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Examining resilience of disaster response system in response to COVID-19

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\textbf{ABSTRACT}

We examine the COVID-19 response in China by conceptualizing resilience from the complex adaptive system perspective, including a discussion of the factors contributing to the resilience of the disaster response system. Methodologically, a network-based model was employed to describe the disaster response system. In addition to a traditional network analysis, the dynamics network analysis was conducted to assess the evolution of the disaster response system with a time slice analysis. This study presents theoretical and practical contributions to the field of disaster management by utilizing the complex adaptive system perspective and investigating context-specific resilience of a disaster response system.

\section{Introduction}

Disaster response systems globally have experienced major crises and disruptive shocks over the past decade. This includes the 2008 global economic crisis, Ebola outbreak, and COVID-19 [1]. As a major public health crisis, the COVID-19 global pandemic is the most extensive impact humanity in over a century [2]. During the COVID-19 response, the situation became more complex because of increasing interactions and interdependency among stakeholders (e.g., individual people and organizations) due to its significant social, economic, physical, and environmental impacts [3].

The ability of a disaster response system involving various stakeholders to maintain its operations, adapt, and recover from a disaster is very critical. This ability, in essence, can be conceptualized as resilience [4,5]. Resilience is an appropriate way to assess and understand the performance of disaster response system during the COVID-19 response [6]. However, there is scarce evidence on how to generate or strengthen resilience because this topic is still predominantly conceptual [7], especially in the context of the COVID-19 response [6]. Little agreement exists between academics and practitioners as to preferential methods to design and build disaster resilience [8-10].

Theoretically, the applications of systems thinking based on Complex Adaptive System (CAS) in understanding disaster resilience have been discussed [11–13]. The inherent similarities between the concept of resilience and CAS could provide ample practical and theoretical contributions to the field of disaster response and facilitate further investigation [14]. An improved understanding of disaster resilience and its underlying dynamic evolution could provide an effective tool to manage disaster risks and build resilience [11].

Understanding a CAS requires an explicit model to represent its interactions that result in subsystem collaboration and emergent system behavior. Methodologically, a complex system can be described as a large network of communicating subsystems [15]. Until recently, characteristic, structure, and performance of disaster response systems [16,17] have been extensively studied using network methods [18,19]. However, since it is difficult to uncover how the systems evolve and adapt, the dynamic nature of a system should be considered when effectively analyzing disaster response systems [20].

Based on the case of the COVID-19 response in China, we examined how resilience was conceptualized from a CAS perspective, and identified the factors that influence resilience of the disaster response system, with some implications and suggestions proposed. Network method was employed to describe the disaster response system with time slice analysis.

\subsection{1.1. Literature review and background}

This section provides literature on Resilience in Disaster Management and Organizational Response to Disasters with an additional emphasis on the necessities and importance of examining resilience in the context of disaster response. Resilience in Disaster Management. The term resilience in disaster management gained prominence in the contemporary post-2005 discourse [21,22]. Meanwhile, many contemporary definitions have
integrated the concepts of resilience and stability, confusing the two concepts as parts of the holistic definition of resilience [23,24]. A resilient system can constantly change and adapt to external or internal pressures, thereby return to an improved (safer) equilibrium state [8,23,25,26].

Currently, the concept of resilience is used in a great variety of interdisciplinary work concerned with the interactions between people and nature, including vulnerability and disaster reduction [27,28]. Adapted, sustainable, and integrated management of natural resources should increase the resilience of communities when confronted with disasters. Adaptation and adaptive capacity are central elements of resilience [29], while characteristics of resilience are self-organization and recovery [28]. Incorporating adaptation in the conception of resilience also has the potential to change orientation towards resilience design [30].

Theoretically, treating resilience from the system perspective will allow for socio-technical systems that design and achieve disaster resilience through dynamic adaptations [31,32]. However, apart from theoretical and philosophical differences in defining and explaining resilience, there are still practical difficulties in measuring resilience or identifying components contributing to resilience improvement [33]. Recently, scholars have attempted to discuss issues with resilience. For example, Li et al. [34] proposed a resilience assessment framework for the Urban Land-Water System. Park et al. [35] identified and discussed drought planning components to secure community resilience.

Organizational Response to Disasters. From the resilience perspective, organizational adaptation is ubiquitous in management research and acts as the glue binding together the central issues of organizational change, performance, and survival [36]. Scholars have attempted to examine inter-organizational roles in the post-disaster period [37], with topics including barriers and facilitators in interorganizational disaster responses [38].

Since disaster response organizations must sustain performance during times of disaster, dynamic capabilities theory is widely used as a theoretical perspective to explain sustained organizational performance in dynamic environments [39]. The literature offers insights into organizations’ defensive capabilities for identifying, forecasting, and preventing the development of a crisis, or lessening the effects of a crisis [40,41].

Several researchers have already suggested that crisis management approaches should be incorporated into broader strategies that enhance adaptation and resilience [42-44]. Crisis management focuses largely on immediate reactions to crisis situations and the mitigation of losses [45], suggesting that disaster management needs to be coupled with organizational adaptation and resilience strategies. Since traditional crisis management approaches, enabling an immediate response [43], cannot fully account for the complexities of responding to disasters, some scholars have argued for an integration of disaster management and organizational strategy [46,47].

1.2. Theoretical Framework

Although the importance of understanding context-specific resilience has been highlighted [26], it might be impossible to design a “one size fits all” model or framework to examine resilience. It is necessary to apply analytical models to discuss the ever-changing dynamics that underlay resilience [12]. Therefore, theoretical models associated with systems thinking to assess and understand resilience are required [48].

Taking a holistic approach based on systems theories will enhance our understanding of disaster risk, assisting in improving adaptation abilities and building resilience [48,49].

Given the challenges posed by disasters, there is a need to understand how organizations in Disaster Response System (DRS) can achieve adaptive responses and form organizational resilience capacities [16]. Resilience is a dynamic process that balances risk against resources and capacity, time against severity of loss, cost against uncertainty, and learning against error [50]. In this dynamic process, many organizations, communities, and jurisdictions act collectively to achieve disaster response. Each organization is changing in a dynamic and complex environment, and the challenge is to synchronize these actions to move approximately in the same direction and to avoid organizational collusion and dysfunction.

As a variation of systems theory, CAS has emerged, aiming at explaining non-linear adaptation [51]. Seeing DRS as a CAS, we propose the framework as shown in Fig. 1. Based on the dynamic impacts of disasters, organizations are constantly revising their rules for interaction. The aggregate behavior of the system continues to evolve due to simultaneous interactions among participating organizations, ensuring that any stimuli (disaster) triggers changes within the system, between the system, and the environment [52]. Due to the dynamic nature, DRS constantly change and evolve, presenting a “moving target” [53].

Resilience emerges, to a large extent, from interactions at much lower scales between individual organizations, short-time scales, and small spatial scales – and feedback to influence the dynamics of the whole system [54], to accomplish effective disaster response. On the other hand, there has been an ongoing debate over the most effective approaches to coordinating disaster response. One school stresses a preestablished hierarchical command and control system that uses authority to synchronize efforts across organizational and jurisdictional boundaries [55]. The other one argues that the hierarchical approach to coordination lacks flexibility and limits the timely exchange of information and resources [56]. Horizontal interorganizational and cross-sector relationships can provide flexible and adaptable structures for coordination [57]. Therefore, it is necessary to move beyond this debate by examining the structure and operational mechanism of Chinese DRS.

In Chinese context, the information and resources are mainly dispersed in different government organizations, and they are required to achieve resources and capabilities integration in a centralized command and control system [58]. We examined whether government agencies played central roles in information and resource allocation and coordination firstly.

Hypothesis 1. Government agencies are central in the DRS to achieve effective and efficient information communication and resource allocation.

Different from managing a single organization, governing a complex system requires network management to gather member organizations, define functional assignments for coordination, mediate differences and conflicts, and bridge connections across political and jurisdictional boundaries [59].

Hypothesis 2. The organizations achieve the adaptive disaster response following their functional assignment within the response network.

In terms of major crises such as COVID-19, numerous and various agencies became involved in disaster response. An effective coordination structure should build upon –an intricate mix of limited (but effective) central governance and a high level of self-organization [60].

Hypothesis 3. In a centralized command and control system, the participant organizations are coordinated by powerful central agencies to achieve effective responses.

As a transboundary crisis, impacts of COVID-19 change and evolve continuously [61]. Accordingly, DRS constantly evolve in dynamic scenarios to adapt to the changing external conditions. Focusing on the key tasks and active organizations in disaster response respectively, we proposed the following hypotheses.

Hypothesis 4.1. Key tasks in disaster response continue to change with the evolutions of scenarios at different stages to adapt to the changing external conditions.

Hypothesis 4.2. Active organizations involved in disaster response...
continue to change with the evolutions of scenarios at different stages to adapt to the changing external conditions.

1.3. Context of the study

As of July 11, 2020, the novel coronavirus (COVID-19) pandemic has claimed 559,000 lives worldwide while the number of infected cases amounted to 12.4 million, with no country exempt from its impact. In China, the virus has spread faster and wider than any others since the founding of the People’s Republic and has proven to be the most difficult to contain [62]. The Chinese government has addressed the pandemic as a top priority and took swift action. To achieve an effective and efficient disaster response, the Chinese National First Level Emergency Response, which started from the “lockdown” of Wuhan city on January 23 and ended on February 26, was activated.

There have been considerable controversies on COVID-19 response in China, concerning transparency and the early response to the pandemic. It is clear that China has managed to contain this unprecedented public health crisis swiftly since the lockdown of Wuhan [63,64]. In little more than a month, the spread of the virus was contained. After about two months, the daily increase in domestic coronavirus cases had fallen to single digits, with a decisive victory secured in the battle to defend Hubei Province and its capital city of Wuhan. The COVID-19 response in China received extensive attention [65,66], with some important issues, including epidemic prevention and control [67,68] and features of China’s response to the COVID-19 pandemic [69].

2. Method

Resilience of DRS is examined using network method from a CAS perspective in the study. The research is conducted following three subsequent procedures.

First, a content analysis was conducted to capture information on network actors, mutual communication and interactive actions [70]. We focus primarily on the data during Chinese National First Level Emergency Response, which started from the “lockdown” of Wuhan on January 23 and ended on February 26 in 2020. Data were collected from government documents, situational reports and news reports published by the National Health Commission of the People’s Republic of China (http://www.nhc.gov.cn/xcs/yqfkdt/gzbd_index.shtml) was used to identify participant organizations. Each Emergency Support Function (ESF) was determined based on official documents including the Law of the People’s Republic of China on the Infectious Diseases Prevention and Treatment, National Emergency Plan for Public Health Emergencies, and Emergency Plan for Public Health Emergencies in Hubei Province, as shown in Table 1.

Second, we conducted static network analysis to achieve holistic analyses on DRS. If organizations engage in the same ESF, it can be determined that there are interactive relationships among them. Based on the list of ESFs, 2-mode matrixes were generated, and 1-mode data was obtained from the 2-mode data [18,71]. Since there were numerous organizations involved in COVID-19 response, we used the blockmodel to generate a simplified network to achieve primary analysis.

Third, we achieved dynamic time analysis to analyze the evolution of DRS by dividing the duration of first level emergency response into five time slices [72]. Based on the 2-mode network developed for each time slice, 1-mode networks were established to discuss the evolution of DRS. This research strategy is presented in Fig. 2.

The overall research strategy of the research can be presented in Fig. 3.

3. Results and discussions

Based on the collected data, static network analysis and dynamic time analysis were conducted.

Results of Static Analysis on Network. According to the results of...
content analysis, 183 organizations were involved in COVID-19 response during first level emergency response. Eight categories were identified among the participant organizations: Enterprises, Government Agencies, Health Sector, International Organizations, Military, Nonprofit Organization, Organization of Communist Party and Research Institution (Fig. 4).

As shown in Fig. 4, government agencies account for 75% of organizations in DRS. Military units and organizations of communist party account for only 1% and 2% respectively. To facilitate further discussion, network-based models were built based on the data collected through document analysis. Based on the list of ESFs, 2-mode matrixes were generated, with the overall network visualization of DRS presented in Fig. 5, where the boxes and circles represent ESFs and involved organizations respectively.

Subsequently, a self-consistent search procedure was used to partition a population into sets of structurally equivalent actors-blocks [73]. We generated simplified network using blockmodel [18], to discuss the structure of the DRS network (Table 2).

Therefore, we obtained image matrix [74] indicating the relationships of blocks (Table 3).

Therefore, a simplified network obtained from the Results is presented in Fig. 6. It can be seen that block 1 mainly includes NHC, TCL,
HBL, WHL and other core leading organizations. This block is the most active and has two-way interactions with others, which indicates that the organizations are in charge of Command and Coordination. Block 2 mainly includes SAM, MTC, NFC and other medical material support departments. It can be interpreted that the function of this block is Medical Assistance. Block 3 mainly includes the agencies, e.g., SMR, MFC, SAS, whose function is Resources and Logistics Support. Blocks 2 and 3 are also relatively active, mainly cooperating with the organizations in Block 1. Block 4 involves CMG, NPP, and other publicity departments which oversee Emergency Communication. Most local authorities are included in Block 5 indicating that active interactions and collaboration among local governments did exist to achieve effective disaster response. Some research institutions such as ABC, SAT, and SHB, which operated as Technical Support, were involved in Block 6. Therefore, DRS can be divided into 6 subsystems, including Command and Coordination Subsystem (Block 1), Medical Assistance Subsystem (Block 2), Resources and Logistics Support Subsystem (Block 3), Emergency Communication Subsystem (Block 4), Local Disaster Response Subsystem (Block 5), and Technical Support Subsystem (Block 6).

Since some agencies are in charge of Command and Coordination,
Hypothesis 2. The function of each subsystem was strengthened through coordination among participating agencies, and powerful command and coordination is critical to effective and efficient crisis response. It can be seen that agencies of the Central Committee of the Communist Party of China or central government are involved in Command and Coordination Subsystem, such as CPS, TCL, and NHC. Moreover, command and coordination subsystems are the most active and have two-way interactions with others, indicating that organizations involved in DRS are coordinated by some powerful agencies to achieve adaptive response. We can conclude that Hypothesis 3 was supported. We also noticed that some temporary agencies, such as JPC and CGH involving principals of powerful agencies, which are not only in charge of coordination but also administrative accountability are more central and powerful in DRS. Practically, centralized administrative accountability system ensures efficient and effective feedbacks [76]. This can be seen as structural adjustment of DRS with the aim to achieve adaptive response.

Results of Time Dynamic Analysis on DRS. Furthermore, we conducted dynamic time analysis and visualized the results (Appendix B), with some information on ESFs degree centrality (Table 4) derived for time dynamic network analysis.

The study on the 2-mode networks in different time slices found that in the whole process of disaster response the topological relationship density of organization-function network initially decreases, but increases in the subsequent stages. On the other hand, it can be observed that the main tasks in each time slice were significantly different from each other. In the DRS, the key ESFs mainly included Control and Coordination, Medical Rescue, Financial Support, and Popular Science Propaganda. However, there was a need for Labor treatment Support, Material Support besides Control and Coordination in T1 period. In T2 period, Emergency Measure Implementation became a new important function besides Control and Coordination and Medical Treatment. In T3 period, Information Release became a new critical function, Material Support was in the central positions in T4 and T5. Command and Coordination is the most important function in T1, T4, and T5, while Medical Rescue and Material Support are in the most central positions in T2 and T3 respectively. The central tasks of emergency response changed over time but some functions such as Command and Coordination were at the central position during the whole response process.

Based on the 2-mode network developed for each time slice, 1-mode networks on participant organizations were established to facilitate analysis on the evolution of DRS (Appendix C). And some information such as the distinct number of organizations (number of nodes) and the frequency of interorganizational interactions (number of links) for each time slice was calculated (Table 5).

### Table 2
Block distribution of DRS.

| Block Name | Involved Organizations |
|------------|------------------------|
| Block 1    | CPS, TCL, JPC, CGH, NHC, HBL, HBN, WHL, MCA, SPC, MI, CA, MST, MTP, CCR, NPH, MPS, DSA, RCS, DGP, GGS, MCP, MNR, WHO, PLA, GAC, MEC, MCT, NDC, NMP, CDC |
| Block 2    | SGL, SMA, JMA, HAM, RBH, NIS, DHC, WHH, UHA, MTC, MT, CR, WHR, BP, AM, NPS, XTS, WM, WM, WM, CNP, CNS, COF, CTG, WHC, HYN, EG, CAG, JD, SF, DD, NIS, OCT, AFA, ICC, CG, COF |
| Block 3    | SMR, MFC, SAS, MJP, STA, MHU, GAS, AGS, CBI, PBC, CCA, ODC, SPP, SPC, MHR, NEA, NAC, NPS, APC, CBI, AMI, APM, APE, NFG, DOS, AFF, AAH |
| Block 4    | CMG, NPP, FJI, FJP, SCO, JLI |
| Block 5    | AHL, SCI, GDL, GSI, HBG, SX, HNG, HNI, SDI, IML, CQL, SJI, FJI, HNP, GZI, JLI, SAL, XZH, TJ, BJI, JSI, XNL, YNL, GXL, SHL, ZJI, HLL, MCL, JXL, FJI, AHF, ADH, ZJI, YNH, JLI, HNL, SHL, GSH, SCH, XZH, QSH, GDI, JIH, HCH, SXH, XSH, ESH, EJI, HSI, SMT, SMI, HBE, HBT, EDC, HBP, HNS, QHS, SCH, DAR, DEA, DEH, JID, JBF, GSF, SCF, QF, HNF |
| Block 6    | ABC, SAT, SHB, SHZ, SHG, CAS, IPB, IMC, CNP, CHD, SID, MGC |

Note: See Appendix A for abbreviations.

### Table 3
Image matrix.

| Block Name | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 | Block 6 |
|------------|---------|---------|---------|---------|---------|---------|
| Block 1    | 1       | 1       | 1       | 1       | 1       | 1       |
| Block 2    | 1       | 1       | 1       | 0       | 1       | 1       |
| Block 3    | 1       | 1       | 1       | 1       | 1       | 0       |
| Block 4    | 1       | 0       | 1       | 1       | 0       | 0       |
| Block 5    | 1       | 1       | 1       | 1       | 1       | 0       |
| Block 6    | 1       | 1       | 0       | 0       | 0       | 1       |

Fig. 6. Simplified network on DRS
According to the Results shown in Table 5, the density of the network is relatively low in the whole process, while the interactions between organizations are the most frequent in T2. In T1, the CPS held a meeting to listen to the report on the epidemic prevention and control, announcing to start the first level response. The density of DRS is the highest, while the average path is the shortest in T2, indicating that the policies have been effectively implemented in the early stage. In T3, the mid-stage of response, large number of organizations got involved, with lowest density of organizational relationships, indicating that the pandemic information was gradually transparent, and risk communication was efficient. The average path of network is the longest in T4, suggesting that with the spread of information, the DRS tends to be sparse and flat. In T5, the number of organizations and the link among them both changing, with the aim of achieving efficient and effective response. Moreover, the density of network, the number of interactions, and the number of links in T5 were much higher than those of each time slice, indicating that there were more organizations and ESFs involved in this period.

To achieve analysis on evolution of DRS, we listed the top 20 active organizational in each time slice (Table 6).

As shown in Table 6, the positions of organizations change over time. Only the National Health Commission (NHC) remained at the core position during the whole response. On the other hand, the Standing Committee of the Political Bureau of the CPC Central Committee, an important decision-making unit, has played an important leading role. The Central Leading Group for COVID-19 Response and the Joint Prevention and Control Mechanism of the State Council have also played important roles in command, coordination, and organizational leadership. Public agencies in Wuhan city and Hubei province played important executive and coordinated roles in preventing the spread of the virus. Therefore, hypothesis 4-1 and 4-2 are supported. It can be concluded that the DRS continues to evolve with the changes of scenarios at different stages to adapt to the change of external situations. Because of complex evolution of external environments, the core ESFs and roles of key organizations at different periods are constantly changing, with the aim of achieving efficient and effective response.

Also, the organizational context suitable for the communication and interaction, which could reduce the information asymmetry and achieve fully use of resources, are needed. In practice, responsibilities of some agencies such as National Health Commission, Joint prevention, and Control mechanism of the State Council have been defined clearly, facilitating effective and efficient joint epidemic prevention and control.

This study utilized CAS theory to understand and explain the evolution of DRS, with theoretical concept and descriptions supplemented based on the case of COVID-19 response. DRS operate as CAS because they consist of multiple organizations, acting on condition and in parallel with member organizations resulting in continuous adaptation and evolution. As a network of organizations, it emerges from the individual and collaborative behaviors of their member organizations. Behaviors at the agency level aggregate to CAS behaviors in reaction to crisis, such as COVID-19. So, we modeled DRS using social network method, linking CAS theory and resilience in the context of COVID-19 response. And this research can be generalized to a broad range, with some topics such as efficiency, performance of disaster response discussed.

4. Conclusion

We examined context-specific resilience of DRS from perspective of CAS. The study contributes to the field of emergency management and disaster response networks through comprehensive social network analysis with emphasis of on resilience and collaborative capacity [76, 77]. This study also presents a new attempt to investigate the time dynamics of network beyond conventional static analysis. The analysis of COVID-19 crisis response in China can also contribute to disaster response at practical level to similar centralized administrative systems. However, there are some limitations of the study. First, this research was conducted primarily based on the data during Chinese National First Level Emergency Response. Besides for First Level Emergency Response, disaster recovery is important. Supplementary analyses are required to discuss the overall disaster response process. Second, the data was collected through content analysis of official documents, and some organizations and their actions may not be recorded. Especially, disaster response at grassroots level is also very critical. In the future, data sources from supplementary surveys, interviews and case studies can be utilized in addition to content analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Table 4**

| Rank | T1/T5 | T1 | T2 | T3 | T4 | T5 | All |
|------|-------|----|----|----|----|----|-----|
| 1    | ESF16 | ESF16 | ESF10 | ESF25 | ESF16 | ESF16 | (31.91) | (31.98) | (23.03) | (25.04) | (33.16) | (29.94) |
| 2    | ESF10 | ESF30 | ESF16 | ESF16 | ESF12 | ESF10 | (26.00) | (29.94) | (22.87) | (23.67) | (25.41) | (28.73) |
| 3    | ESF25 | ESF10 | ESF17 | ESF22 | ESF25 | ESF25 | (23.41) | (25.31) | (16.33) | (19.82) | (24.04) | (24.02) |
| 4    | ESF14 | ESF17 | ESF14 | ESF17 | ESF14 | ESF25 | (20.36) | (25.06) | (13.30) | (17.22) | (22.26) | (22.41) |
| 5    | ESF17 | ESF25 | ESF11 | ESF10 | ESF10 | ESF12 | (17.97) | (25.02) | (13.26) | (16.17) | (20.86) | (18.79) |
| 6    | ESF22 | ESF31 | ESF3 | ESF31 | ESF22 | ESF18 | (15.26) | (23.56) | (12.71) | (15.89) | (17.05) | (18.67) |
| 7    | ESF3 | ESF22 | ESF25 | ESF13 | ESF18 | ESF28 | (14.48) | (19.41) | (12.66) | (13.97) | (14.70) | (18.08) |
| 8    | ESF18 | ESF3 | ESF20 | ESF14 | ESF13 | ESF14 | (14.08) | (17.47) | (9.88) | (13.20) | (14.51) | (16.07) |
| 9    | ESF31 | ESF14 | ESF13 | ESF18 | ESF28 | ESF13 | (14.01) | (17.11) | (8.21) | (11.65) | (14.01) | (12.73) |
| 10   | ESF12 | ESF18 | ESF12 | ESF3 | ESF17 | ESF20 | (13.71) | (12.96) | (8.08) | (10.30) | (12.85) | (12.43) |

(Note: the number in parentheses indicate Degree Centrality of each ESF).

**Table 5**

|          | T1  | T2  | T3  | T4  | T5  | All  |
|----------|-----|-----|-----|-----|-----|------|
| #of Organizations (nodes) | 53  | 64  | 82  | 68  | 97  | 183  |
| #of Interactions (Links)  | 151 | 261 | 206 | 150 | 331 | 4795 |
| Density (%)               | 5.3094 | 6.4603 | 3.3348 | 3.3007 | 3.5490 | 14.4107 |
| #of Average Path         | 1.459 | 1.351 | 1.422 | 1.579 | 1.592 | 1.439 |
| #of Cohesion (%)          | 0.774 | 0.824 | 0.789 | 0.724 | 0.734 | 0.781 |
| Network Centralization (%) | 16.21 | 10.67 | 12.38 | 17.37 | 15.58 | 6.64 |
### Appendix A. Organizations involved in COVID-19 Crisis Response

| Organization Name |
|-------------------|
| Administration of Animal Husbandry and Veterinary of Ministry of Agriculture and Rural Affairs of the People’s Republic of China |
| Administration of Biological Center of Ministry of Science and Technology of the People’s Republic of China |
| Air Force |
| Administration of Fishery and Fishery Administration of Ministry of Agriculture and Rural Affairs of the People’s Republic of China |
| Administration of Goods and Services Tax Division of State Taxation Administration |
| Health Commission of Anhui Province |
| Anhui Provincial Leading Group for COVID-19 Prevention and Control |
| Administration of Marketing and Informatization of Ministry of Agriculture and Rural Affairs of the People’s Republic of China |
| Administration of Market Supervision of State Post Bureau of the People’s Republic of China |
| Administration of Price Control and Competition of State Administration for Market Regulation |
| Asia-Pacific Economic Cooperation |
| Administration of Planning Management of Ministry of Agriculture and Rural Affairs of the People’s Republic of China |
| The Association of Southeast Asian Nations-China, Japan, Korea |
| Administration of Service of Ministry of Transport of the People’s Republic of China |
| Bill & Melinda Gates Foundation |
| Beijing Leading Group for COVID-19 Prevention and Control |
| Civil Aviation Administration of the People’s Republic of China |
| China Aoyuan Group Limited |
| Chinese Academy of Sciences |
| China Banking and Insurance Regulatory Commission |
| Office of the Central Cyberspace Affairs Commission |
| Central Committee for the Rule of Law |
| China Construction Third Engineering Bureau |
| Chinese Center for Disease Control and Prevention |
| Country Garden |
| Central Guidance Group to Hubei |
| Center for Health Development Research of National Health Commission of the People’s Republic of China |
| China Media Group |
| China National Pharmaceutical Group |
| China National Salt Industry Group |
| COFCO Corporation |
| China Post |
| Central Politburo Standing Committee of the Communist Party of China |
| Chongqing Leading Group for COVID-19 Prevention and Control |
| China State Railway Group |
| China Three Gorges Corporation |
| Department of Agriculture and Rural Affairs of Anhui Province |
| Department of Education of Anhui Province |
| Department of Education of Hunan Province |
| Department of Financial Inclusion of China Banking and Insurance Regulatory Commission |
| Department of Grass-roots Political Power Building and Community Governance of Ministry of Civil Affairs of the People’s Republic of China |
| Department of Health of Central Military Commission |

(Note: Org.Name and nDegree represent the Name of Organization and Standard Centrality Degree respectively, with the abbreviations shown in Appendix).

Table 6

| Organizations involved in DRS. |
|-------------------------------|
| Time Slice | All | T1 | T2 | T3 | T4 | T5 |
| Rank | Org.Name | nDegree | Org.Name | nDegree | Org.Name | nDegree | Org.Name | nDegree | Org.Name | nDegree | Org.Name | nDegree |
| 1 | NHC | 6.805 | NHC | 17.946 | HBL | 11.740 | NHC | 13.620 | NHC | 19.154 | NHC | 17.673 |
| 2 | CPS | 4.146 | CPS | 11.833 | NHC | 10.368 | JPC | 8.465 | AHL | 10.448 | HBG | 12.642 |
| 3 | ABC | 2.869 | HBL | 10.180 | CPS | 5.039 | CPS | 5.927 | CPS | 8.841 | CPS | 12.557 |
| 4 | TGL | 2.639 | TGL | 9.141 | TGL | 4.610 | HBL | 4.938 | HNL | 7.981 | HNL | 11.614 |
| 5 | JPC | 1.977 | MTP | 6.203 | WHL | 4.544 | CGH | 4.887 | NHG | 7.131 | SDL | 11.543 |
| 6 | WHL | 1.877 | JPC | 6.039 | CGH | 3.648 | WHL | 4.418 | TGL | 6.571 | AHL | 10.69 |
| 7 | CGH | 1.717 | MGP | 5.475 | JPC | 3.510 | FGL | 4.144 | HBL | 6.488 | HBL | 8.624 |
| 8 | HNL | 1.630 | WHL | 4.534 | MII | 3.202 | CDC | 4.052 | WHL | 6.188 | TJL | 8.532 |
| 9 | ZJL | 1.599 | NDC | 3.895 | ZJL | 2.497 | SAL | 3.932 | ZJL | 5.690 | ZJL | 8.270 |
| 10 | SDL | 1.611 | MPS | 3.470 | NDC | 2.258 | TCL | 3.161 | SDL | 5.442 | JSL | 7.433 |
| 11 | JSL | 1.533 | XZL | 3.126 | MCA | 2.154 | GZL | 3.075 | HNL | 5.431 | PLA | 5.804 |
| 12 | AHL | 1.253 | JSL | 2.913 | SCL | 2.051 | FJL | 2.984 | JSL | 4.082 | SHL | 5.768 |
| 13 | NDC | 1.083 | MFC | 2.758 | SDL | 2.040 | HNG | 2.212 | NDC | 4.001 | XJL | 5.385 |
| 14 | MTP | 1.009 | MCA | 2.700 | CDC | 1.930 | MCA | 2.172 | HBG | 3.814 | WHL | 5.166 |
| 15 | MPS | 0.973 | PBC | 2.524 | XJL | 1.643 | CGH | 2.086 | MPS | 3.379 | GZL | 4.712 |
| 16 | NDC | 0.867 | GAS | 2.242 | JSL | 1.632 | NDC | 1.915 | JSL | 2.591 | SXL | 4.528 |
| 17 | MII | 0.821 | MIR | 1.727 | HBH | 1.546 | MCP | 1.858 | MCA | 2.539 | FJH | 4.507 |
| 18 | MCA | 0.817 | MII | 1.563 | MFP | 1.338 | AHL | 1.829 | MII | 2.498 | CDC | 4.174 |
| 19 | CDC | 0.799 | CGH | 1.097 | GDL | 1.293 | MFC | 1.795 | XZL | 2.436 | HNP | 3.975 |
| 20 | MFP | 0.739 | AHL | 0.990 | FJL | 1.241 | MAR | 1.749 | MCA | 2.177 | JPC | 3.664 |

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| Organization Name                                                                 | Abbreviation |
|----------------------------------------------------------------------------------|--------------|
| Department of Old-age Services of Ministry of Civil Affairs of the People’s Republic of China | DOS          |
| Department of Passenger Transport of China State Railway Group                   | DPT          |
| Department of Social Affairs of Ministry of Civil Affairs of the People’s Republic of China | DSA          |
| Evergrande Group                                                                  | EG           |
| Health Commission of Fujian Province                                             | FJH          |
| Fujian Provincial Information Office of the People’s Republic of China            | FJI          |
| Fujian Provincial Leading Group for COVID-20 Prevention and Control               | FJL          |
| Fujian Provincial Publicity Department of the Communist Party of China            | FJP          |
| Fujian Provincial Science and Technology Department                              | FJS          |
| General Administration of Customs People’s Republic of China                     | GAC          |
| General Administration of Sport of China                                          | GAS          |
| Guangxi Center for Disease Control and Prevention                                 | GDC          |
| Health Commission of Guangdong Province                                          | GDH          |
| Guangdong province Leading Group for COVID-19 Prevention and Control              | GDL          |
| Guidance Group of the State Council                                              | GGS          |
| Department of Finance of Gansu Province                                           | GSF          |
| Health Commission of Gansu Province                                              | GSH          |
| Gansu province Leading Group for COVID-19 Prevention and Control                  | GSL          |
| Guangxi province Leading Group for COVID-19 Prevention and Control                | GXL          |
| Heilongjiang Aid Medical Team to Wuhan                                            | HAM          |
| Department of Economy and Technology of Hubei Province                            | HBE          |
| Hebei province Leading Group for COVID-19 Prevention and Control                  | HBG          |
| Health Commission of Hubei Province                                              | HBH          |
| Hubei province Leading Group for COVID-19 Prevention and Control                  | HBL          |
| Public Security Department of Hubei Province                                      | HBP          |
| Department of Transportation of Hubei Province                                    | HBT          |
| Heilongjiang province Leading Group for COVID-19 Prevention and Control           | HLL          |
| Department of Finance of Hunan Province                                          | HNF          |
| Health Commission of Hunan Province                                             | HNH          |
| Hunan province Leading Group for COVID-19 Prevention and Control                  | HNG          |
| Henan province Leading Group for COVID-19 Prevention and Control                  | HNL          |
| Hennan province Leading Group for COVID-19 Prevention and Control                 | HNP          |
| Health Commission of Hennan Province                                            | HCH          |
| Department of Human Resources and Social Security of Hunan Province              | HNS          |
| Hanyang Municipal Construction Group                                              | HYM          |
| China Chamber of International Commerce                                          | ICC          |
| Institute of Microbiology of Chinese Academy of Sciences                          | IMC          |
| Inner Mongolia Leading Group for COVID-19 Prevention and Control                  | IML          |
| Institute of Pathogenic Biology of Chinese Academy of Medical Sciences             | IPR          |
| JingDong Logistics                                                               | JD           |
| Health Commission of Jilin Province                                              | JIL          |
| Jilin Provincil Information Office of the People’s Republic of China              | JLI          |
| Industry and Information Technology Department of Jilin Province                   | JLD          |
| Jilin province Leading Group for COVID-19 Prevention and Control                  | JLL          |
| Jilin Medical Aid Team to Hubei Province                                         | JMA          |
| Joint Prevention and Control Mechanism of the State Council                       | JPC          |
| Jiangsu province Leading Group for COVID-19 Prevention and Control                 | JSL          |
| Health Commission of Jiangxi Province                                           | JXH          |
| Jiangxi province Leading Group for COVID-21 Prevention and Control                 | JXL          |
| Liaoning province Leading Group for COVID-19 Prevention and Control                | LNL          |
| Ministry of Agriculture and Rural Affairs of the People’s Republic of China       | MAR          |
| Ministry of Civil Affairs of the People’s Republic of China                       | MCA          |
| Macao Leading Group for COVID-24 Prevention and Control                           | MCL          |
| Ministry of Commerce of the People’s Republic of China                            | MCP          |
| Ministry of Culture and Tourism of the People’s Republic of China                 | MCT          |
| Ministry of Education of the People’s Republic of China                           | MEC          |
| Ministry of Finance of the People’s Republic of China                             | MFC          |
| Anhui Mingguang Charity Association                                              | MGH          |
| Ministry of Housing and Urban-Rural Development of the People’s Republic of China | MHR          |
| Ministry of Industry and Information Technology of the People’s Republic of China | MIU          |
| Ministry of Justice of the People’s Republic of China                             | MJU          |
| Administration of Prison of the Ministry of Justice of the People’s Republic of China | MJP          |
| Ministry of Human Resources and Social Security of the People’s Republic of China | MHR          |
| The Ministry of Public Security of the People’s Republic of China                 | MPS          |
| Ministry of Science and Technology of the People’s Republic of China              | MST          |
| Medical Team of China-Japan friendship Hospital                                   | MTC          |
| Ministry of Transport of the People’s Republic of China                           | MTP          |
| Medical Team of Third Military Medical University                                 | MTT          |
| National Development and Reform Commission                                        | NDC          |
| National Energy Administration                                                    | NEA          |
| National Emergency Medical Rescue Team                                            | NEM          |
| National Emergency Medical Rescue Team(Shanghai)                                  | NES          |
| National Forestry and Grassland Administration of the People’s Republic of China | NFG          |
| National Food and Strategic Reserves Administration                               | NFS          |
| National Health Commission of the People’s Republic of China                     | NHC          |

(continued on next page)
| Organization Name                                                                 | Abbreviation |
|----------------------------------------------------------------------------------|--------------|
| National Healthcare Security Administration                                      | NHS          |
| National Medical Products Administration                                        | NMP          |
| The National People’s Congress (NPC) of the People’s Republic of China           | NPC          |
| National Patriotic Health Campaign Committee                                    | NPH          |
| National Press and Publication Administration                                  | NPP          |
| Ningxia Leading Group for COVID-19 Prevention and Control                        | NXL          |
| The Organization Department of the Central Committee of the CPC                   | ODC          |
| People’s Bank of China                                                         | PBC          |
| People’s Liberation Army of China                                                | PLA          |
| Department of Finance of Qinghai Province                                       | QHF          |
| Health Commission of Qinghai Province                                           | QHH          |
| Qinghai province Leading Group for COVID-19 Prevention and Control               | QHL          |
| Department of Human Resources and Social Security of Qinghai Province            | QHS          |
| Red Cross Society of China                                                      | RCS          |
| Renmin Hospital in Binhai                                                        | RHB          |
| Shaanxi province Leading Group for COVID-19 Prevention and Control               | SAL          |
| State Aid Medical Team to Hubei Province                                         | SAM          |
| State Administration for Market Regulation                                       | SMR          |
| State-owned Assets Supervision and Administration Commission of the State Council| SAS          |
| State Administration of Traditional Chinese Medicine of the People’s Republic of | SAT          |
| China                                                                            |              |
| Department of Finance of Sichuan Province                                       | SCF          |
| Health Commission of Sichuan Province                                           | SCH          |
| Department of Human Resources and Social Security in Sichuan                     | SGR          |
| Sichuan Provincial Healthcare Security Administration                          | SCS          |
| The State Council Information Office of the People’s Republic of China          | SCO          |
| Sichuan province Leading Group for COVID-19 Prevention and Control              | SCL          |
| State Council of the People’s Republic of China                                 | SCP          |
| Department of Finance of Shandong Province                                      | SDF          |
| Health Commission of Shandong Province                                          | SDH          |
| Shandong province Leading Group for COVID-19 Prevention and Control              | SDL          |
| SF-Express                                                                       | SF           |
| Shanghai BioGerm Medical Technology                                             | SHB          |
| Shanghai GenoDx Biotech                                                          | SHG          |
| Shanghai Municipal Health Commission                                            | SMH          |
| Shanghai Leading Group for COVID-19 Prevention and Control                       | SHL          |
| Shanghai Municipal Public Security Bureau                                       | SMP          |
| Shanghai Municipal Transportation Commission                                   | SMT          |
| Shanghai ZJ Bio-Tech                                                            | SHZ          |
| Society of Infectious Diseases of Chinese Medical Association (Chinese Medical Association) | SID          |
| Shaanxi Medical Aid Team to Hubei Province                                       | SMA          |
| The Supreme People’s Court of The People’s Republic of China                    | SPC          |
| The Supreme People’s Procuratorate of the People’s Republic of China            | SPP          |
| State Taxation Administration                                                   | STA          |
| Health Commission of Shanxi Province                                            | XKX          |
| Shanxi province Leading Group for COVID-19 Prevention and Control                | XSL          |
| The Central response Leading Group of the Communist Party of China for COVID-19 | TCL          |
| National Medical Team of Traditional Chinese Medicine                           | TCM          |
| Tianjin Leading Group for COVID-22 Prevention and Control                        | TJL          |
| Union Hospital Affiliated to Tongji Medical College of Huazhong University of Science and Technology | UHA          |
| Wuhan Construction                                                              | WHC          |
| Wuhan Leading Group for COVID-19 Prevention and Control                         | WHL          |
| Wuhan Municipal Construction Group                                              | WHM          |
| World Health Organization                                                        | WHO          |
| Wuhan Railway Administration                                                     | WHR          |
| Renmin Hospital of Wuhan University                                              | WHH          |
| Wu Mart                                                                          | WM           |
| Xinjiang province Leading Group for COVID-19 Prevention and Control               | XJL          |
| “Xiaotangshan” in Wuhan                                                         | XTS          |
| Health Commission of Xizang Province                                            | XZH          |
| Xizang Leading Group for COVID-19 Prevention and Control                         | XZL          |
| Health Commission of Yunnan Province                                            | YNH          |
| Yunnan province Leading Group for COVID-19 Prevention and Control                | YNL          |
| Health Commission of Zhejiang Province                                          | ZJH          |
| Zhejiang Province Leading Group for COVID-19 Prevention and Control              | ZJL          |
Appendix B. 2-Mode network for each time slice

(a) 2-Mode Network in Time Slice T1

(b) Mode Network in Time Slice T2
(c) 2-Mode Network in Time Slice T3

(d) 2-Mode Network in Time Slice T4

(continued)
(e) 2-mode network in Time Slice T5

(continued)
Appendix C. 1-Mode network for each time slice

(a) 1-Mode Network for Time Slice T1

(b) 1-Mode Network for Time Slice T2
(c) 1-Mode Network for Time Slice T3

(d) 1-Mode Network for Time Slice T4

(continued)
References

[1] L.K. Comfort, N. Kapucu, K. Ko, S. Menoni, M. Siciliano, Crisis decision making on a global scale: transition from cognition to collective action under threat of COVID-19, Publ. Adm. Rev. 80 (4) (2020) 616–622.

[2] N. Tomer, Collateral effects of COVID-19 pandemic emergency response on worldwide immunizations, Vacunas 21 (2) (2020) 73–75.

[3] L. Pastin, Nicolò Sella, C. Correale, A. Boscolo, P. Navalese, Regional COVID-19 network for coordination of SAS-COV-2 outbreak in Veneto, Italy, J. Cardiothorac. Vasc. Anesth. 34 (9) (2020) 2341–2345.

[4] K. Kim, K. Jung, K. Chilton, Strategies of social media use in disaster management: lessons in resilience from Seoul, South Korea, Int. J. Emerg. Serv. 5 (2) (2016) 110–125.

[5] S.C. Somers, Building Organizational Resilience Potential: an Adaptive Strategy for Operational Continuity in Crises, Arizona State University, Arizona, 2007.

[6] S.S. Rai, S. Rai, N.K. Singh, Organizational Resilience and Social-Economic Sustainability: COVID-19 Perspective, Environment, Development and Sustainability, 2021, https://doi.org/10.1007/s10668-020-01154-6.

[7] E. Barasa, R. Mbau, L. Gilson, What is resilience and how can it be nurtured? A systematic review of empirical literature on organizational resilience, Int. J. Health Pol. Manag. 7 (6) (2018) 491–503.

[8] J.C. Gaillard, Vulnerability, capacity and resilience: perspectives for climate and development policy, J. Int. Dev. 22 (2) (2010) 218–232.

[9] C.W. Zobel, Representing perceived tradeoffs in defining disaster resilience, Decis. Support Syst. 50 (2) (2011) 394–403.

[10] J.S. Mayunga, Understanding and applying the concept of community disaster readiness, Am. J. Community Psychol. 41 (1) (2008) 127–150.

[11] F.H. Norris, S.P. Stevens, B. Pfefferbaum, K.F. Wyche, R.L. Pfefferbaum, Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness, Am. J. Community Psychol. 41 (1) (2008) 127–150.

[12] D.E. Alexander, Resilience and disaster risk reduction: an etymological journey, Nat. Hazards Earth Syst. Sci. 15 (11) (2015) 2707–2716.

[13] L.K. Comfort, N. Oh, G. Ertan, The dynamics of disaster recovery: resilience and entropy in hurricane response systems 2005–2008, Publ. Organ. Rev. 9 (4) (2009) 309–323.

[14] G. Freks, J. Warner, B. Wejs, The politics of vulnerability and resilience, Ambiente Sociedade 14 (2) (2011) 105–122.

[15] J.R. Clymer, Simulation-based engineering of complex adaptive systems, Simulation 72 (4) (1999) 250–260.

[16] L.K. Comfort, K. Ko, A. Zagorecki, Coordination in rapidly evolving disaster response systems: the role of information, Am. Behav. Sci. 48 (3) (2004) 295–313.

[17] R. Wilding, A. Paraskevas, Crisis management or crisis response system? Manag. Decis. 44 (7) (2012) 892–907.

[18] X. Guo, N. Kapucu, Examining collaborative disaster response in China: network perspectives, Nat. Hazards 79 (3) (2015) 1773–1789.

[19] A. Abbasi, A. Sadeghi-Niaraki, M. Jallil, S.M. Choi, Enhancing response coordination through the assessment of response network structural dynamics, PloS One 13 (2) (2018) 1–17.

[20] A. Abbasi, N. Kapucu, Structural dynamics of organizations during the evolution of interorganizational networks in disaster response, J. Homel. Secur. Emerg. Manag. 9 (1) (2012) 1–19.

[21] R. Shaw, Indian Ocean tsunami and aftermath: need for environment-disaster synergy in the reconstruction process, Disaster Prev. Manag. 15 (1) (2006) 5–20.

[22] R. Djalel, Adaptive governance and resilience: the role of multi-stakeholder platforms in disaster risk reduction, Nat. Hazards Earth Syst. Sci. 12 (9) (2012) 2923, 2923.

[23] A. Rose, Economic resilience to natural and man-made disasters: multidisciplinary origins and contextual dimensions, Environ. Hazards 7 (4) (2007) 383–398.

[24] D.A. McEntire, Why vulnerability matters: exploring the merit of an inclusive disaster reduction concept, Disaster Prev. Manag. 14 (2) (2005) 206.

[25] F.H. Norris, S.P. Stevens, B. Pfefferbaum, K.F. Wyche, R.L. Pfefferbaum, Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness, Am. J. Community Psychol. 41 (1–2) (2008) 127–150.

[26] H. Zhou, J. Wang, J. Wan, H. Jia, Resilience to natural hazards: a geographic perspective, Nat. Hazards 53 (1) (2010) 21–41.

[27] S. Cutter, L. Burton, E. Evans, E. Tate, J. Webb, A place-based model for understanding community resilience to natural disasters, Global Environ. Change 15 (3–4) (2005) 299–307.

[28] C. Coetzee, D.V. Niekerk, E. Raju, Disaster resilience and complex adaptive systems theory: finding common grounds for risk reduction, Disaster Prev. Manag. 25 (2) (2016) 196–211.
S. Hunt, K. Smith, H. Hamerton, R.J. Sargisson, An incident control centre in
X. Guo et al.
N. Kapucu, A. Ozerdem, Managing Emergencies and Crises, Jones
E.B. Villar, F. Miralles, Beyond resources and dynamic capabilities during disaster
P.J. Schweizer, O. Renn, Governance of systemic risks for disaster prevention and
Al-Manji Suad, J. Lovett, G. Mitchell, Factors affecting disaster resilience in Oman:
W.L. Waugh, G. Streib, Collaboration and leadership for effective emergency
J. Goniewicz, A. Khorram-Manesh, A.J. Hertelendy, M. Goniewicz, K. Naylor, F.
J.M. Col, Managing disasters: the role of local government, Publ. Adm. Rev. 67 (5) (2003) 544–657.
J.D. Sterman, System dynamics modeling: tools for learning in a complex world
L. Holden, Complex adaptive systems: concept analysis, J. Adv. Nurs. 52 (6) (2005) 651–657.
J.D. Sterman, System dynamics modeling: tools for learning in a complex world
J. Holland, Complex adaptive system theory, Daedalus 121 (1) (1992) 17–30.
S. Levin, Towards a Science of Sustainability Complex Adaptive Systems and the
S. Hunt, K. Smith, H. Hamerton, R.J. Sargisson, An incident control centre in
X. Guo et al.
N. Kapucu, A. Ozerdem, Managing Emergencies and Crises, Jones
E.B. Villar, F. Miralles, Beyond resources and dynamic capabilities during disaster
P.J. Schweizer, O. Renn, Governance of systemic risks for disaster prevention and
Al-Manji Suad, J. Lovett, G. Mitchell, Factors affecting disaster resilience in Oman:
W.L. Waugh, G. Streib, Collaboration and leadership for effective emergency
J. Goniewicz, A. Khorram-Manesh, A.J. Hertelendy, M. Goniewicz, K. Naylor, F.
J.M. Col, Managing disasters: the role of local government, Publ. Adm. Rev. 67 (5) (2003) 544–657.