efficient alliance formation. The findings of this study contribute to the promotion of public cooperation and improvement in the efficiency of natural hazard emergency relief.

Keywords: natural hazards; multi-agent system; emergency relief; public participation

1. Introduction

As a result of its vast territory, complex environmental conditions, large population, low disaster prevention, and management capabilities, China has suffered serious losses and used a great deal of human and material resources for natural hazard prevention and relief. The government plays an important role in emergency management, but it is difficult to achieve high efficiency by only relying on the strength of the government [1]; therefore, determining how the public can effectively participate in natural hazard emergency relief has become an urgent task. Emergency relief refers to the money, goods, rescue, and services provided for victims after natural hazards [2]. Practice has proven that due to traffic inconveniences, secondary disasters, and an imperfect system, public participation has

caused a certain degree of traffic congestion and disorder. Therefore, determining how to organize the public to participate in emergency relief in an orderly and effective way has become a popular topic.

In 2016, the new "National Natural Hazard Emergency Relief Plan" was released in China, but the subject of public participation in emergency relief has concerned scholars.

Questions to clarify this emergency plan are listed below.

a.   What technology should be used to formalize the emergency relief alliance?
b.   How is the emergency relief alliance constructed? What about its performance?
c.   Does the participation degree affect emergency alliance construction?

This paper will address these questions. The remainder of this paper is structured as follows. In Section 2, we review relevant literature and identify the research gap that this paper focuses on. In Section 3, we give a formal expression based on a multi-agent system negotiation interval, the participation decision function is presented, and the interaction process of the participants is analyzed. Section 4 gives the formal definition of the participation degree and participation strategy function, and an algorithm for constructing an emergency relief alliance is proposed. In Section 5, we compare our approach and the competing algorithms and summarize our results. Conclusions and an outlook on future research directions are given in Section 6.

Our contributions are as follows: We propose the establishment of a method for creating a natural hazard emergency relief alliance. At present, research regarding the field of public participation in emergency management mainly focuses on macroscopic, qualitative research, such as participation status and problems, influencing factors, and participation strategy; however, quantitative research is mainly concerned with resource allocation, personnel evacuation and path planning, and a lack of quantitative analysis of participation models. This paper presents a model for an emergency relief alliance and proposes a corresponding algorithm.

Moreover, taking into account that different participants have different resources and participation attitudes, we put forward the concept of public participation degree. The adoption of multi-agent technology reflects autonomy, and a natural hazard emergency relief alliance based on the public participation degree is proposed. The experiment shows that our method is reliable and applicable.

2. Literature Review

2.1. Disaster Risk Reduction

Many scholars have done large amounts of research in the field of disaster risk reduction. Adnan et al. [3] selected eleven precedent (model) cities to study their various initiatives for reducing coastal flood risks. Their findings showed that protecting cities from flooding and reducing exposure to floods are two different but interrelated approaches to disaster risk reduction (DRR). Few et al. [4] discussed findings from a two-year research project on DRM (Disaster Risk Management) capacity development. They pointed out that adaptability, ownership, sustainability, the inclusion of actors, and scales reflect the capacity of DRR. Sim et al. [5] explored the way that social workers can apply transdisciplinary strategies to work with other professional practitioners and stakeholders in meeting disaster risk reduction needs in a remote Chinese village. Marlowe et al. [6] emphasized the importance of incorporating the concepts of reach, relevance, receptiveness, and relationships into a DRR approach; these concepts were presented as an embedded guiding framework that can aid in disaster communication. Carrao et al. [7] assessed drought hazard (DH) changes for the mid-century (2021–2050) and late-century (2071–2099). The results showed that a major challenge for risk management is for human populations or their activities to not adapt to DH changes; instead, they should continue developing global initiatives that mitigate their impact on the entire carbon cycle by the late-century. Migliorini et al. [8] conducted surveys and interviews with National Sendai Focal Points and stakeholders in science and research, governmental agencies, non-governmental organizations, and industry, enhancing data interoperability for disaster risk reduction. Marchal et al. [9] pointed out

that reinsurance and insurance industries play a role in helping to manage risks and improve disaster risk reduction (DRR) as well as loss prevention. Webb [10] stated that early tropical cyclone warnings are necessary but not sufficient to ensure that households and communities are prepared. There is a strong case for investments in mid- to long-term DRR focused on community and household capacity, prioritizing women's active and equal participation as community leaders, and disability inclusion. Totaro et al. [11] drew maps of monothematic and synthetic indices to describe the hazard status of metropolitan areas; a hazard hotspot map was also elaborated to identify areas with high hazards.

2.2. Emergency Relief for Natural Hazards

Many scholars have researched in the field of natural hazard emergency relief. Narayanan et al. [12] built a disaster recovery network that provides food, water, shelter, medical services, and other relief resources for the affected people through reliable communication network coordination to avoid social chaos caused by natural hazards. Wachinger [13] pointed out that personal experience, government investment, experts' awareness of disaster risk, and media reports have a significant impact on natural hazard emergency relief. Wex et al. [14] proposed a decision support model of disaster emergency relief based on the heuristic algorithm of Monte Carlo, which can effectively allocate and dispatch rescue units, greatly reducing the casualties and economic losses. Oral et al. [15] assessed the impact of earthquake experience on earthquake preparedness, and the results showed that disaster experience, residential area, and disaster relief work have an obvious relationship, and reasonable suggestions were put forward for disaster relief. Berariu et al. [16] analyzed the cascade effects of natural hazards and investigated their impact on relief operations concerning critical infrastructure; in particular, the transport infrastructure, electricity, and human health.

Alem et al. [17] took into account practical characteristics, such as budget allocation and fleet sizing of multiple types of vehicles, and developed a new two-stage stochastic network flow model to help decide how to rapidly supply humanitarian aid to victims of a disaster. Toyasaki et al. [18] focused on horizontal cooperation in inventory management, which is currently implemented in the United Nations Humanitarian Response Depot (UNHRD) network, and proposed a policy priority for the first-best system of optimal inventory management. Deo [19] used integrated disaster management technology, a quantitative method, and big data analysis to create disaster and early warning models to reduce the impact of these disasters and provide a comprehensive method for disaster management systems. Nassereddine et al. [20] presented a multi-criteria decision-making approach to evaluate emergency response systems by taking into account the interaction synergy. Borowska-Stefanska et al. [21] developed an optimization pattern for the process of a preventive evacuation of people from flood-risk areas aimed at mitigating the negative effects of the flood.

Some scholars have researched natural disaster management based on multi-agent system theory. Izida et al. [22] pointed out that communication in natural disasters can be simulated through the multi-agent paradigm, which provides better assistance in emergencies of natural disasters. Yue et al. [23] built a disaster emergency collaborative decision-making framework based on a multi-agent system, designed a collaborative decision-making model, and achieved a natural disaster dynamic emergency decision-making process. Naqvi et al. [24] proposed an agent-based model of a stylized low-income region to study the impact of natural disasters on population displacement, income, prices, and consumption with a focus on low-income groups. Na et al. [25] developed an agent-based discrete-event simulation (ABDES) modeling framework based on an embedded GIS module for making no-notice natural disaster evacuation planning. Lee et al. [26] presented a novel and efficient rescue system with a multi-agent simultaneous localization and mapping (SLAM) framework, which was proposed to reduce the rescue time while rescuing the people trapped inside a burning building.

2.3. Public Participation in Natural Hazard Emergency Relief

Since Sherry Arnstein published his famous paper "A Ladder of Citizen Participation" in 1969 and John Clayton Thomas proposed an effective decision model of citizen participation, more and more

scholars have studied public participation. The research on public participation focuses on community development, e-government, social governance, environmental science, and democratic construction.

Chen et al. [27] developed an Environmental Community Consultative Group (ECCG), a small local group that can promote public environmental awareness, improve public environmental behavior, and facilitate public engagement in environmental management. Werner [28] pointed out that policymakers' dependencies, motivations, and decision-making processes lead them to evaluate firms by using a sociopolitical reputation as a differentiating heuristic. Say et al. [29] shed light on the basic principles related to the process of public participation and how effective participation can be attained in SEA (Strategic Environmental Assessment) practices at the policy, plan, and program levels. Park et al. [30] aimed to investigate the legal opportunities of public participation in managing state forests in the case of the Republic of Korea (ROK), which provide legal insights on promoting public participation in managing state forests. Xi [31] analyzed the problems of public participation in environmental protection and put forward three ways to optimize the system of public participation in environmental protection. Li [32] indicated that it is not necessary to impose a kind of external force on residents through empowerment, then make them engage in tourism. Self-empowerment means consciousness, awareness, and promotion of participation ability; these are fundamental and critical points for community residents participating in tourism. Xiao et al. [33] established a structural equation model to identify key factors influencing citizen environmental willingness to participate in waste management, and this indicated that the most important influencing factor was citizen knowledge, followed by social motivation, while institutional factors had the smallest positive effect. Ruiz-Villaverde et al. [34] identified several advantages of public and stakeholder participation in water management, such as the better use of knowledge and experiences from different stakeholders, increases in public acceptance, and reduced litigation, delays, and inefficiencies in implementation. Chen et al. [35] pointed out that government supervision has a positive effect on environmental governance and can urge enterprises to actively perform pollution control. The effect of government supervision is constrained by the income and costs of enterprises, and the penalties for passive pollution control should be raised.

In summary, scholars have done a lot of research in the field of natural hazard emergency relief and public participation. However, most of the studies are focused on issues such as the positive role of public participation, the influencing factors, and the ways of public participation. Some scholars have put forward quantitative models and methods of emergency management, but multi-agent system technology is rarely used, and it is mostly used for research of material distribution and personnel evacuation. The agent has the characteristics of autonomy, sociality, and initiative. It also has some human characteristics, such as knowledge, belief, obligation, intention, and so on. So, we can regard the public as agents, and management of such emergency relief is improved by combining human intelligence with efficiencies of multi-agent systems, and we adopt agent automatic negotiation coalition technology [36] to carry out our research.

3. The Establishment of the Natural Hazard Emergency Relief Alliance

3.1. The Formalization of the Natural Hazard Emergency Relief Alliance

The public refers to the masses, nongovernmental organizations (NGO), profit organizations, and individuals. The participants of natural hazard relief include governments and the public. We define the government, social masses, NGO, profit organizations, and individuals as agents. The natural hazard alliance, composed of multiple agents, is a connected graph with the agent as the node. $Agents = \{At_1, At_2, \ldots, At_n\}$, where $Agents$ is set of agents. The agent that communicates directly with At_i is defined as the immediate neighbor of At_i, expressed as $DN(i) = \{i|(i,j) \in E, i \neq j\}$, where E represents the set of edges that are connected between agents. R_i is the resource that At_i can provide when carrying out natural hazard relief. The multiple agents may form alliances of $RA_1, RA_2, \ldots, RA_n \in 2^I$, where each member At_i in the alliance RA_i has the resource R_i, so that the

resources that the alliance RA_i owns are described as $R_{RA} \in \prod_{i \in RA} R_i$. After the formation of alliance RA_i, the overall utility can be obtained as $P(R_{RAi}) \in Z^+$, which represents the aid given to the victims after the alliance was established. Based on the theory of stakeholders, the public, whether organizations or individuals, gains corresponding utility from participating in natural hazard relief activities; for example, an enterprise provides excavators and transportation vehicles, and gets rewards of social recognition and good reputation. The masses and volunteers get psychological satisfaction and a sense of accomplishment through donations and rescue services, which belong to the invisible utility. Thus, each member At_i can get a utility value, which is $p_i \in Z^+$, $\sum_{i \in RA} p_i = P(R_{RA})$.

3.2. Participation Proposal

At_i can invite direct neighbor At_j to join an alliance by sending a proposal when At_j agrees with the proposal; At_i and At_j will combine their resources to complete a disaster relief mission and receive corresponding utility. At_i sending a proposal to At_j defined as follows.

$$S_{ij}(R_i) = ((R_{RA-i}, R_i), p_i^{R_i}) \tag{1}$$

where $S_{ij}(R_i)$ means that At_i sends a proposal to At_j. R_{RA-i} is the total resources owned by alliance RA before joining At_i; $RA-i$ stands for the alliance without At_i; RA is the alliance after At_i joins; $p_i^{R_i}$ is the utility that At_i gained after At_i joins the alliance RA and provides resource R_i. When At_i sends a proposal to neighbor At_j, At_j will evaluate the utility before deciding whether to accept the proposal or not. If At_i's proposal does not meet At_j's minimum requirement, At_j will send a counter-proposal S_{oppose}^{ji} and will require higher utility. At_i might not immediately agree to the counter-proposal, and will continue to send a new anti-proposal S_{oppose}^{ij} to At_j, assigning a new utility value to At_j at the same time. In this way, both participants in the alliance will conduct several rounds of negotiation.

3.3. The Negotiation Interval

The negotiation interval is the fluctuation range of the utility distribution between the two participants, that is, the minimum utility and the maximum utility. Suppose that At_i has formed an alliance RA with other agents; when At_j joins the alliance RA, the added utility is given in Formula (2).

$$\Delta P(R_{RA}, R_j) = P(R_{RA}, R_j) - P(R_{RA}) \tag{2}$$

The maximum utility that At_i can obtain is given in Formula (3).

$$p_i^{\max}(R_{RA}, R_j) = \Delta P(R_{RA}, R_j) \tag{3}$$

The optimal participation proposal that At_i received is $S^* = \max_{s \in proposal_i} p(S)$, where $proposal_i$ represents the participation proposal set that At_i received. The At_i's minimum utility is given in Formula (4).

$$p^{\min}(R_{RA}, R_j) = \max(0, p_i(S^*)) \tag{4}$$

Therefore, the negotiation interval is given as follows.

$$\left[p^{\min}(R_{RA}, R_j), p^{\max}(R_{RA}, R_j) \right] \tag{5}$$

3.4. The Negotiation Decision-Making Function

The negotiation decision-making function reflects that agents choose their behavior with the principle of maximizing their own utility after receiving the participation proposal. S_j represents the proposal that At_i received from At_j, S_{oppose} represents the counter-proposal; S_{oppose} is generated

according to the participation strategy. $S^*_{m\_join}$ represents the participation proposal sent to the neighbor At_m that has the highest participation degree. $\overline{S}$ represents the history of the participation proposal; it is a set of participation proposals that At_i had proposed. The participation strategy of the inviter agent is defined as a Formula (6). The participation strategy of the invited agent is defined as Formula (7).

$$T_i([p_i^{\min}, p_i^{\max}], \overline{S}) = p_i^{\min} + f_{\partial_{ij}^n}(x)(p_i^{\max} - p_i^{\min}) \tag{6}$$

$$T_i([p_i^{\min}, p_i^{\max}], \overline{S}) = p_i^{\max} - f_{\partial_{ij}^n}(x)(p_i^{\max} - p_i^{\min}) \tag{7}$$

where $f_{\partial_{ij}^n}(x)$ represents the participation strategy function; the participation strategy can be divided into three types according to the different values of participation attitude values ∂_{ij}:

(1)   Negative type ($\partial_{ij}^n < 0$). This means that At_i makes a quick concession at the start stage of the participation negotiations and quickly reaches its maximum concession state.
(2)   Neutral type ($\partial_{ij}^n \approx 0$). This means that the concession process of At_i is approximately linear, i.e., the utility of agents varies linearly with the number of participation negotiation rounds.
(3)   Positive type ($\partial_{ij}^n > 0$). This means that At_i makes a slow concession at the starting stage of the participation negotiations, only makes a quick concession when $x = round/MAX\_Round \to 1$, where *round* is the number of negotiation rounds, with an initial value of 0; *MAX_Round* is the maximum number of negotiation rounds.

$S_k^*(k \in proposal_i)$ represents the participation proposal sent by At_k that belongs to the best alliance, that is, At_k can provide the highest utility for At_i in the neighborhood.

$$S_k^* = \max_{k \in DN(i) \cup \{i\}} p_i(T_i([p_i^{\min}, p_i^{\max}], \overline{S_k})) \tag{8}$$

The decision function for At_i that participates in the alliance is given in Formula (9):

$$S_{Decision i} = \arg\max(S_j, S_{oppose}S_k^*, S_{m\_jon}^*) \tag{9}$$

The negotiation process of agent participation in the alliance is to produce different types of participation proposals: Acceptance proposal, counter-proposal, new proposal, and rejection proposal, so that decisions that can be made by At_i as follows. (1) At_i proposes a counter-proposal according to the participation strategy. (2) At_i sends a proposal to the agent who belongs to the optimal alliance and invites At_i to join the alliance, and At_i joins the optimal alliance. (3) At_i creates a new alliance, namely At_i sends a participation proposal to its neighbor At_m and invites At_m to participate in the alliance.

3.5. The Agent Interaction Process

The state of agents is defined as *State* = {Sleep, Wait, Done}, where the Sleep indicates the initial state of the agents and when waiting for other agents to send participation proposals; the Wait indicates that the agent has sent a participation proposal to another agent and wait for its response; the Done indicates that the agent has accepted a participation proposal and the participation negotiation has been completed.

The agent interaction process of public participation in the alliance is given as follows.

A.   Initialization: All agents are in the Sleep state when they begin to establish alliances.
B.   The interaction process: (1) When At_j sends a participation proposal to At_i, At_j sets $State_j$ = Wait; in order to avoid deadlock, all agents in the $DN\{j\}\backslash\{i\}$. $DN\{j\}\backslash\{i\}$ means that all agents cannot send a new proposal to At_j. At this time, only At_i can communicate with At_j. (2) At_i will send to At_j a counter-proposal, acceptance proposal, or rejection proposal. (3) If At_i accepts At_j's proposal, then At_i sets $State_i$ = Done. At this time, At_i will send an acceptance proposal to At_j and send a rejection proposal to the other agents; then, At_i will no longer receive any participation proposals.

At_j adds At_i to the alliance set *proposal set$_j$* and sets *State$_j$* = Sleep, and then At_j can receive the new participation proposal. (4) If At_i sends a counter-proposal to At_j, then At_j sets *State$_j$* = Sleep, and At_i sets *State$_i$* = Wait. (5) If At_i sends a rejection proposal to At_j, then At_j sets *State$_j$* = Sleep.

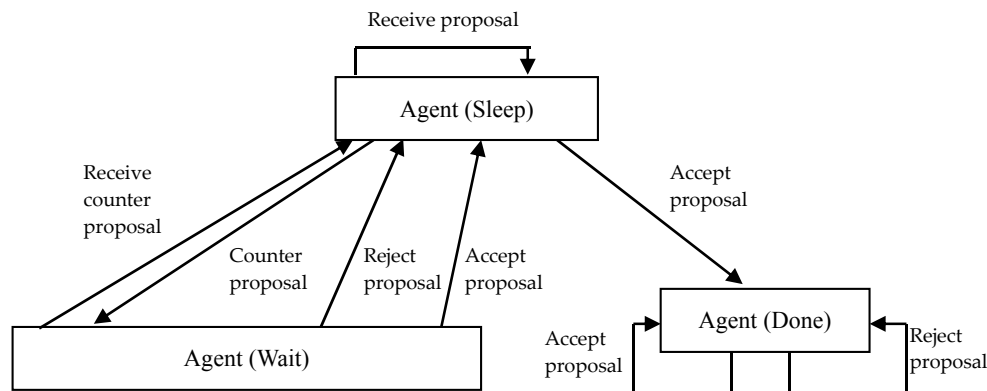The agent interaction process is given in Figure 1.

Figure 1. The agent interaction process.

4. The Participation Strategy Based on Participation Degree

4.1. The Participation Strategy Function

The participation strategy function given in Formula (10) uses an exponential function to gradually produce new proposals after concessions.

$$f_\partial(x) = e^{\partial_{ij}^n x} - 1 / e^{\partial_{ij}^n} - 1 \tag{10}$$

The domain and range of $f_\partial(x)$ are [0, 1]; they are monotonically increasing, but with different values of ∂_{ij}^n, the concave and convex of the function will change. The agent concession degree can be adjusted by changing the value of ∂_{ij}^n; ∂_{ij}^n is At_i's participation attitude value when At_j invites At_i to participate in the alliance in round n. The independent variable x is the ratio between the actual number of negotiation rounds and the maximum assignment negotiation rounds. That is, *x=round/MAX_Round*, *round* changes from 0 to *MAX_Round*, so x is guaranteed to change from 0 to 1.

4.2. The Participation Degree

The concept of the participation degree is proposed to reflect that different participants have different resources and different participation histories, and the participation process, guided by different strategies, is realized through the influence of participation degree on participation attitude value. The different values of the participation degree lead to different values of participation attitude, then lead to different participation strategies, and then lead to construction of different alliances. The details are given as follows.

Definition 1. *The historical participation degree of At$_j$ relative to At$_i$*

$$pd_{ij-ADV} = \sum_{negotiation}^{participation\_success} (i \to j) \Big/ \sum_{negotiation}^{participation\_all} (i \to j) \tag{11}$$

where $pd_{ij-ADV} \in$ [0, 1]. The denominator is the number of historical mutual proposals proposed by At$_i$ and At$_j$, the molecule is the number of successful historical negotiations between At$_i$ and At$_j$. Formula (11) reflects the probability of At$_j$ accepting At$_i$'s participation proposal in historical negotiations, which is called the historical

participation degree of At_j relative to At_i. The higher the historical participation degree is, the higher the agent's participation consciousness is, and the higher the probability of At_i and At_j building the alliance is.

Definition 2. *The current participation degree of At_j relative to At_i*

$$pd_{ij-current} = \left. |DN(i)| \middle/ \sum_{n=neighbor_i} |DN(n)| \right. \tag{12}$$

where $pd_{ij-current} \in [0, 1]$. The denominator is the sum of resources owned by At_i's neighbors, and the molecule is the number of At_j 's resources who are At_i's neighbors. When At_j has more resources relative to At_i's other neighbors, we think that At_j's current participation degree is high relative to At_i. The current participation degree reflects the resources owned by an agent. The more resources an agent has, the higher the current participation degree.

Definition 3. *The participation degree of At_j relative to At_i*

$$pd_{ij} = a \times pd_{ij-ADV} + b \times pd_{ij-current} \tag{13}$$

where $pd_{ij} \in [0, 1]$, $a + b = 1$. Definition 3 takes into account the historical participation degree in Definition 1 and the current participation degree in Definition 2. The a represents the weight of historical participation situations, and the b represents the weight of the current resource occupancy.

Based on the above definition of the participation degree, the participation attitude value of At_i relative to At_j is given as follows.

$$\partial_{ij}^n = \begin{cases} \partial_{ij}^n - \beta_\partial(pd_{ij} - \Delta T), \partial \geq \partial_{\min} \\ \partial_{\min}, \partial < \partial_{\min} \end{cases} \tag{14}$$

where the initial participation attitude value ∂_{ij}^0 can be negative, neutral, or positive. β_∂ is the influence factor of the participation degree. The bigger the β_∂ value is, the bigger the impact of participation degree on participation strategy. ΔT represents the threshold of the participation strategy. $\partial_{\min}$ represents the minimum value of the participation attitude.

By proposing the concept of the participation degree, the participation process presents the following three characteristics.

(1) For participant At_j with a bigger participation degree ($pd_{ij} > \Delta T$), At_i will reduce the participation attitude value relative to At_j, which will make the participation strategy become passive.

(2) For participant At_j with a lower participation degree ($pd_{ij} < \Delta T$), At_i will increase the participation attitude value relative to At_j, which will make the participation strategy become positive.

(3) In the process of public participation in the disaster relief alliance, agents always preferred to negotiate with higher participation attitude values.

From these characteristics, we can see that the neighbor's participation attitude value is always referenced in the process of disaster relief alliance formation. The participation attitude values of the neighbors with low participation degree are reduced and the participation attitude values of the neighbors with high participation degree are increased. Agents prefer to negotiate with the neighbor with the best cession strategy and gradually eliminate the neighbor with the lowest participation degree, which makes the participation strategy intelligent and more efficient.

4.3. An Algorithm for Establishing the Emergency Relief Alliance

We give an Algorithm 1 for establishing the emergency relief alliance as follows:

Algorithm 1: The establishment of the emergency relief alliance

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Input: Randomly generated agent networks

Output: The structure of the emergency relief alliance

{

Graph=graphGen. getGg ( );

Participation=participationInitialization ( ); //Randomly generate agent network, initialize the current participation degree and historical participation degree.

participationTemporary; //*participationTemporary* is used to save the historical participation degree.

for *times*:1→*MaxADVTime* //Construction of alliances for *MaxADVTime* rounds by dynamically updating the participation degree.

{

Agentall=initialiser. createAgents ( ); //Initialization of the agent set

Participation=participationTemporary; //Assign the value of the last round of participation degree to this agent

For *clock*:1→*MAX_Round*; //The maximum number of negotiation rounds shall not exceed *MAX_Round*

{

for *agent*: *Agentall*

{

if (*agent. Issleep* && !*nonwaiting. isEmpty*) //If the agent is not convergent, and some neighbors of the agent are in the Wait state.

{

PtDecision=agent. getPtDecision( ); //According to the negotiation decision-making function, the agent carries out negotiation and makes a decision

updateParticipation (*PtDecision, Parameters*); //Update parameters for calculating participation degree

updateState(*PtDecision*); //Update the state of agents based on the result of the participation decision

sortAgentneighbor(*Participation*); //Sort agent's neighbors according to values of participation degree; in the next round of negotiation, it will be preferred to choose the agent with the bigger participation degree.

}

End if

End for

}

clock=clock+1

End for

}

CalculateParticipation (*participationTemporary, parameters*);//Calculate the participation degree

End for

}

}

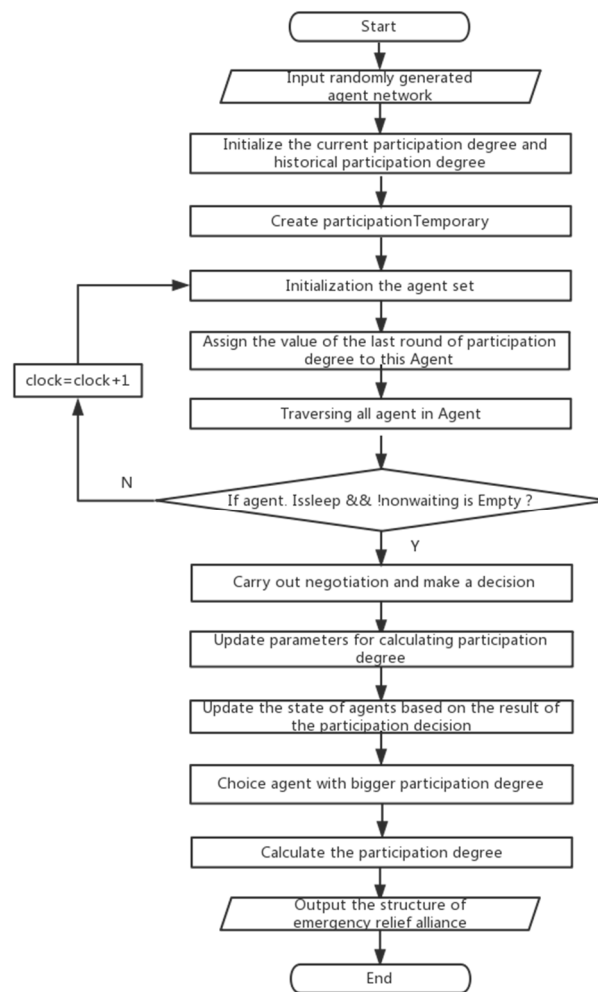The algorithm flow chart is shown in Figure 2.

Figure 2. The algorithm flow chart.

5. Experiments and Analysis of Results

5.1. Experiments and Results

The experiments adopt an Eclipse platform to simulate the formation process of a multi-agent alliance; we verify the reliability and validity of our proposed model and Algorithm 1 by comparing with References [37,38].

We did three experiments: (1) Comparison and analysis of the influence of different parameters on the participation strategy and negotiation result. (2) By comparing and analyzing Reference [37] and our proposed method, we show the concession change caused by the dynamic change of participation degree. (3) As for the performance of alliance establishment, the differences among the References [37,38] and our proposed method are compared.

The initial parameters are given in Table 1.

Table 1. Parameter assignment.

Parameter Name	Parameter Values
Agent Number	10, 50, 100, 200, 500, 800
Single Agent Cost	$C_i \sim U(0,1)$
Single Agent Utility	$p_i \sim U(1.5C_i, 3C_i)$
Repeat Times	100
Confidence Level	95%
∂_{ij}^0	15 (Positive), 0.001 (neutral), −5 (negative)
a	0.5
b	0.5
β_0	5
ΔT	0.5
Alliance Number	10

To validate the adaptability of different alliance construction methods for large-scale agent sets, the agent set scales are 10, 50, 100, 200, 500, and 800; single-agent overhead is a uniform distribution of [0, 1] and the single-agent utility is greater than the overhead. To remove the effect of a series of random numbers on the experimental results, a single alliance construction is repeated 100 times; the confidence level is 95%.

The first experiment is the comparative analysis of the effects of the parameters (a, b), β_0, and ΔT on the experimental results. The agent set scale is 100. The ∂_{ij}^0 value is a random selection of 15, 0.001, and −5. The experimental results are shown in Tables 2–4.

Table 2. The effect of (a,b) on the alliance construction ($\beta_0 = 5$, $\Delta T = 0.5$).

(a,b)	Average Negotiation Rounds (times)	Average Agent Utility	Negotiation Efficiency	Average Negotiation Success Rate (%)
(0.1,0.9)	10.30 ± 0.86	28.96 ± 4.29	2.81 ± 0.04	58 ± 4
(0.5,0.5)	7.41 ± 0.87	34.03 ± 3.21	4.59 ± 0.12	65 ± 5
(0.9,0.1)	6.11 ± 0.34	39.11 ± 4.52	6.40 ± 0.15	70 ± 6

Table 3. The effect of β_0 on the alliance construction ($(a,b) = (0.5,0.5)$, $\Delta T = 0.5$).

β_0	Average Negotiation Rounds (times)	Average Agent Utility	Negotiation Efficiency	Average Negotiation Success Rate (%)
2	15.41 ± 0.75	30.22 ± 3.25	1.96 ± 0.06	56 ± 3
5	7.39 ± 0.88	33.08 ± 4.16	4.48 ± 0.13	65 ± 5
9	6.18 ± 0.77	39.47 ± 6.41	6.39 ± 0.14	69 ± 6

Table 4. The effect of ΔT on the alliance construction ($(a,b) = (0.5,0.5)$, $\beta_0 = 5$).

ΔT	Average Negotiation Rounds (times)	Average Agent Utility	Negotiation Efficiency	Average Negotiation Success Rate (%)
0.2	6.71 ± 0.82	38.21 ± 3.21	5.69 ± 0.06	69 ± 7
0.5	7.38 ± 0.89	33.09 ± 4.15	4.48 ± 0.14	65 ± 5
0.9	16.40 ± 0.84	31.31 ± 2.23	1.91 ± 0.06	58 ± 4

We can see from Table 2 that the higher the percentage of *a* in (*a*,*b*) is, the better the negotiation performance; this is because we do not consider different network topologies so that the resource owned by the agent does not change when an alliance is formed every time, while the participation attitude towards each other is dynamically changed with the process of alliance construction. The higher the proportion of *a*, the higher the performances of negotiation success rate, average agent utility, and negotiation efficiency are. As can be seen in Table 3, the bigger the β_0 value, the better the performance of the alliance construction; this is because when the β_0 value increases, the participation degree will play a greater role in the participation strategy. As shown in Table 4, the performance of the alliance construction becomes worse when the ΔT value increases; this is because ΔT is a threshold of the participation strategy—only when the participation degree is greater than ΔT will the participation attitude tend to be moderate. When the ΔT value increases, the agent requires that negotiation partners have higher participation degrees, which makes the moderate participation attitude more difficult to achieve.

As can be seen from the above experiment, the different sets of parameters have a significant influence on the performance of the participation alliance. In order to make good comparisons among our method and the References [37,38], in the following experiments, the parameters are set compromise values, namely a = 0.5, b = 0.5, β_0 = 5, ΔT = 0.5.

In the second experiment, in order to obtain an empirical set of participation degrees, the 10 alliances are constructed and recorded as Alliance1, Alliance2, ... , Alliance10. The parameters are given in Table 1; the alliances are constructed by Reference [38] and our method, respectively. The agent set scale is 100, and positive, neutral, and passive participation strategies are adopted to construct alliances. The comparison between Reference [38] and our method (Alliance5, Alliance8, Alliance9, Alliance10) is given in Figure 3.
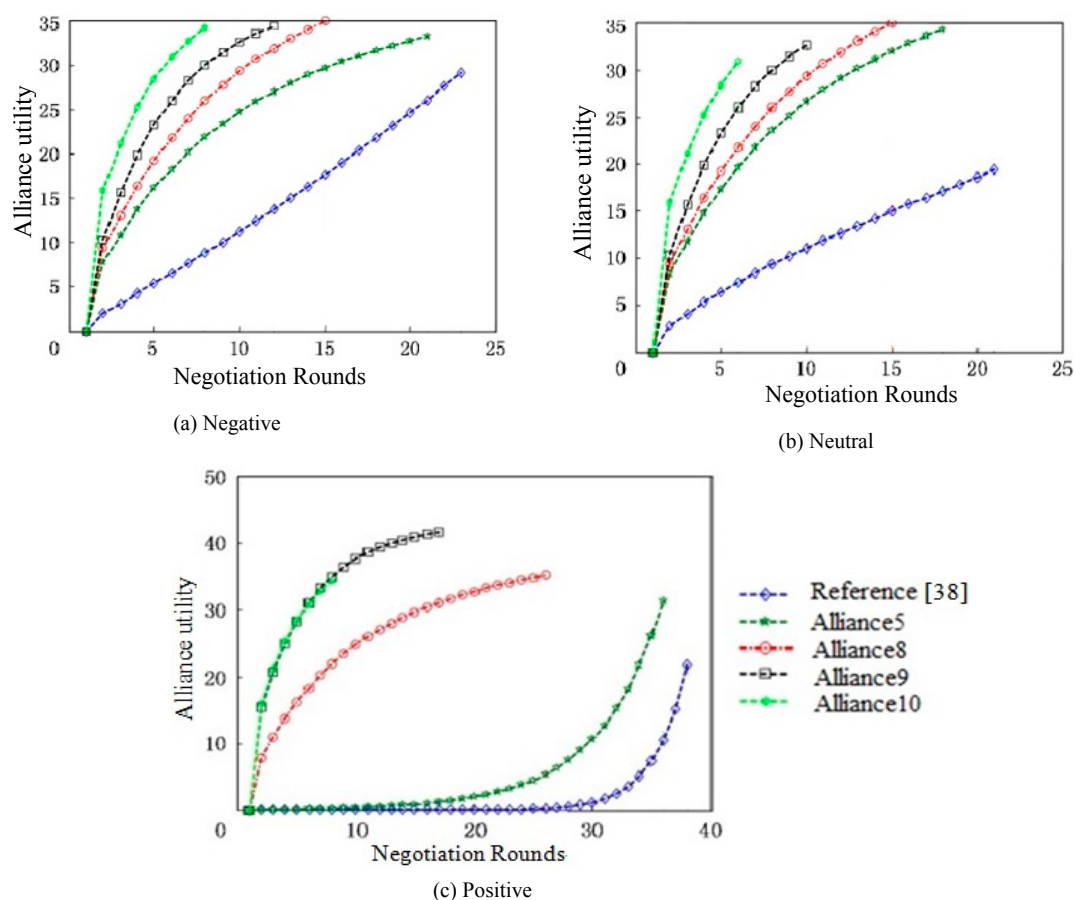

(a) Negative

(b) Neutral

(c) Positive

Figure 3. Experiment results.

As we can see from Figure 3, our proposed method can achieve better negotiation results by dynamically changing participation attitude values and selecting neighbors with better participation attitude values. The participation attitude becomes more and more moderate and achieves convergence after fewer rounds of negotiation.

In Reference [38], the parameter ∂_{ij}^n is assigned in advance and cannot change in the negotiation process, and the concession extent is relatively fixed. The ability of negotiation participants cannot be fully reflected in Reference [38], while the parameter ∂_{ij}^n is not assigned in advance in our proposed method. Once each alliance is formed, the negotiation data will be saved. The alliance formed in the next round will use this series of data to calculate the agent's participation degree, followed by the dynamic assignment of ∂_{ij}^{n+1} according to the ∂_{ij}^n value. This participation strategy based on participation degree fully reflects the difference in negotiation ability and negotiation situation.

The third experiment is a comparative analysis of References [37,38] and our proposed method. The parameters are given in Table 1. The agent set scales are 10, 50, 100, 200, 500, and 800; a single alliance construction is repeated 100 times, and the confidence level is 95%. The tenth-time experimental results of alliance construction (Alliance10) are adopted for comparison. The comparison results are given in Table 5.

Table 5. The performance comparison for alliance construction.

Type	Agent Number	Average Negotiation Rounds (times)	Average Agent Utility	Negotiation Efficiency	Average Negotiation Success Rate (%)
Reference [37]		69.88 ± 3.32	10.19 ± 1.65	0.15 ± 0.04	91 ± 4
Reference [38]	10	50.17 ± 2.63	16.74 ± 2.28	0.33 ± 0.07	51 ± 1
Alliance10		17.46 ± 2.04	19.23 ± 3.24	1.10 ± 0.10	61 ± 2
Reference [37]		82.17 ± 3.64	15.71 ± 2.08	0.19 ± 0.03	84 ± 3
Reference [38]	50	47.45 ± 3.31	18.82 ± 2.59	0.39 ± 0.06	51 ± 2
Alliance10		15.56 ± 2.18	21.61 ± 2.68	1.39 ± 0.08	61 ± 4
Reference [37]		85.16 ± 4.92	18.51 ± 3.12	0.22 ± 0.05	79 ± 5
Reference [38]	100	27.47 ± 5.26	25.42 ± 3.54	0.93 ± 0.10	56 ± 4
Alliance10		7.31 ± 0.96	33.21 ± 4.03	4.54 ± 0.13	63 ± 5
Reference [37]		86.28 ± 5.06	18.19 ± 3.09	0.21 ± 0.04	80 ± 3
Reference [38]	200	25.59 ± 5.12	26.38 ± 3.22	1.03 ± 0.15	60 ± 3
Alliance10		7.19 ± 0.88	35.17 ± 4.96	4.89 ± 0.07	68 ± 5
Reference [37]		89.52 ± 5.11	19.19 ± 3.95	0.21 ± 0.02	74 ± 5
Reference [38]	500	20.78 ± 4.30	29.68 ± 3.92	1.43 ± 0.14	62 ± 8
Alliance10		6.99 ± 0.78	39.17 ± 5.13	5.60 ± 0.27	70 ± 9
Reference [37]		91.14 ± 6.90	15.93 ± 2.03	0.17 ± 0.04	71 ± 2
Reference [38]	800	19.19 ± 4.45	31.32 ± 4.92	1.63 ± 0.15	67 ± 9
Alliance10		6.89 ± 0.62	42.44 ± 6.14	6.16 ± 0.41	80 ± 8

As can be seen from Table 5, our proposed method has obvious advantages in the negotiation rounds; because of the lack of an intelligent negotiation strategy in Reference [37], the negotiation rounds are greater than in the latter two methods, and our method reduces the negotiation rounds by more than 50% compared with the Reference [38], which is without the participation degree. In terms of the negotiation success rate, the negotiation success rate of Reference [37] is much larger than the latter two methods because Reference [37] is based on the candidate union set, and the negotiation success rate of our method is 10% higher than that of Reference [38]. As for average agent utility, Reference [38] is significantly higher than Reference [37] and our method, which shows that Reference [38] achieves higher individual utility. As for the negotiation efficiency, our method is much better than the other

two methods, which shows that our method can achieve higher utility in a few rounds of negotiation, so the negotiation efficiency is high.

As for the different scales of the agent set, we can see that the larger the agent scale, the higher the negotiation success rate in our method; this is because the resources among agents have increased. However, in Reference [37], the negotiation success rate decreases with the increase of agent scale. From the perspective of negotiation efficiency, our method has the absolute advantage compared with the other two methods; this advantage is more obvious with the increase of agent scale, and shows that our method is suitable for large-scale agent systems. This is because the heterogeneity among agents is more pronounced when the agent scale increases. Our method, based on the participation degree, can well reflect this heterogeneity to improve the negotiation efficiency and make it easier to reach agreement.

5.2. Results Discussion

5.2.1. Experiment 1

As can be seen from Table 2, the bigger the proportion of *a* in (*a*,*b*), the fewer the negotiation rounds, and the higher the negotiation success rate and negotiation efficiency. However, the bigger the proportion of *b* in (*a*,*b*), the more the negotiation rounds, and the lower the negotiation success rate and negotiation efficiency. The reason is that for the public, such as enterprises, NGOs, and volunteers, if they have higher historical participation degrees, that means that they have a sense of participation and positive participation attitude, and it is easy to build alliances in the face of natural hazards, so the negotiation efficiency and negotiation success rate are high. If the public provides more resources and gets less utility from participating in natural hazard relief, they will refuse to build an alliance. Therefore, more rounds of negotiation are needed, and the negotiation efficiency and success rate are low.

As can be seen from Table 3, the bigger the β_0, the fewer the negotiation rounds, and the higher the negotiation success rate and negotiation efficiency. The reason is that the bigger the β_0 is, the higher the participation degree is, and, the more positive the public's participation attitude is, the easier it is to build alliances in natural hazard relief, so the negotiation efficiency and success rate are high.

As can be seen from Table 4, the bigger the ΔT, the more negotiation rounds there will be, and the lower the negotiation success rate and negotiation efficiency. The reason is that if a certain type of public continuously requires others to provide more resources and services, but does not provide more resources and services itself, it will be difficult to build an alliance, so the negotiation efficiency and success rate are low.

5.2.2. Experiment 2

Experiment 2 verified that our proposed method can achieve better negotiation efficiency by dynamically changing participation attitude values. The reason is that the traditional negotiation-based alliance formation method does not take into account the heterogeneity of agents, but makes consistent assumptions about the negotiation attitudes and resources of all agents. The negotiation is conducted in the order of agent ID number.

Our method proposes that the participation degree will be dynamically calculated in real time according to the agent's historical participation performance and the resources owned by the agent. The agent dynamically adjusts the participation degree, and chooses agents with higher participation degrees to negotiate and build alliances. This is also in line with the actual situation of emergency relief for natural hazards. The public can dynamically decide whether to join or leave an alliance according to their participation attitude and resources.

5.2.3. Experiment 3

Compared with Reference [37], our method is only slightly lower in the negotiation success rate, and has better performance than that of the Reference [38]. This shows that our method has better negotiation efficiency and higher agent utility than the other two methods, and is more suitable for large-scale multi-agent systems. This coincides with the fact that many public subjects participate in natural hazard relief. With the increase of the public scale, the number of interactive objects also increases, which greatly improves the possibility of forming alliances. Therefore, our method is practical.

6. Conclusions

Although the government is the main body of emergency management, our era is an unprecedented stage in which natural hazards frequently happen, so relying solely on the government's efforts to deal with natural hazards is almost impossible. We must actively encourage the public to participate in natural hazard relief. Through this research, we draw following conclusions.

(1) A natural hazard emergency relief alliance can be formalized based on the multi-agent system theory. It takes the participants as agents and makes use of a multi-agent system to construct the emergency relief alliance model. According to the paradigm of agent dynamic negotiation alliance, the emergency relief alliance is composed of two parts: ① Negotiation elements. Negotiation elements include the participation proposal, negotiation interval, and negotiation decision function. Negotiation elements are the premise and foundation of emergency relief alliances. ② Dynamic negotiation protocol. Dynamic negotiation protocol includes the agent interaction process and participation strategy. The dynamic negotiation protocol guarantees the convergence, non-deadlock, and consistency of an emergency relief alliance.

(2) Our proposed model and algorithm have good performance. Computational experiments were performed to evaluate and compare our proposed model and algorithm. Through the Eclipse platform, we made three experiments to prove that our model and algorithm have better performance in negotiation success rate, negotiation efficiency, and agent utility than other methods, and our model is more in line with the actual situation of natural hazard emergency relief.

(3) The participation degree influences the construction of an emergency relief alliance. The historical participation degree reflects the participation consciousness of the public, and the current participation degree reflects the resources owned by the public. The findings of the study indicate that the historical participation degree has a positive impact on emergency relief alliance formation; the more positive the public attitude is, the easier it is to build alliance. The current participation degree has no direct positive impact on emergency relief alliance formation. It is not that the more resources the public has, the easier it is to build alliance.

Based on this, to encourage the public to participate in natural hazard relief, we put forward the following countermeasures and suggestions.

On the one hand, foster a sense of public participation. The government makes use of traditional and modern media, such as radio, television, portal site, government websites, mobile phone short messages, WeChat, official accounts, and short videos, to widely publicize the knowledge of crisis management. Meanwhile, disaster relief courses, lectures, training, and professional schools should be set up to cultivate the awareness of public participation, improve the attitude of participation, and enhance public participation.

On the other hand, incentives should be increased. Through preferential tax policies, financial discount policies, commercial publicity, material rewards, and other incentive measures, the government guides NGOs, enterprises, institutions, and the masses to actively participate in emergency relief. At the same time, spiritual incentives are given to the public, such as the honorary titles of "philanthropist" and "good citizen". When the utility for the public increases, the public is willing to build an emergency relief alliance.

In our future research, we will consider a different network topology and a dynamic agent resource change process in each instance of the construction of an alliance. More factors will be taken account, such as rescue time, participants' characteristics, and so on.

References

1. Yu, X.B.; Yu, X.R.; Li, C.L.; Ji, Z.H. Information diffusion-based risk assessment of natural hazards along the Silk Road Economic Belt in China. *J. Clean. Prod.* **2020**, *244*, 118744.

2. Ren, Z.Y. General concept, current situation and development of emergency relief. *China Soc. Welf.* **2008**, *10*, 15–17. (In Chinese)

3. Adnan, S.G.; Kreibich, H. An evaluation of disaster risk reduction (DRR) approaches for coastal delta cities, a comparative analysis. *Nat. Hazards* **2016**, *83*, 1257–1278. [CrossRef]

4. Few, R.; Scott, Z.; Wooster, K.; Avila, M.F.; Tarazona, M. Strengthening capacities for disaster risk management II, Lessons for effective support. *Int. J. Disaster Risk Reduct.* **2016**, *20*, 154–162. [CrossRef]

5. Sim, T.; Liu, Y.; Li, S.J. Working together, Developing disaster risk reduction first aid training in a post-earthquake Chinese context. *J. Soc. Work.* **2017**, *17*, 491–497. [CrossRef]

6. Marlowe, J.; Neef, A.; Tevaga, C.R.; Tevaga, C. A New Guiding Framework for Engaging Diverse Populations in Disaster Risk Reduction, Reach, Relevance, Receptiveness, and Relationships. *Int. J. Disaster Risk Sci.* **2018**, *9*, 507–518. [CrossRef]

7. Carrao, H.; Naumann, G.; Barbosa, P. Global projections of drought hazard in a warming climate, a prime for disaster risk management. *Clim. Dyn.* **2018**, *50*, 2137–2155. [CrossRef]

8. Migliorini, M.; Hagen, J.S.; Mihaljevic, J.; Mysiak, J.; Rossi, J.L.; Siegmund, A.; Meliksetian, K.; Sapir, D.G. Data interoperability for disaster risk reduction in Europe. *Disaster Prev. Manag. Int. J.* **2019**, *28*, 796–808. [CrossRef]

9. Marchal, R.; Piton, G.; Gunn, L.-; Miras, Z.-; Der Keur, V.; Dartée, K.; Pengal, P.; Matthews, J.; Tacnet, J.-M.; Graveline, N.; et al. The (Re) Insurance Industry's Roles in the Integration of Nature-Based Solutions for Prevention in Disaster Risk Reduction-Insights from a European Survey. *Sustainability* **2019**, *11*, 6212. [CrossRef]

10. Webb, J. What difference does disaster risk reduction make? Insights from Vanuatu and tropical cyclone Pam. *Reg. Environ. Chang.* **2020**, *20*, 20. [CrossRef]

11. Totaro, F.; Alberico, I.; Di Martire, D.; Nunziata, C.; Petrosino, P. The key role of hazard indices and hotspot in disaster risk management, the case study of Napoli and Pozzuoli municipalities (Southern Italy). *J. Maps* **2020**, *16*, 68–78. [CrossRef]

12. Narayanan, R.G.L.; Ibe, O.C. A joint network for disaster recovery and search and rescue operations. *Comput. Netw.* **2012**, *56*, 3347–3373. [CrossRef]

13. Wachinger, G.; Renn, O.; Begg, C.; Kuhlicke, C. The Risk Perception Paradox—Implications for Governance and Communication of Natural Hazards. *Risk Anal.* **2013**, *33*, 1049–1065. [CrossRef]

14. Wex, F.; Schryen, G.; Feuerriegel, S.; Neumann, D. Emergency response in natural hazards management, Allocation and scheduling of rescue units. *Eur. J. Oper. Res.* **2014**, *235*, 697–708. [CrossRef]

15. Oral, M.; Yenel, A.; Oral, E.; Aydin, N.; Tuncay, T. Earthquake experience and preparedness in Turkey. *Disaster Prev. Manag. Int. J.* **2015**, *24*, 21–37. [CrossRef]

16. Berariu, R.; Fikar, C.; Gronalt, M. Hirsch, P. Understanding the impact of cascade effects of natural hazards on disaster relief operations. *Int. J. Disaster Risk Reduct.* **2015**, *12*, 350–356. [CrossRef]

17. Alem, D.; Clark, A.; Moreno, A. Stochastic network models for logistics planning in disaster relief. *Eur. J. Oper. Res.* **2016**, *255*, 187–206. [CrossRef]

18. Toyasaki, F.; Arikan, E.; Silbermayr, L.; Sigala, I.F. Disaster Relief Inventory Management, Horizontal Cooperation between Humanitarian Organizations. *Prod. Oper. Manag.* **2016**, *26*, 1221–1237. [CrossRef]

19. Deo, R.C.; Salcedosanz, S.; Carrocalvo, L. BeatrizSaavedra, M. Drought prediction with standardized precipitation and evapotranspiration index and support vector regression models. *Integr. Disaster Sci. Manag.* **2018**, *2818*, 151–174.

20. Nassereddine, M.; Azar, A.; Rajabzadeh, A.; Afsar, A. Decision making application in collaborative emergency response, A new PROMETHEE preference function. *Int. J. Disaster Risk Reduct.* **2019**, *38*, 101221. [CrossRef]

21. Borowska-Stefańska, M.; Kowalski, M.; Turoboś, F.; Wiśniewski, S. Optimisation patterns for the process of a planned evacuation in the event of a flood. *Environ. Hazards* **2019**, *18*, 335–360. [CrossRef]

22. Izida, A.; Tedrus, T.D.; Marietto, M.D.B.; Steinberger-Elias, M.; Botelho, W.T.; Franca, R.D. Emergency Care in Situations of Natural Disaster, A Multi-Agent Approach. In Proceedings of the 2012 International Conference for Internet Technology and Secured Transactions, London, UK, 10–12 December 2012; pp. 237–242.

23. Yue, E.; Zhu, Y.P. Study on Emergency Decision-making of Natural Disaster Based on collaboration of Multi-Agent. In Proceedings of the 2nd International Conference on Information Technology and Management Innovation (ICITMI 2013), Zhuhai, China, 23–24 July 2013; pp. 2684–2693.

24. Naqvi, A.A.; Rehm, M. A multi-agent model of a low income economy, simulating the distributional effects of natural disasters. *J. Econ. Interact. Co-Ord.* **2014**, *9*, 275–309. [CrossRef]

25. Na, H.S.; Banerjee, A. Agent-based discrete-event simulation model for no-notice natural disaster evacuation planning. *Comput. Ind. Eng.* **2019**, *129*, 44–55. [CrossRef]

26. Lee, S.; Kim, H.; Lee, B. An Efficient Rescue System with Online Multi-Agent SLAM Framework. *Sensors* **2020**, *20*, 235. [CrossRef]

27. Chen, M.; Qian, X.; Zhang, L.J. Public Participation in Environmental Management in China, Status Quo and Mode Innovation. *Environ. Manag.* **2015**, *55*, 523–535. [CrossRef]

28. Werner, T. Gaining Access by Doing Good, the Effect of Sociopolitical Reputation on Firm Participation in Public Policy Making. *Manag. Sci.* **2015**, *61*, 1989–2011. [CrossRef]

29. Say, N.; Herberg, A. The Contribution of Public Participation in a Good-Quality Strategic Environmental Assessment (Sea). *Fresenius Environ. Bull.* **2016**, *25*, 5751–5757.

30. Park, M.S.; Lee, H. Legal Opportunities for Public Participation in Forest Management in the Republic of Korea. *Sustainability* **2016**, *8*, 369. [CrossRef]

31. Xi, W. A Study on China's System of Public Participation in Environmental Protection-Taking Haikou's "Two Constructions" for Example. In Proceedings of the International Conference on Environmental Engineering and Sustainable Development (CEESD), Sanya, China, 3–6 December 2016.

32. Li, J. Public Participation in Tourism Development, an Analysis of Community Development in Underdevelopment Areas. In Proceedings of the 3rd Asian Pacific Conference on Energy, Environment and Sustainable Development (APEESD), Singapore, 21–22 January 2017; pp. 237–240.

33. Xiao, L.S.; Zhang, G.Q.; Zhu, Y.; Lin, T. Promoting public participation in household waste management, A survey based method and case study in Xiamen city, China. *J. Clean. Prod.* **2017**, *144*, 313–322. [CrossRef]

34. Ruiz-Villaverde, A.; Garcia-Rubio, M.A. Public Participation in European Water Management, from Theory to Practice. *Water Resour. Manag.* **2016**, *31*, 2479–2495. [CrossRef]

35. Chen, Y.X.; Zhang, J.; Tadikamalla, P.R.; Gao, X.T. The Relationship among Government, Enterprise and Public in Environmental Governance from the Perspective of Multi-player Evolutionary Game. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3351. [CrossRef]

36. Soh, I.K. *Negotiation-Based Coalition Formation Model for Agents with Incomplete Information and Time Constraints*; Department of Computer Science and Engineering, University of Nebraska-Lincoln: Lincoln, NE, USA, 2002.

37. Goradia, H.; Vidal, J. *Negotiation-Based Coalition Formation among Selfish Agents [R/OL]*; Department of Computer Science and Engineering, University of South Carolina: Columbia, SC, USA, 2007.

38. Ramchurn, S.; Gerding, E.; Jennings, N.R.; Hu, J. Practical distributed coalition formation via heuristic negotiation in social networks [C/OL]. In Proceedings of the 5th International Workshop on Optimization in Multi-Agent Systems (OPTMAS), Valincia, Spain, 4 June 2012.