Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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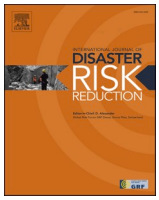

Examining resilience of disaster response system in response to COVID-19

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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.

1. 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 to 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.

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

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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 adaption 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 collision 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

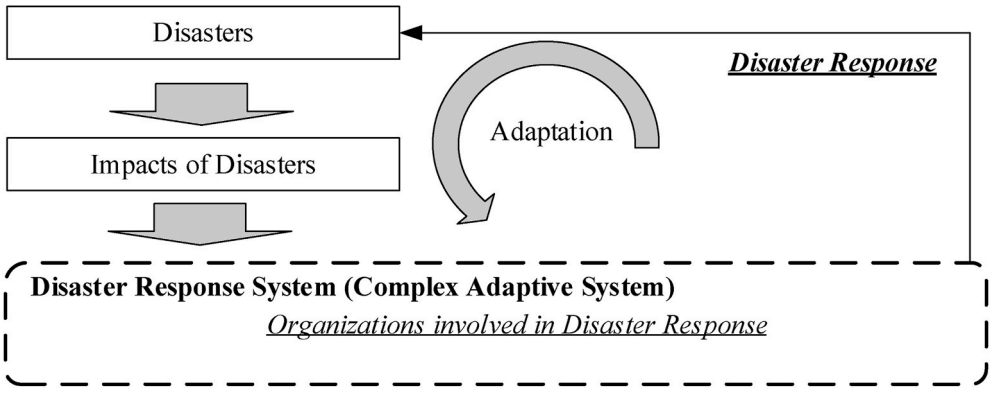


Fig. 1. Theoretical framework.

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 "closure" 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.

Table 1
Emergency support functions.

Serial Number	Function
ESF1	Prevention and Emergency Preparedness
ESF2	Monitoring and Warning
ESF3	Epidemic Control
ESF4	Graded Response
ESF5	Aid Supplies
ESF6	Team Support
ESF7	Information Reports
ESF8	Scientific Research and Judgment
ESF9	Traffic Health Quarantine
ESF10	Medical Rescue
ESF11	Tracking Management
ESF12	Emergency Disposal
ESF13	Publicity and Guidance of Public Opinion
ESF14	Popular Science Propaganda
ESF15	Supervision and Administration
ESF16	Command and Coordination
ESF17	Emergency Measure
ESF18	Joint Prevention and Control
ESF19	Mass Prevention and Management
ESF20	Social Mobilization
ESF21	Social Assistance
ESF22	Information Release
ESF23	Social Stability Maintenance
ESF24	Financial Support
ESF25	Material Support
ESF26	Logistical Support
ESF27	Communication and Transportation Support
ESF28	Technology Support
ESF29	Recovery and Reconstruction
ESF30	Treatment Support
ESF31	Legal Support
ESF32	Reward and Accountability

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

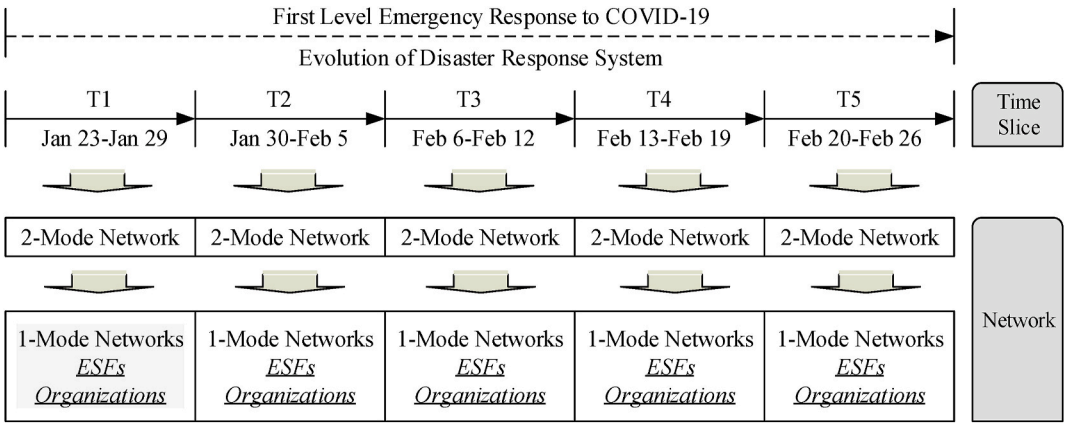


Fig. 2. Research strategy of dynamic time analysis.

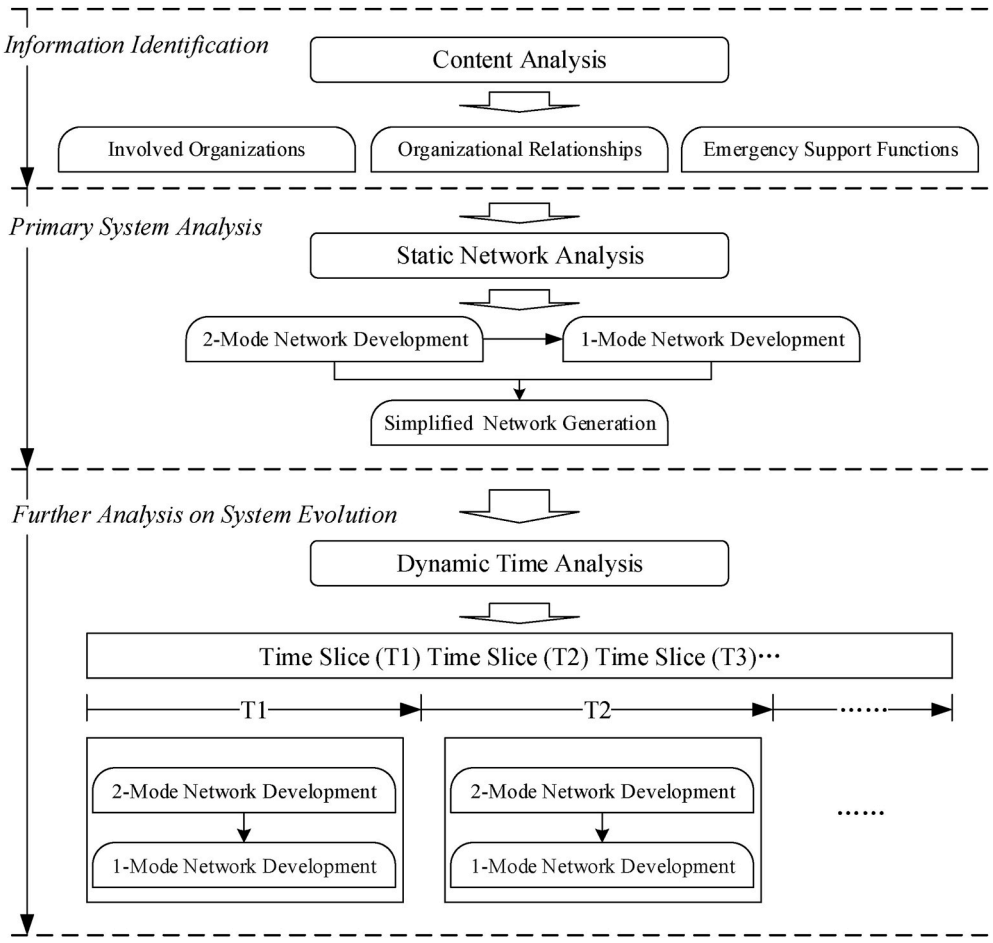


Fig. 3. Overall research strategy.

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,

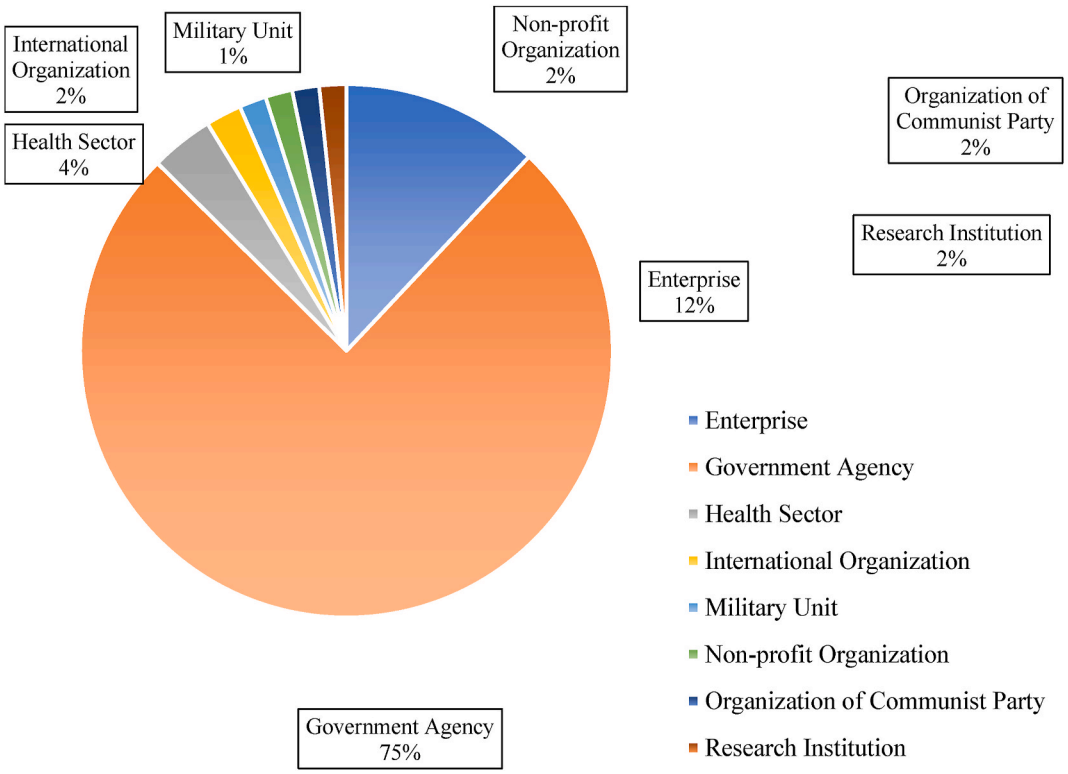


Fig. 4. Organizations involved in COVID-19 Response.

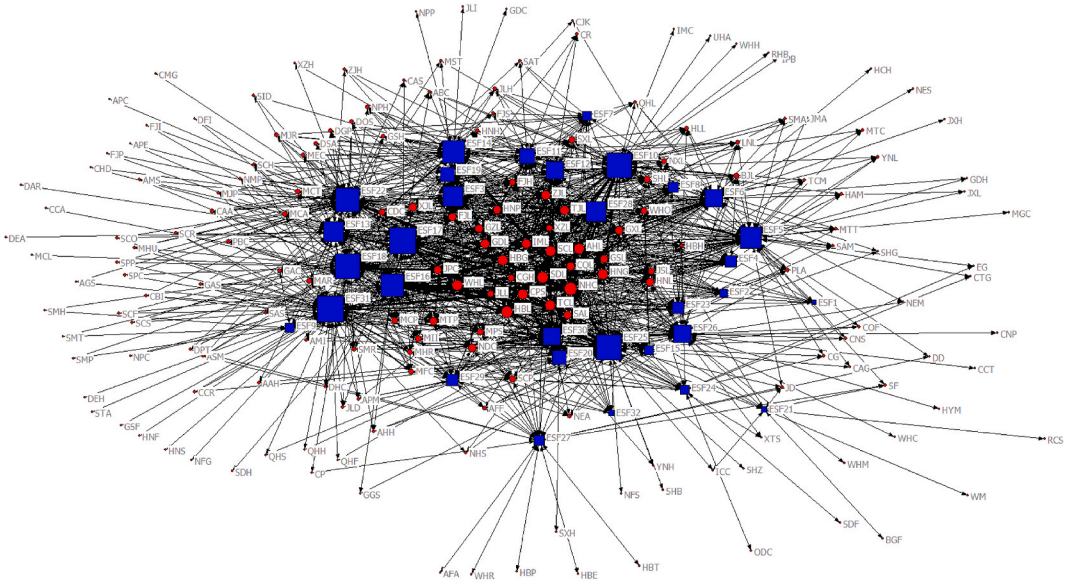


Fig. 5. 2-Mode Network on COVID-19 Response. *Note*: see Appendix A for abbreviations, and 1-Mode Network is difficult to be visualized due to numerous involved organizations.

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,

Table 2
Block distribution of DRS.

Block Name	Involved Organizations
Block 1	CPS, TCL, JPC, CGH, NHC, HBL, HBH, WHL, MCA, SPC, MII, CAA, MST, MTP, CCR, NPH, MPS, DSA, RCS, DGP, GGS, MCP, MJR, WHO, PLA, GAC, MEC, MCT, NDC, NMP, CDC
Block 2	SAM, SMA, JMA, HAM, RHB, NES, DHC, WHH, UHA, MTC, MTT, CR, WHR, DPT, ASM, NFS, XTS, WHM, WM, CNP, CNS, COF, CTG, WHC, HYM, EG, CAG, JD, SF, DD, NHS, CCT, AFA, ICC, CG, COF
Block 3	SMR, MFC, SAS, MJP, STA, MHU, GAS, AGS, CBI, PBC, CCA, ODC, SPP, SPC, MHR, NEA, NPC, AMS, APC, CBI, AMI, APM, APE, NFG, DOS, AFF, AAH
Block 4	CMG, NPP, FJI, FJP, SCO, JLI
Block 5	AHL, SCL, GDL, GSL, HBG, SXL, HNG, HNL, SDL, IML, CQL, SJL, FJL, HNP, GZL, JLL, SAL, XZH, TJL, BJL, JSL, NXL, YNL, GXL, SHL, ZJL, HLL, MCL, JXL, FJH, AHH, ADH, ZJH, YNH, JLH, HNH, SMH, GSH, SCH, XZH, QHH, GDH, JXH, HCH, SXH, SCS, FJS, JLD, SMT, SMP, HBE, HBT, GDC, HBP, HNS, QHS, SCH, DAR, DEA, DEH, JLD, SDF, GSF, SCF, QHF, 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	0	1	0
Block 6	1	1	0	0	0	1

playing leading roles, it can be confirmed that public agencies are more central in the whole network as stated in Hypothesis 1. However, other agencies including enterprises (such as CP, CR and JD), non-governmental organization (such as RCS, SID) and research institutions (such as CAS, SHB) got involved in response and played important and unreplaceable roles. So, it can be highlighted that the COVID-19 response in China is achieved following the *hybrid modes of coordination* [75]. Examining the whole network, it can be observed that the organizations involved in subsystems according to the functional assignments (see details in analyses on subsystems of DRS), supporting Hypothesis 2. The function of each subsystem was strengthened though 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 has 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 Recue*, 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 *Command 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).

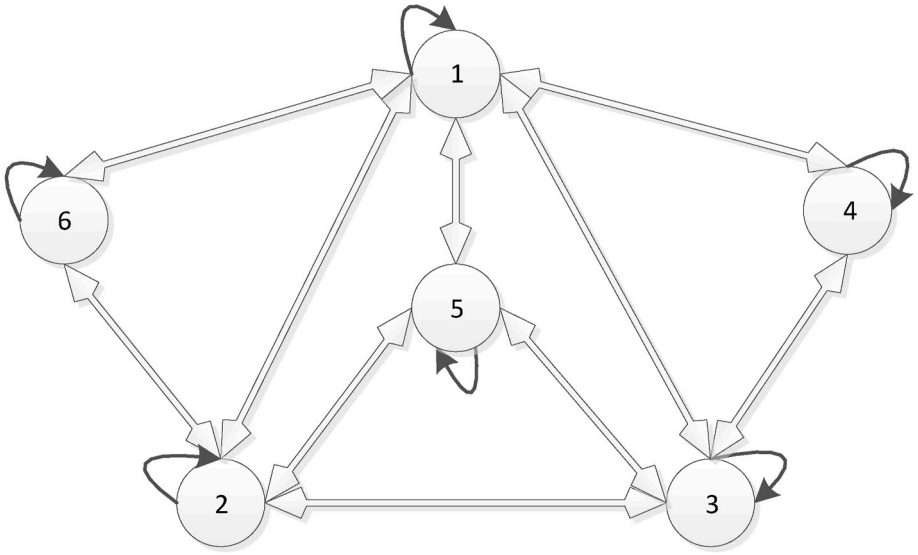


Fig. 6. Simplified network on DRS

Table 4
ESFs degree centrality (%) measures.

Rank	Total: T1-T5	T1	T2	T3	T4	T5
1	ESF16 (31.97)	ESF16 (31.98)	ESF10 (23.03)	ESF25 (25.04)	ESF16 (33.16)	ESF16 (29.94)
2	ESF10 (26.00)	ESF30 (29.94)	ESF16 (22.87)	ESF16 (23.67)	ESF12 (25.41)	ESF10 (28.73)
3	ESF25 (23.41)	ESF10 (25.31)	ESF17 (16.33)	ESF22 (19.82)	ESF25 (24.04)	ESF5 (24.02)
4	ESF14 (20.36)	ESF17 (25.06)	ESF14 (13.30)	ESF17 (17.22)	ESF14 (22.26)	ESF25 (22.41)
5	ESF17 (17.97)	ESF25 (25.02)	ESF11 (13.26)	ESF10 (16.17)	ESF10 (20.86)	ESF12 (18.79)
6	ESF22 (15.26)	ESF31 (23.56)	ESF3 (12.71)	ESF31 (15.89)	ESF22 (15.07)	ESF18 (18.67)
7	ESF3 (14.48)	ESF22 (19.41)	ESF25 (12.66)	ESF13 (13.97)	ESF18 (14.70)	ESF28 (18.08)
8	ESF18 (14.08)	ESF3 (17.47)	ESF20 (9.88)	ESF14 (13.20)	ESF13 (14.51)	ESF14 (16.07)
9	ESF31 (14.01)	ESF14 (17.11)	ESF13 (8.21)	ESF18 (11.65)	ESF28 (14.01)	ESF13 (12.73)
10	ESF12 (13.71)	ESF18 (12.96)	ESF12 (8.08)	ESF3 (10.30)	ESF17 (12.85)	ESF20 (12.43)

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

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 polices has 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 first level emergency response was activated all over the country, making the number of organizations and the link among them both reach the maximums. Meanwhile, all organizations were actively seeking cooperation to implement accurate policies and improve the efficiency of response. Moreover, the density of network, the number of organizations, 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 5
Statistics and measures of DRS over time.

	T1	T2	T3	T4	T5	All
	Jan23-Jan29	Jan30-Feb5	Feb6-Feb12	Feb13-Feb19	Feb 20–26	Jan23-Feb26
#of Organizations (nodes)	53	64	82	68	97	183
#of Interactions (Links)	151	261	206	150	331	4795
Density (%)	5.5094	6.4603	3.3348	3.3007	3.5490	14.4107
#of Average Path	1.459	1.351	1.422	1.579	1.532	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

Table 6
Top 20 active organizations 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	HBL	4.146	**CPS**	11.833	**NHC**	10.368	**JPC**	8.465	AHL	10.448	HBG	12.642
3	**CPS**	2.869	HBL	10.180	**CPS**	5.039	**CPS**	5.927	**CPS**	8.841	**CPS**	12.557
4	TCL	2.639	TCL	9.141	TCL	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	TCL	6.571	AHL	10.69
7	CGH	1.717	MCP	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	FJH	2.984	JSL	4.882	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	2.324	XJL	1.643	CGH	2.086	MPS	3.379	GZL	4.712
16	MCP	0.867	GAS	2.242	JSL	1.632	NDC	1.915	JLL	2.591	SXL	4.528
17	MII	0.821	MHR	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

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

Appendix A. Organizations involved in COVID-19 Crisis Response

Organization Name	Abbreviation
Administration of Animal Husbandry and Veterinary of Ministry of Agriculture and Rural Affairs of the People's Republic of China	AAH
Administration of Biological Center of Ministry of Science and Technology of the People's Republic of China	ABC
Air Force	AFA
Administration of Fishery and Fishery Administration of Ministry of Agriculture and Rural Affairs of the People's Republic of China	AFF
Administration of Goods and Services Tax Division of State Taxation Administration	AGS
Health Commission of Anhui Province	AHH
Anhui Provincial Leading Group for COVID-19 Prevention and Control	AHL
Administration of Marketing and Informatization of Ministry of Agriculture and Rural Affairs of the People's Republic of China	AMI
Administration of Market Supervision of State Post Bureau of the People's Republic of China	AMS
Administration of Price Control and Competition of State Administration for Market Regulation	APC
Asia-Pacific Economic Cooperation	APE
Administration of Planting Management of Ministry of Agriculture and Rural Affairs of the People's Republic of China	APM
The Association of Southeast Asian Nations-China, Japan, Korea	CJK
Administration of Service of Ministry of Transport of the People's Republic of China	ASM
Bill & Melinda Gates Foundation	BGF
Beijing Leading Group for COVID-19 Prevention and Control	BJL
Civil Aviation Administration of the People's Republic of China	CAA
China Aoyuan Group Limited	CAG
Chinese Academy of Sciences	CAS
China Banking and Insurance Regulatory Commission	CBI
Office of the Central Cyberspace Affairs Commission	CCA
Central Committee for the Rule of Law	CCR
China Construction Third Engineering Bureau	CCT
Chinese Center for Disease Control and Prevention	CDC
Country Garden	CG
Central Guidance Group to Hubei	CGH
Center for Health Development Research of National Health Commission of the People's Republic of China	CHD
China Media Group	CMG
China National Pharmaceutical Group	CNP
China National Salt Industry Group	CNS
COFCO Corporation	COF
China Post	CP
Central Politburo Standing Committee of the Communist Party of China	CPS
Chongqing Leading Group for COVID-24 Prevention and Control	CQL
China State Railway Group	CR
China Three Gorges Corporation	CTG
Department of Agriculture and Rural Affairs of Anhui Province	DAR
DiDi Corporation	DD
Department of Education of Anhui Province	DEA
Department of Education of Hunan Province	DEH
Department of Financial Inclusion of China Banking and Insurance Regulatory Commission	DFI
Department of Grass-roots Political Power Building and Community Governance of Ministry of Civil Affairs of the People's Republic of China	DGP
Department of Health of Central Military Commission	DHC

(*continued on next page*)

(*continued*)

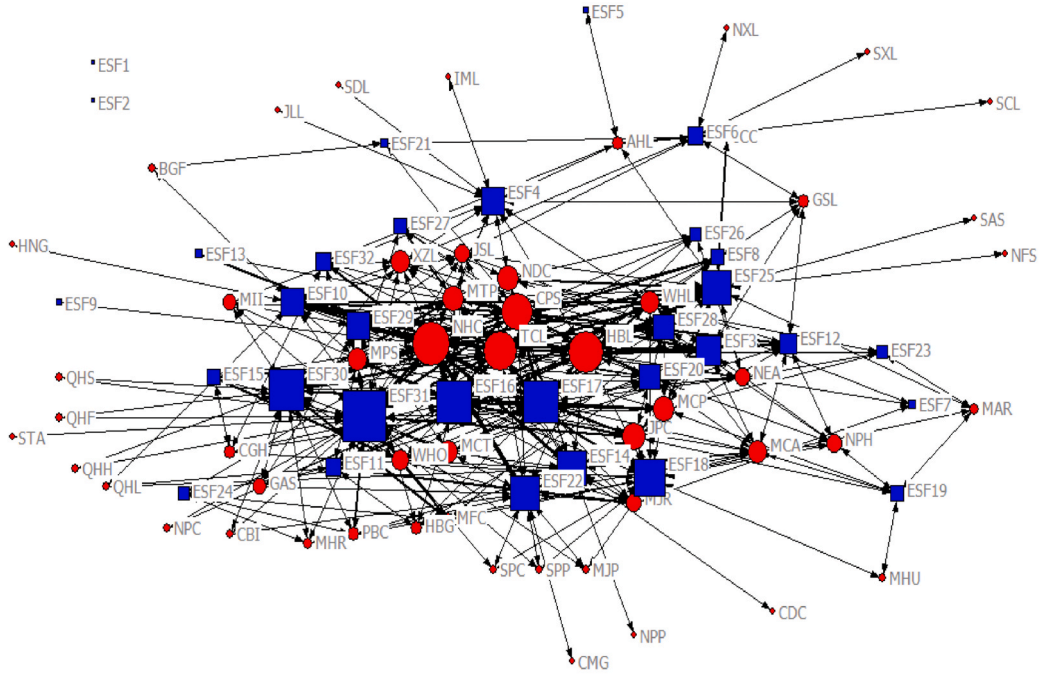
Organization Name	Abbreviation
Department of Old-age Services of Ministry of Civil Affairs of the People's Republic of China	DOS
Department of Passenger Transport of China State Railway Group	DPT
Department of Social Affairs of Ministry of Civil Affairs of the People's Republic of China	DSA
Evergrande 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
Guizhou province Leading Group for COVID-19 Prevention and Control	GZL
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
Hannan province Leading Group for COVID-19 Prevention and Control	HNP
Health Commission of Hannan 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	IPB
JingDong Logistics	JD
Health Commission of Jilin Province	JLH
Jilin Provincial 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	MGC
Ministry of Housing and Urban-Rural Development of the People's Republic of China	MHU
Ministry of Industry and Information Technology of the People's Republic of China	MII
Ministry of Justice of the People's Republic of China	MJP
Administration of Prison of the Ministry of Justice of the People's Republic of China	MJR
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*)

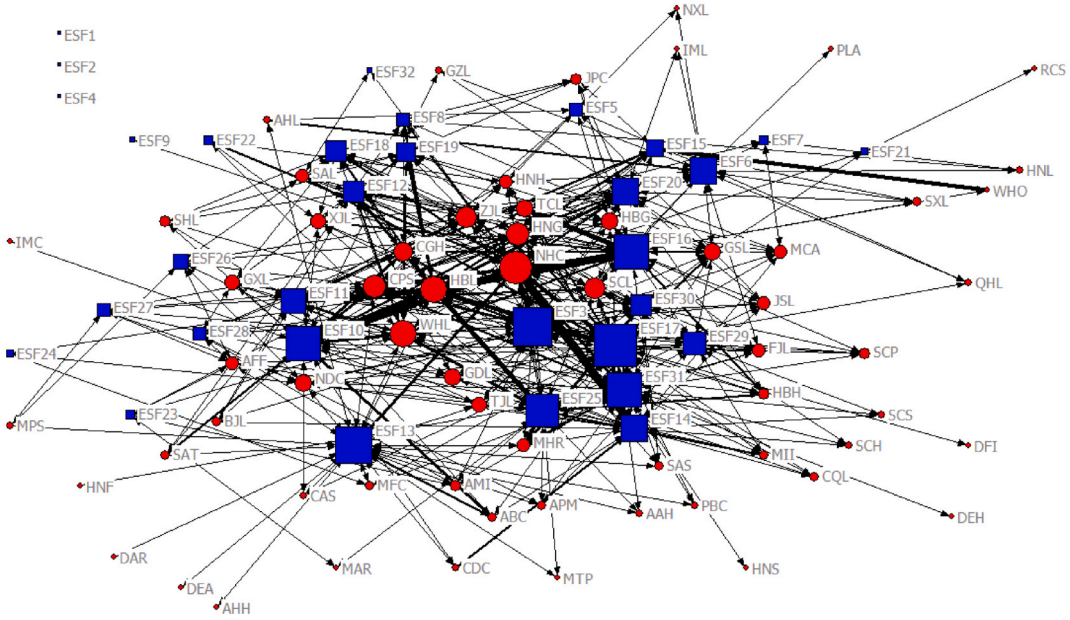
(*continued*)

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 Bozhou	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 China	SAT
Department of Finance of Sichuan Province	SCF
Health Commission of Sichuan Province	SCH
Department of Human Resources and Social Security in Sichuan	SCR
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
Shangdong province Leading Group for COVID-19 Prevention and Control	SDL
SF-Express	SF
Shanghai BioGerm Medical Technology	SHB
Shanghai GeneoDx 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	SXH
Shanxi province Leading Group for COVID-19 Prevention and Control	SXL
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

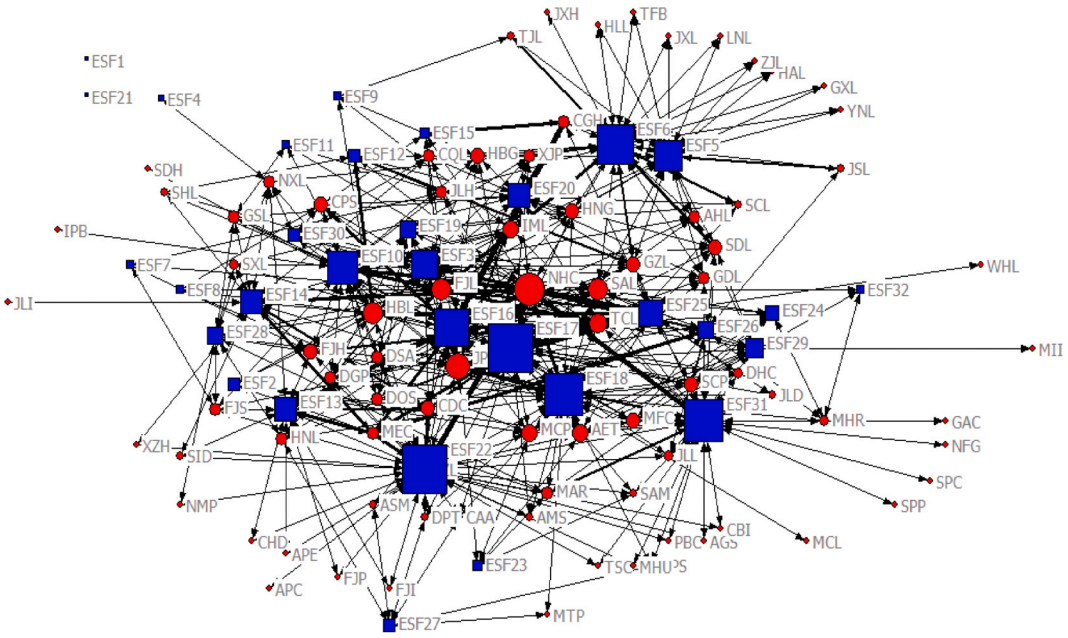
Appendix B. 2-Mode network for each time slice



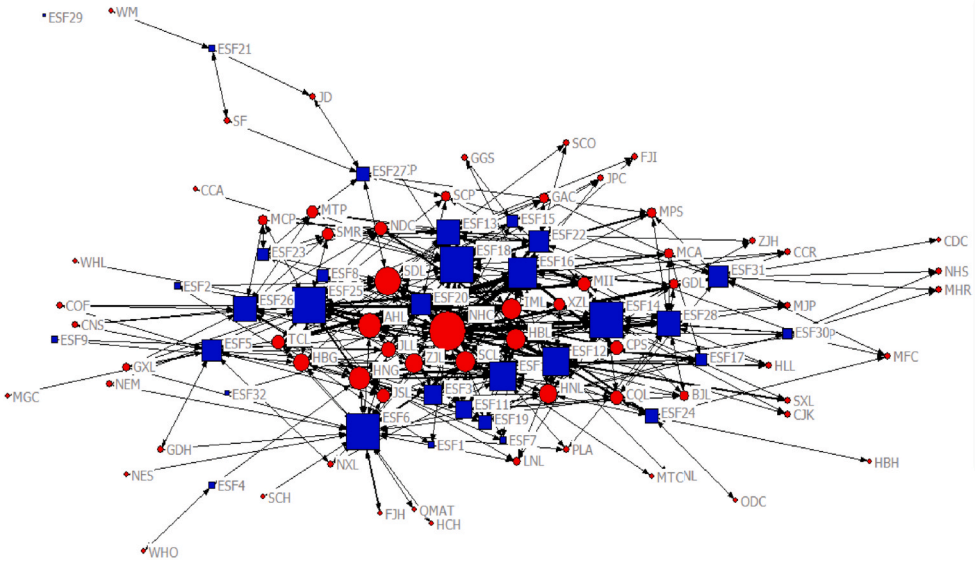
(a) 2-Mode Network in Time Slice T1



(b) Mode Network in Time Slice T2

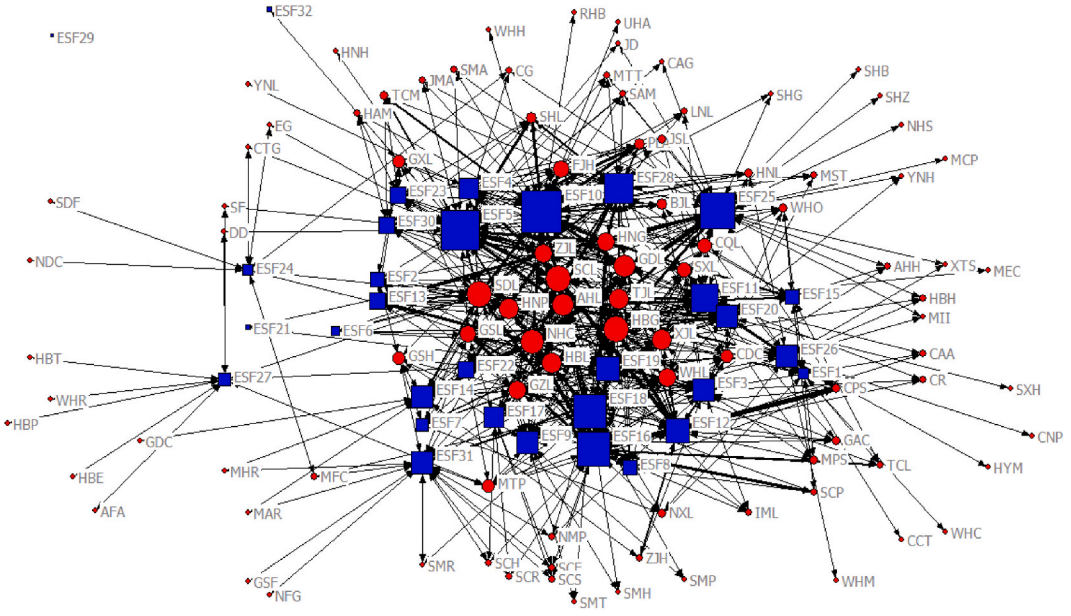


(c) 2-Mode Network in Time Slice T3



(d) 2-Mode Network in Time Slice T4

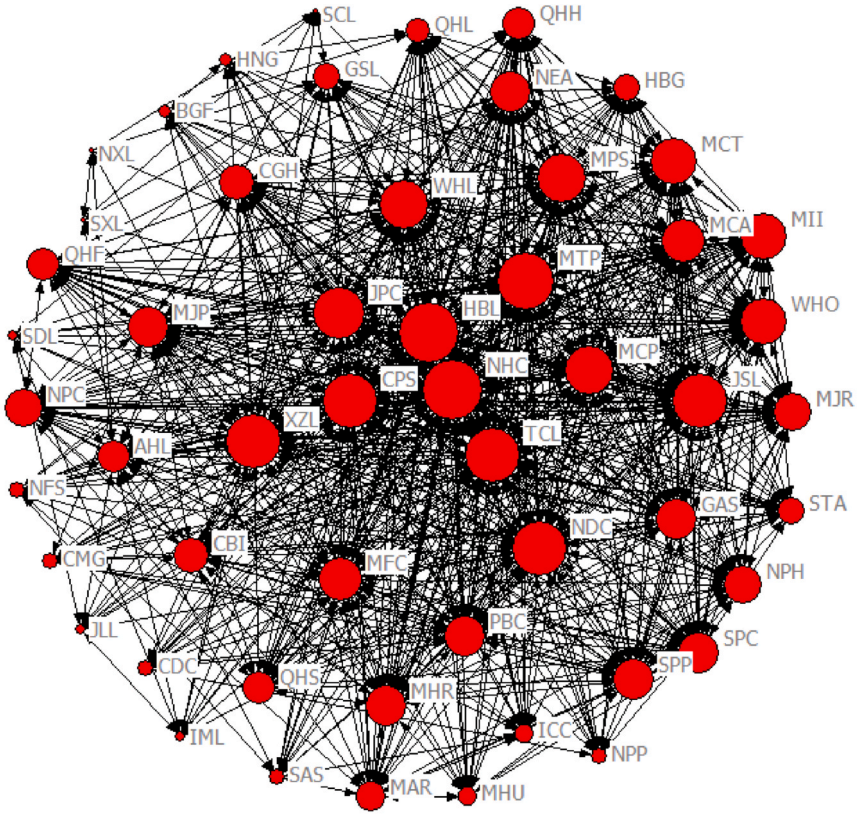
. (*continued*).



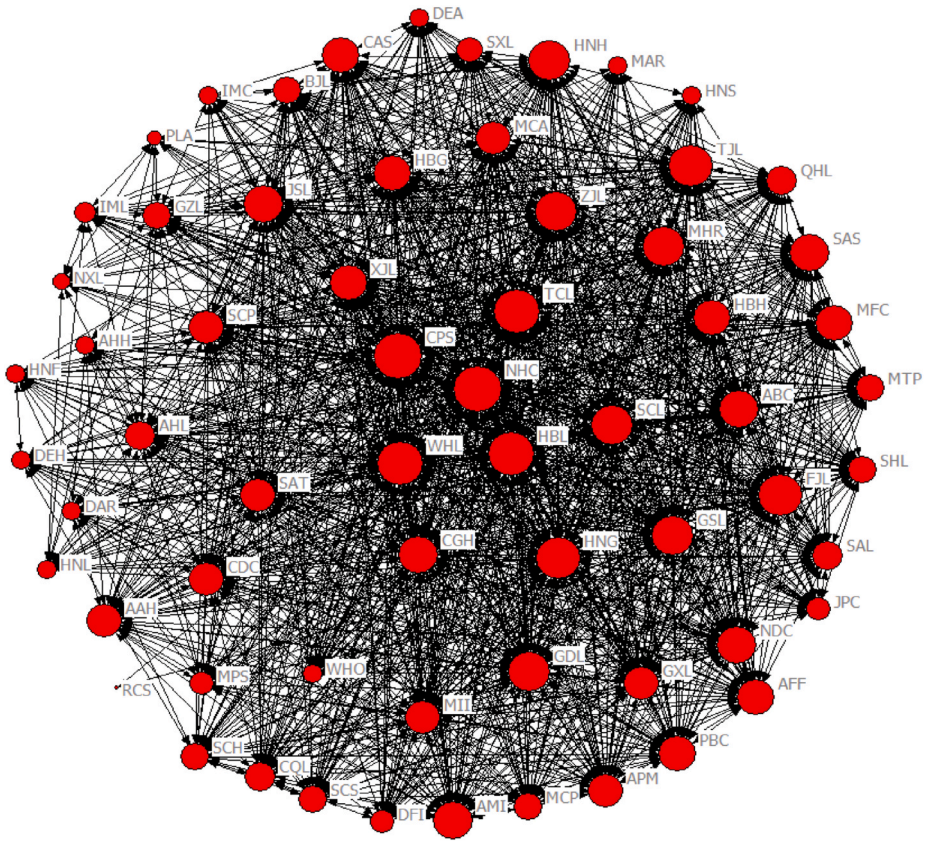
(e)2-Mode Network in Time Slice T5

. (*continued*).

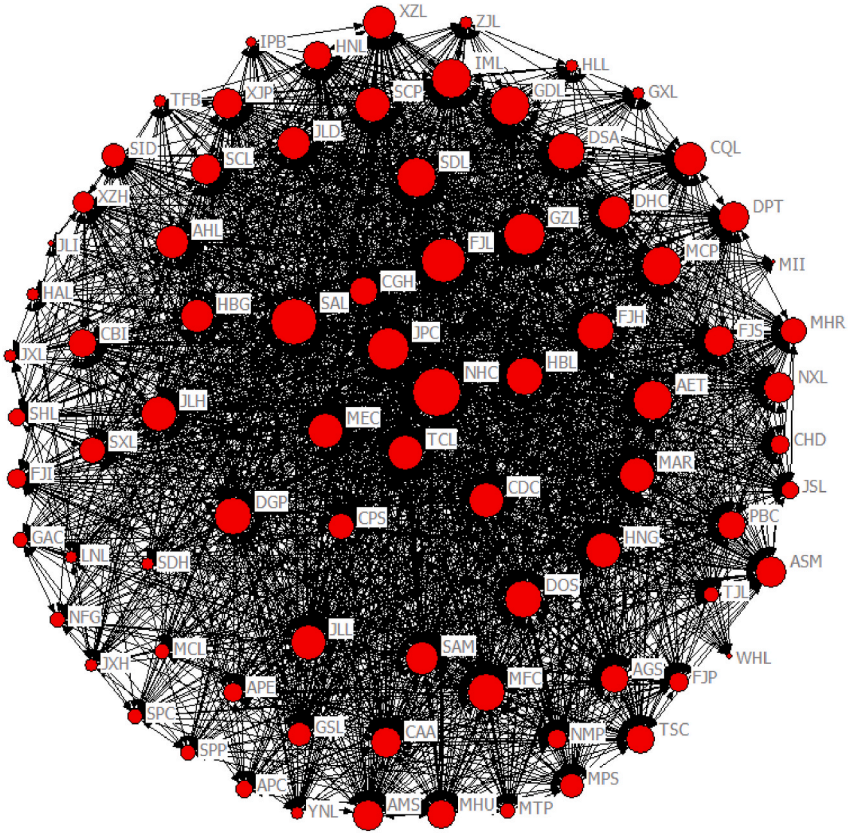
Appendix C. 1-Mode network for each time slice



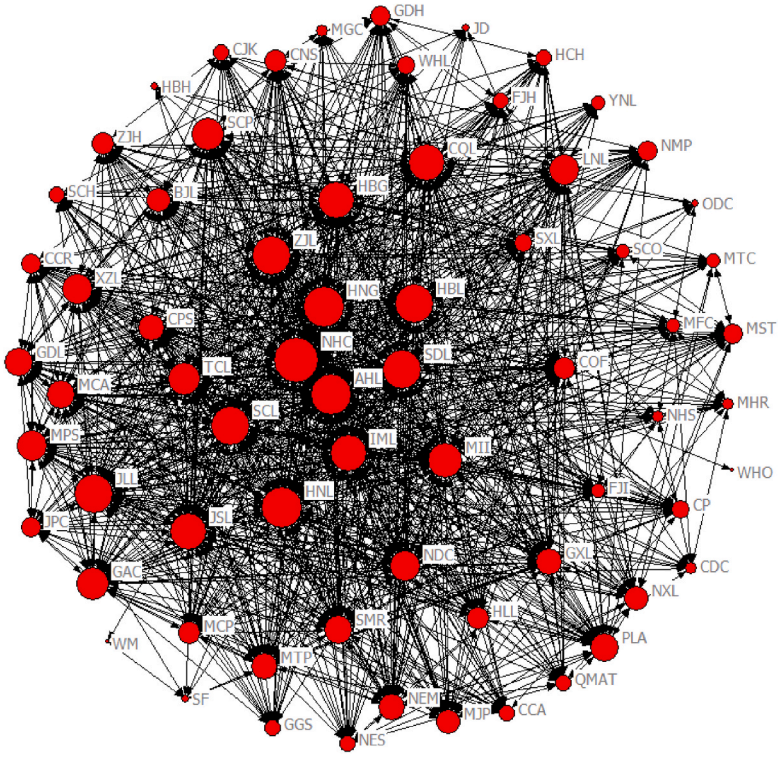
(a) 1-Mode Network for Time Slice T1



(b) 1-Mode Network for Time Slice T2

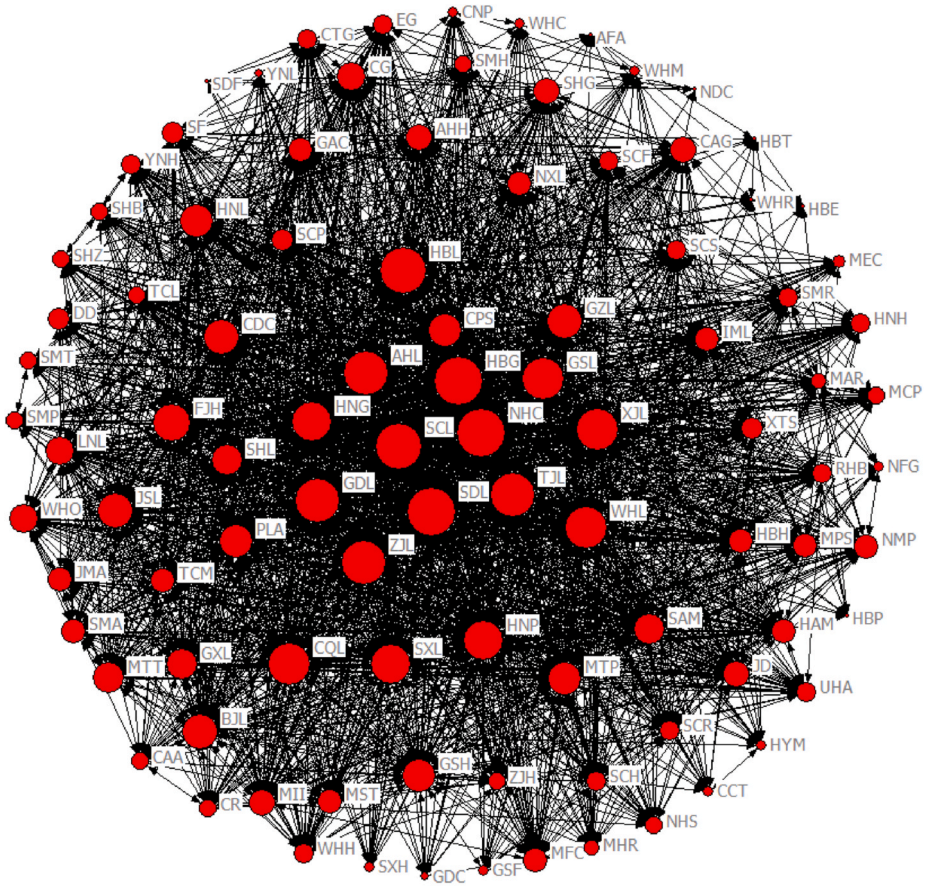


(c) 1-Mode Network for Time Slice T3



(d) 1-Mode Network for Time Slice T4

. (*continued*).



(e) 1-Mode Network for Time Slice T5

. (*continued*).

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