

Dynamic Analysis of Emergency Inter-organizational Communication Network under Public Health Emergency – A case study of COVID-19 in Hubei Province of China

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Research Article

Keywords: Emergency communication network, Public health emergencies, Dynamic evolution, COVID-19 emergency, network analysis

Posted Date: May 3rd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-359038/v1>

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Version of Record: A version of this preprint was published at Natural Hazards on July 6th, 2021. See the published version at <https://doi.org/10.1007/s11069-021-04908-1>.

Abstract

Public health emergencies, especially major infectious diseases, may cause global crises. Timely and effective communication is essential for response to such incidents. However, the emergency response to such incidents usually lasts longer and break out repeatedly, and the existing static emergency communication network (ECN) analysis cannot fully reflect the dynamic information interaction between organizations during the emergency process. Therefore, this article takes the recent COVID-19 epidemic in Hubei, China as a case, and uses social network analysis (SNA) to reveal the dynamic evolution of communication networks, organizational positions, roles, and organizational tasks from the time dimension. The results show that: (1) The ECN has changed from concentrated to decentralized over time; (2) The positions and roles of participating organizations in the ECN has changed, but there are still a few key organizations that at the central position in all phases of emergency communication; (3) The core tasks have changed due to emergency needs at each stage; (4) Under the concentrated management system, the core organization of the ECN mainly comes from government organizations. The research results reveal the dynamic evolution of communication networks between different types of emergency organizations, which is beneficial to guide emergency management of public health emergencies. In actual emergency, the emergency communication mode should be dynamically adjusted based on the characteristics of the emergency situation at different stages, comprehensively using the advantages of the concentrated and decentralized emergency network. In addition, communication between different types of organizations such as governments, research institutions, and enterprises should be strengthened, and channels for diversified organizations to participate in emergency communication should be set up. The research helps to improve communication between emergency response organizations and is of great significance to controlling and reducing the harm caused by public health emergencies.

1. Introduction

In the emergency management of public health emergencies, due to the limitations of the public health department in terms of manpower, resources, information, etc., it is necessary to rely on the coordinated response of government organizations and non-governmental organizations to avoid the collapse of the entire system due to the fragility of the emergency system. In particular, major infectious diseases are likely to cause widespread epidemics, such as the spread of the COVID-19 worldwide (Adiyoso 2020; Lim and Nakazato 2020; Liu et al. 2020). In December 2019, the disease was reported for the first time by Wuhan (CDC 2020), and was declared by World Health Organization (WHO) as a “Public Health Emergencies of International Concern” (PHEIC) on January 30, 2020 (WHO 2020a). On March 11, the WHO announced that the COVID-19 can be characterized as a global pandemic (WHO 2020b). As of February 4, 2021, the COVID-19 has caused 103,631,793 infections and 2,251,613 deaths worldwide according to the situation reports by WHO (WHO 2020b). Major epidemics are characterized by risk uncertainty, multiple subjects, risk sharing, and huge damage, which challenge the country's emergency response capabilities. Due to the high degree of uncertainty in the virus characteristics and response measures in the epidemic,

it requires timely and sensitive information communication between emergency organizations to promote the rational flow and optimal allocation of resources, and then make effective emergency response.

The emergency evolution of public health emergencies is actually a series of effects of the spread of emergency information (Wen et al. 2011). Emergency information exists in the emergency collaboration network, and efficient communication between organizations is a key step to support their emergency collaboration, and it is vital to the implementation of emergency operations (Clark-Ginsberg 2020; Chamlee-Wright 2010; Wolbers et al. 2013). However, there are still some challenges in the current emergency work, such as insufficient communication and collaboration (Pasman and Suter 2005). Therefore, some scholars began to pay attention to inter-organizational communication and collaboration during emergency response. For example, Harris and Doerfel (2017) analyzed the emergency cooperation relationship between organizations in the emergency response under the superstorm Sandy and explained that it played an important role in emergency response and disaster recovery. Rajput et al. (2020) analyzed the information communication between government organizations and non-governmental organizations on social media under Hurricane Harvey in Houston, revealing the role of organizations in disasters. Kapucu (2005) studied the inter-organizational collaboration in the emergency response to the terrorist attack on September 11, 2001, and found that effective response requires a well-coordinated inter-organizational network. In addition, there are many uncertain factors in the communication process of emergency information, such as the changes in external environment, emergency organizations and their interaction, and the timeliness of emergency information. The SNA is an effective method to analyze the complexity and uncertainty of an event (Agranoff and McGuire 2001; Comfort et al. 2012). This method graphically shows the relationship between emergency collaboration and information interaction between organizations, and can be used to analyze and explain the communication between emergency organizations (Mitchell 2006; Hu and Kapucu 2016). Through networked analysis, it can be used to guide more effective actions to adapt to changing emergency situations (Alkhatib et al. 2019; Kapucu and Hu 2016).

Researchers have used SNA to carry out a series of studies on organizational collaboration and communication in emergency response in different fields. Du et al. (2020) has built a collaborative network to deal with hazardous chemical accidents, emphasizing the need to strengthen collaboration among public sector organizations, non-profit organizations (NPOs) and private organizations (POs). Comfort and L. (2006) analyzed the interactive network between organizations during the Katrina emergency and found that the information asymmetry between organizations led to the collapse of disaster action coordination. Kapucu and Demiroz (2011) used SNA to find that the actual collaborative network of the September 11 attacks was different from the Federal Response Plan network. In addition, some research focuses on using node centrality measures to identify important participants in the emergency network (Hu et al. 2014; Koliba et al. 2018). Guo and Kapucu (2015) identified the key emergency actor by analyzing the emergency cooperation network of China's low temperature freezing rain and snow disasters. Moore et al. (2003) explored the emergency cooperation network during the Mozambique floods, and their centrality analysis clarified that the Mozambique Red Cross has more

connections and is located in a more central position. Kim et al. (2013) discussed the status of participants in disaster response networks.

Although the above-mentioned emergency response researches are based on the static snapshots of inter-organizational interaction provided by SNA (Choi and Brower 2006), which clearly illustrates the composition and structure of the network, the dynamic characteristics of the emergency process are not reflected. In recent years, some studies have begun to focus on the dynamics of the emergency process (Abrahamsson et al. 2010; Abbasi and Kapucu 2012). In order to clarify the evolution mechanism of the emergency cooperation network, Abbasi (2014) explored the formation of connections between participants in the emergency cooperation network. Abbasi et al. (2018) explored the temporal dynamics of Australia's extreme bushfire response network structure, and found that the response network is gradually decentralized. However, few studies have analyzed the dynamics of the emergency coordination network for public health emergencies. As for the emergency response to public health emergencies, it involves the participation of many different types of organizations, and the participants and their roles continue to change with the evolution of the event. At the same time, as emergency information flows through the network, organization joining, exiting, location changes, as well as the interruption of a contact and the establishment of new contacts will have an important impact on emergency communication between organizations. Therefore, in the rapidly changing emergency environment of public health emergencies, it is necessary to analyze the dynamic evolution of its communication network and pay attention to how the communication network changes over time, so as to effectively guide actual emergency activities.

The COVID-19 epidemic is a major public health emergency with the fastest spread, the widest range of infections, and the most difficult prevention and control since the founding of China. In order to prevent the spread of the COVID-19 epidemic, Hubei, China, was the first to adopt prevention and control measures such as a lockdown strategy on Wuhan. And as the understanding of the epidemic has gradually deepened, a reasonable emergency management mechanism for joint prevention and control has been formed. In this process, there are many points worthy of reflection and reference for emergency management and communication. In addition, the emergency network is related to the inter-organizational relationship in the management system (Waugh and Streib 2006). And the inter-organizational relationship between decentralized management and centralized management system are significant different to each other (Guo and Kapucu 2015). But most researches has focused on emergency response under the decentralized management system (Abbasi and Kapucu 2012; Abbasi et al. 2018). Therefore, this research focuses on the COVID-19 Emergency Inter-organizational Communication Network (COVID-19-EIOCN) in Hubei, China from the perspective of time dynamics. Specifically, this article attempts to answer the following questions: (1) How does COVID-19 ECN evolve over time? (2) How does the position/role of an organization in the network changes in different stages? (3) How does the relationship between emergency organizations and their communication tasks change in different stages of COVID-19 emergency?

2. Data And Method

2.1. Study design

In the emergency process of public health emergencies, participating organizations need to conduct timely and effective communication. In order to comprehensively analyze the communication and its dynamic evolution among emergency organizations of such uncertain events, we designed the research framework shown in Fig. 1. The research framework includes three steps: (1) Data collection and coding, to extract various organizations participating in the COVID-19 emergency and their communication relationships, and tasks supported by emergency communications. First, identify the emergency organizations and their interactions from the epidemic prevention and control situation reported by official government websites and news reports. Then, according to the actual emergency activities and emergency plans of public health emergencies, the inter-organizational emergency communication support task (EIOCST) was determined. (2) Build networks. Based on the development of COVID-19, the emergency interactions are divided into three stages by time slicing, thereby obtaining the communication relationship matrix of each stage, and constructing a visual network topology diagram, where nodes represent organizations, colors represent organization types, and lines represent communication relationships between emergency organizations. (3) Conduct ECN analysis. First, analyze the dynamic evolution of the network through indicators such as network density, average path length and network centrality. Secondly, using node degree centrality and betweenness centrality to examine the changes of organizational positions and roles in the network. Then, according to the relationship between the organization and communication tasks, a two-mode network is constructed to identify key communication tasks at different stages and analyze the evolution of the organization's emergency communication tasks. Finally, Finally, the frequency of communication between different types of organizations in the entire network is discussed.

2.2. Case background

In December 2019, cases of COVID-19 were detected in Wuhan, Hubei Province, and some public health departments conducted etiological and epidemiological investigations. On January 23, 2020, the Chinese government implemented a lockdown strategy on Wuhan to control and prevent the further spread of the epidemic. Subsequently, Hubei Province raised the emergency level of COVID-19 to the highest emergency state (first-level response). On February 21, 2020, Effective progress was made in curbing the spread of the virus. According to the development of the epidemic prevention and control situation, the Central Committee of the Communist Party of China (CCCPC) made the decision to coordinate the epidemic prevention and control and economic development, and began to resume work and production orderly. The case we selected in the study because:

(1) COVID-19 is considered to be the most widespread global pandemic. 95.44% of the confirmed cases in China are concentrated in Wuhan, Hubei Province (updated to March 17, 2020). Hubei COVID-19 emergency communication research can reflect China's emergency response to the epidemic, which is representative.

(2) The effect of non-pharmaceutical interventions implemented in Wuhan is obvious, which may reduce the number of COVID-19 infections by 67 times (Lai et al. 2020). These non-pharmaceutical interventions require different types of organizations to conduct emergency interaction around the core tasks of "monitoring and early warning, comprehensive coordination and medical rescue, etc."

(3) Due to the long duration of the COVID-19 epidemic and its emergency, the participating organizations and their main tasks in emergency communication change dynamically over time.

2.3. Data collection

This sub-section collects and extracts the data on the prevention and control of the COVID-19 epidemic on government official websites and news reports. These data are derived from the epidemic prevention and control situation and official documents published on the official websites of the People's Republic of China (CPGPRC), National Health Commission of the People's Republic of China (NHCCPRC), The Government of Hubei Province (GHP) and Health Commission of Hubei Provincial (HCHP), including Hubei Province's situation update of COVID-19, Hubei Province epidemic prevention and control notice and emergency plan for public health emergencies in Hubei Province, etc., which records the emergency interactions between organizations in detail. In addition, news reports (China News, People's Daily) provide multi-source data on interactions between organizations in epidemic prevention and control (Abbasi et al. 2018).

We sorted out the information materials from December 27, 2019 to March 17, 2020, numbered and classified all participating organizations, including the names and types of emergency organizations, and recorded the communication relationships and communication time. Based on actual epidemic prevention and control activities, we have identified 137 organizations and 472 links, including 38 national government organizations (NGOs), 56 provincial government organizations (PGOs), and 20 municipal government organizations (MGOs), 8 research institutions (RIs), 9 private organizations, 3 non-profit organizations and 3 international organizations (IO).

Next, we have determined the EIOCSTs. The emergency plan for public health emergencies is a key guideline for emergency response recognized by government agencies, which is the most authoritative source for determining emergency communication tasks. Therefore, we have compiled 11 EIOCSTs, as shown in Table 1.

Table 1
Emergency inter-organizational communication support tasks (EIOCSTs).

Number	emergency communication support tasks
EIOCST1	Logistic Support
EIOCST2	Monitoring and Warning
EIOCST3	Communications and Transportation
EIOCST4	Medical treatment and Epidemic prevention
EIOCST5	Material Support
EIOCST6	Order Maintenance
EIOCST7	Comprehensive Coordination
EIOCST8	Technology Support
EIOCST9	Information Release
EIOCST10	Security Maintenance
EIOCST11	Work Resumption

2.4. Network analysis of COVID-19-EIOCN

SNA can reveal the evolution of communication relationships between emergency organizations, which can provide visual analysis (Howes et al. 2015; Provan and Lemaire 2012). Measuring the relationship between nodes and identifying key nodes is an important part of SNA (Scott 2013). The COVID-19 emergency requires flexible and dynamic communication and collaboration between organizations to implement non-pharmacological interventions or rescue operations. Based on the above COVID-19 data, we transformed the inter-organizational interactions into an adjacency matrix and constructed the COVID-19-EIOCN, as shown in Fig. 2. The study measures the dynamic characteristics of COVID-19-EIOCN through the density, network centrality and node centrality indicators to effectively analyze the evolution of the COVID-19-EIOCN, organizational positions, and organizational tasks.

Note

The size of nodes set by degree centrality. The Organization's full names in Fig. 2 are listed in Table A1 of Appendix A.

(1) Network structure analysis

The Network structure analysis of this study mainly examines the comprehensive structure and closeness of COVID-19-EIOCN through the network density and network centralization. Network density and network

centralization reflect different levels of network compactness. Density represents the cohesion of the network, and network centralization explains the degree of this cohesion around a specific node (Scott 2017).

Density: Density is the ratio between the number of links actually established in the network and the total number of links that can theoretically exist at most. The calculation formula for the theoretical maximum number of links is $n(n-1)/2$, where n is the number of nodes. Density measures the level of interconnection among all participants in the network and reflects the cohesion of the network (Provan and Milward 1995). The reliability and speed of emergency information flow between nodes are critical to emergency response (Wolbers et al. 2013). In a denser network, the higher the connectivity of information exchange between members, efficient information interaction helps to improve the operating efficiency of the network (Abbasi and Kapucu 2016), but their establishment and maintenance costs are very high.

Network centralization: Network centrality refers to the degree of centralization of the entire network, which can be used to determine whether the network has a centralized structure (Provan and Milward 1995). The centrality of the network reveals the degree of difference in the centrality of each member (Abbasi and Kapucu 2012). The calculation method of which is to evaluate the difference between the centrality score of the most central node and the centrality scores of other nodes, and calculate the ratio of the sum of these differences to the sum of the largest possible differences. In a high-centered network, emergency communication is mainly concentrated on a small number of members, which may cause the paralysis of information dissemination between organizations due to information overload.

(2) Node centrality analysis

Evaluating the centrality of nodes in the network helps us understand the role and behavior of organizations in emergency situations (Rajput et al. 2020). In the COVID-19-EIOCN node centrality assessment, we mainly examined two attributes: Degree centrality and Betweenness centrality, revealing the importance of each organization's role and location in the network (Bavelas and Alex 1950).

Degree centrality: Degree centrality is measured by the number of direct connections a node has in the network (Freeman 1978), which can identify participants with extensive direct interaction. In the ECN, organizations with a high degree of centrality may have access to more information and resources (Liu et al. 2020), and they are usually regarded as emergency information hubs in actual emergency scenarios.

Betweenness centrality: Betweenness centrality refers to the degree to which a node is located on the shortest path between each pair of nodes in the network (Robinson 2012), it measures the degree of a node's monopoly on information between nodes. In the ECN, participants with greater betweenness centrality play the role of information bridge, occupying the main path of information flow, so they have more opportunities to control and guide the information flow between participants.

3. Results

This section explores the actual interactions during the COVID-19 emergency in different phases. According to the evolution of Wuhan COVID-19 and related literature, we sliced its emergency response process into three phases: (1) Phase P1: From December 27, 2019 to January 20, 2020, cases of COVID-19 were detected in Wuhan. (2) Phase P2: From January 20, 2020 to February 21, 2020, the newly confirmed cases increased rapidly, and the prevention and control situation was extremely severe. Wuhan implemented a city lockdown strategy. (3) Phase P3: From February 21, 2020 to March 17, 2020, the spread of the virus had been contained.

3.1 The evolution of COVID-19-EIOCN

To explore the evolution of COVID-19-EIOCN, this study uses Pajek to measure the structural characteristics of COVID-19-EIOCN at different stages. Table 2 shows the measurement indicators for the whole process and three phases, including the number of organizations (nodes), the frequency of inter-organizational communication (links), network density, and network centrality.

Table 2
The attributes of COVID-19-EIOCN over time.

	Whole Process	P1	P2	P3
# of Organizations(nodes)	137	20	101	69
# of Interactions(links)	472	34	356	122
Density(%)	5.07	17.89	7.05	5.2
Network Centralization(%)	27.69	61.99	28.52	26.45
# of Components (sub-networks)	1	1	1	1
Average path length	2.81	2.12	2.8	3.24

As shown in Table 2, from 27 Dec 2019 to March 17, 2020, the constructed COVID-19-EIOCN consists of 137 emergency organizations, and 472 links have been established between them. The measured density and centralization of the network are 5.07% and 27.69%, respectively, which indicates that the communication network in the whole process is sparse. The average path length of the network is 2.81, indicating that on average, about 3 intermediaries are needed between organizations to get contact.

In addition, the statistical indicators of P1, P2, and P3 show that COVID-19-EIOCN has evolved from concentrated to decentralized. Firstly, the network densities of P1 to P3 are 17.89%, 7.05%, and 5.2%, respectively, showing a gradual decline. It shows that the network in phase P1 is the closest, and then becomes sparse. Secondly, the network centralization and density have the same trend. The network centralization in phase P1 is the highest, at 61.99%, indicating that the network is concentrated in one or several organizations. To a certain extent, the communication between emergency organizations depends

on a small number of organizations. In phases P2 and P3, the centralization of the network gradually declines, indicating that the information and power of the organizations in COVID-19-EIOCN are gradually being dispersed, and the network have changed from centralized to decentralized. Thirdly, the number of organizations and communication relationships are increasing first and then decreasing. In phase P1, the number of organizations is the least (20), and the communication relationships between organizations is 34. In phase P2, the number of organizations and interactions is the largest, with 356 communication relationships among 101 organizations. Finally, the average path length of the three phases gradually increases, which indicates that the average number of intermediaries that organizations need to pass through to get in touch with each other has increased. The average path of phase P3 is 3.24, which is the longest, indicating that the relationship between organizations at this phase is relatively sparse. This result also reflects that the emergency task allocation of each organization at this phase is clear, and the probability of task redundancy among organizations is the lowest.

3.2 Dynamic analysis of emergency organization positions

This section analyzes the degree centrality and betweenness centrality of organizations in COVID-19-EIOCN at different phases to identify the key organizations and reveal the dynamic changes in the position of organizations. Figure 3 visualizes the COVID-19-EIOCN and its node degree centrality in whole phases, P1, P2 and P3.

The color and size of the nodes in Fig. 3 indicate the category and position of the organization. In the whole phase communication network, HCPCH, NHCPRC, GHP, HCHP and HPDRC are the five most influential organizations, which are both national and provincial government agencies. From P1 to P3, the key organizations at each phase change with the development of the network. In phase P1, NHCPRC, CCDC, WMHC, MI and HCHP are active participant, which occupy central positions. It is worth noting that the organizations involved in phase P1 are mainly health administrative departments and research institutions. In stage P2, HCPCH, GHP and HPGAMR occupy the new center position of the network. They interact with private organizations, research institutions and non-profit organizations, and play an important role in resource coordination. In stage P3, the HPDRC, DFHP and DHRSSHP have become the new key nodes of the network. Although the key emergency organizations at each phase have changed, government organizations are in a more central position compared with other types of organizations in COVID-19-EIOCN.

Table 3
Top 10 emergency organizations with degree centrality (%).

	whole phase	Phase 1	Phase 2	Phase 3
1	HCPCH(44)	NHCPRC(14)	HCPCH(35)	HPDRC(21)
2	NHCPRC(39)	CCDC(6)	GHP(29)	NHCPRC(19)
3	GHP(31)	WMHC(5)	HPGAMR(22)	HCPCH(13)
4	HCHP(28)	MI(4)	HCHP(22)	CSG(12)
5	HPDRC(24)	HCHP(4)	HPHEAC(21)	HCHP(10)
6	SCPRC(23)	SCPRC(4)	AIRAS(21)	DFHP(8)
7	HPGAMR(23)	AMMS(4)	CPCS(20)	DTHP(7)
8	MI(21)	WCDC(4)	SCPRC(18)	DHRSSHP(7)
9	HPHEAC(21)	CAMS(4)	MIITPRC(18)	MI(7)
10	AIRAS(21)	WIVCAS(4)	NHCPRC(18)	DEITHP(5)
Note: The Organization's full names in Table 3 are listed in Table A1 of Appendix A.				

To accurately analyze the position of the organizations, we analyzed the degree centrality and betweenness centrality of the COVID-19-EIOCN node in each phase. Table 3 shows the top-ten degree centrality participants. In the ECN, organizations with greater degree of centrality have more resources and information, and are more likely to generate and disseminate information. In Table 3, SCPRC, NHCPRC and HCHP have all remained in the top 10 in the three phases, playing the role of the information hub. It is worth noting that although the HCPCH was established in Phase P2, it remained in the top 3 at Phases P2 and P3. In addition, we analyzed important organizations that only became information hubs at a certain phase. In phase P1, many of the top 10 participants are research institutions, which are AMMS, CAMS and WIVCAS. These subjects mainly carry out etiological and epidemiological investigations. And in phase P2, most of the organizations with high degree centrality scores are provincial governments, which indicates that the communication in this phase may be centered on provincial governments. Among them, HCPCH has the highest degree centrality in the network, followed by GHP, 2 of the top 10 participants are artificial intelligence systems. These artificial intelligence systems have made great contributions to epidemic monitoring and disease diagnosis. In phase P3, as the epidemic situation is under phased control, the main task of emergency response is to coordinate epidemic prevention and control and economic development. HPDRC, DFHP and DHRSSHP have become several information centers. These results reflect that the position of the organization is related to their core emergency tasks. The information center at a certain phase does not maintain a fixed

position in each phase, but there are several core coordination organizations that maintain active in two or more phases.

Table 4
Top 10 emergency organizations with betweenness centrality (%).

	whole phase	P1	P2	P3
1	NHCPRC(28.9)	NHCPRC(77.05)	SCPRC(19.6)	NHCPRC(44.41)
2	HCPCH(20.27)	CCDC(16.03)	GHP(17.47)	HPDRC(41.39)
3	HCHP(13.06)	WMHC(6.48)	HCPCH(16.98)	HCHP(30.53)
4	SCPRC(12.73)	SCPRC(5.56)	NHCPRC(15.95)	HCPCH(26.23)
5	HPDRC(10.41)	HCHP(4.87)	HCHP(13.89)	CSG(13.57)
6	GHP(9.71)	CCCPC(4.68)	MIITPRC(11.98)	MFAPRC(8.56)
7	HPGAMR(9.28)	AMMS(2.1)	HPGAMR(11.77)	DFHP(7.16)
8	MIITPRC(6.69)	CAMS(2.1)	HPHEAC(8.93)	NPHCC(5.84)
9	MI(6.26)	WIVCAS(1.75)	DFHP(7.77)	CAAC(5.84)
10	CSG(5.65)	WCDC(1.75)	HPDRC(5.16)	DTHP(5.39)
Note: The Organization's full names in Table 4 are listed in Table A1 of Appendix A.				

The betweenness centrality of a node is used to measure the extent to which an organization plays an intermediary role between each pair of nodes. Table 4 lists the top 10 organizations with high betweenness centrality in each phase. Similar to the results of degree centrality analysis, most organizations with high betweenness centrality come from government organizations, especially provincial government organizations.

In Table 4, from P1 to P3, the betweenness centrality of NHCPRC and HCHP is in the top five, have always been in bridge positions in COVID-19-EIOCN, which provide other participants with shorter communication path. Among them, NHCPRC has the highest betweenness centrality in phase P1 and P3, while the SCPRC has the highest betweenness centrality in P2 phase, they were the information broker. And, HCPCH entered the network in phase P2, and then remained in a bridge position, playing an important information broker role. In addition, research institutions have high betweenness centrality in phase P1. While HPGAMR, MIITPRC and DFHP are important bridge organizations that play the connecting tasks in phase P2. In phase P3, resumption of work and production has become a new emergency demand, and HPDRC, DFHP and DTHP have become important bridge organizations. Therefore, organizations with higher bridge capabilities in a certain phase do not remain the same in all phases, it will change with changes in emergency needs.

Based on the above analysis of COVID-19-EIOCN's node degree centrality and betweenness centrality, it is confirmed that the communication between COVID-19 emergency organizations is a dynamic process,

and the roles and positions of most organizations in different phases will change. However, there are also a few key organizations, such as the NHCPRC, HCPCH, SCPRC, and HCHP, which have a central position in all phases of emergency communication. This shows that they assume the responsibility of connecting other organizations and have a strong influence on the information resources

3.3 Dynamic analysis of emergency organizations-communication tasks

The coupling relationship between organization and task will change over time. This section mainly analyzes the Two-Mode network between emergency organization and communication tasks at each phase. Figure 4 shows the constructed Two-Mode network. Among them, the displayed node size is determined by the degree centrality.

As shown in Fig. 4, there are differences in the number of EIOCSTs involved in different phases. The whole emergency response process includes a total of 11 EIOCSTs, of which the number of EIOCSTs in phases P1, P2, and P3 are 5, 10, and 10, respectively. According to the analysis of the task position shown by the size of the nodes in the figure, in the early phase of the epidemic, the emergency task is mainly to organize medical treatment and epidemic prevention, and the main emergency organization is the health department. In phase P2, a large number of new organizations are engaged in new emergency tasks such as communication and transportation, logistics support, and order maintenance, and these tasks receive attention. On the contrary, in phase P3, as the epidemic is under control, many organizations withdraw, the influence of logistics support, communication and transportation and some other tasks has declined, and the resuming work and production is in a central position. The work and production resumption organization led by the State Council issued various policies to promote the resumption of work and production according to the level of the epidemic in each district. The analysis shows that in the process of emergency response, the position of a communication task will change due to the phased needs of the emergency.

In addition, the number and types of the participating organizations in the same EIOCST have changed over time. At phase P2, the task of material support is mainly participated by 16 organizations including DFHP, HPMSB and enterprises. In phase P3, the participants in this task changed to 8 organizations including RCSC, HPPSD and enterprises, indicating that the number of participating organizations in the same EIOCST has changed. Meanwhile, the medical rescue and epidemic prevention during phase P1 involved government organizations (NHCPRC, HCHP, WMHC, etc.) and research centers (CAMS, AMMS). But in phase P2, artificial intelligence (AIDS) and non-profit organizations (RCSC) have become the new types of emergency organizations to participate in this task. Therefore, the types of participating organizations in the same EIOCST have also changed over time.

We measured further the betweenness centrality of EIOCSTs and analyzed the evolution of the position of each EIOCSTs. As shown in Fig. 5, in phase P1, the betweenness centrality of EIOCST4 is the largest, indicating that at phase P1, a large number of organizations have communicated and cooperated around this task. This result is consistent with actual demand at the early stage of the COVID-19 emergency, such as organizing infectious epidemiological investigations and medical rescue. In phase P2, the

betweenness centrality of EIOCST7 is greatest. With the investment of a large number of organizations and resources, emergency response has transformed from a small number of core tasks to the need for comprehensive coordination of rescue, logistics, communications and transportation, making EIOCST7 more prominent from phase P1 to phase P2. In phase P3, EIOCST7 is still in an important position, and the EIOCST11 has become an important task for the first time due to the need for economic development. The above analysis shows that in the whole emergency process, EIOCST7 has always been in an important position, and the main tasks of COVID-19 emergency have changed to some extent over time.

3.4 Analysis of emergency communication frequency between different types of organizations

Due to the large number of participating organizations and their complex interactions in the whole COVID-19 emergency process, this section analyzes the communication relationship between different levels of government organizations and between different types of organizations from the horizontal and vertical dimensions. Table 5 shows the frequency of communication between different types of organizations. Firstly, the communication within the government system is frequent, and the frequency of communication between GOs at the same level is more prominent, especially between PGOs. Secondly, compared with the communication within the government system, the communication in NGOs and between NGOs and GOs is relatively poor. However, it is worth noting that the communication between POs and PGOs is relatively active, which may be related to the active cooperation of relevant enterprises (such as medical supplies, finance, logistics and e-commerce enterprises) in the epidemic emergency to provide material guarantees for the fight against the epidemic. In addition, research institutions also maintain certain communication with government organizations and private organizations, which is related to the cooperation and exchanges between research institutions and these organizations under normal epidemic conditions. On the whole, in the COVID-19 emergency, the communication within the government system is the most active, the communication between NGOs is relatively weak, and some NGOs maintain a certain degree of communication with GOs.

Table 5
The frequency of communication between different types of emergency organizations.

	NGO	PGO	MGO	RI	PO	NPO	IO
NGO	109	123	62	14	8	3	6
PGO	–	295	55	9	32	9	4
MGO	–	–	37	1	9	2	3
RI	–	–	–	6	8	0	2
PO	–	–	–	–	1	4	3
NPO	–	–	–	–	–	3	0
IO	–	–	–	–	–	–	0

4. Discussion

(1) Statistical analysis of indicators such as network density, network centrality, and average path length shows that COVID-19-EIOCN is dynamically evolving, and it changes from concentrated to decentralized. In the early phase of the epidemic, there were only a few types of participating organizations, mainly government organizations and research institutions, and interactions between organizations were frequent, so the overall network was relatively concentrated. During the outbreak phase of the epidemic, a large number of organizations joined in coordinating to handle the booming emergency tasks, and the organizations did not establish as many contacts as possible, so the overall cohesion of the network decreased. After the epidemic was controlled, the urgency of emergency response was reduced, and the withdrawal of some organizations caused related communication links to be interrupted. As a result, network cohesion was further reduced.

(2) The node centrality analysis shows that in COVID-19-EIOCN, the positions and roles of organizations have changed at different phase, and the central nodes of the network are mostly composed of government organizations. The national and provincial health committees are responsible for responding to public health emergencies and providing medical rescue services, always acted as information hubs and bridges. After the establishment of the HCPCH, it has become the direct commander and organizer of COVID-19 emergency activities, which was a central node and bridge organization. In addition, in the early phase of COVID-19 epidemic, government organizations and research institutions were in an important position. During the outbreak period, except the above two types of organizations, the newly added artificial intelligence systems and enterprises have also played an important role in providing medical supplies and services. In the later phase of the epidemic response, due to the needs of resuming production, emergency organizations such as HPDRC and DHRSSH have significantly improved their status in the network.

(3) The analysis of the Two-mode network shows that the importance tasks supported by emergency organization communication change dynamically in different phases. In the early phase of COVID-19 epidemic, Medical treatment, Medical treatment and Epidemic prevention and comprehensive coordination occupy an important position. During the outbreak of the epidemic, the core emergency communication tasks are mainly logistics support, comprehensive coordination and order maintenance. In the later phase of emergency response, comprehensive coordination still occupies an important position, and the resumption of work and production has also become a new important emergency task. Therefore, the importance of tasks is related to emergency demand of major epidemics at a specific stage, which is consistent with the viewpoint of Galaskiewicz (1985). Thus, in response to emergency tasks in different phases, emergency communication strategies should be dynamically adjusted in time.

(4) Analysis of the frequency of communication among various types of organizations shows that the emergency communication within the government system is relatively smooth. In the COVID-19

emergency, the communication between non-governmental organizations is relatively weak, and the interaction between the government system and the non-governmental system is limited. However, for the prevention and control of major epidemics, the effective implementation of non-pharmaceutical intervention emergency activities cannot rely on a single type of organization, it requires the coordinated response of the government and non-governmental organizations. To reduce the pressure and risks caused by solely relying on government emergency response, the communication between the GOs and RIs, POs and NPOs should be strengthened.

In summary, because the communication between emergency organizations mainly supports the implementation of emergency tasks, the organizations need to maintain smooth communication to efficiently carry out emergency response. This article provides a new perspective for the research on emergency communication of public health emergencies from the perspective of time dynamics. The analysis found that there are dynamic changes in the tasks supported by emergency communication at different stages, and the positions and roles of participating organizations have also changed. However, there are also several core emergency organizations with a relatively stable position. They are all government organizations, which help to integrate resources and information in a short time. Since China currently implements a joint emergency response mode led by governments at several levels and supplemented by social efforts. The COVID-19 emergency response is carried out under this hierarchical centralized command scenario. In the early phase of the COVID-19 emergency, due to the urgency and uncertainty of the epidemic, the health administrative department efficiently organized emergency teams and integrated resources to achieve rapid coordinated response. It proves that the centralized management system is more conducive to the rapid coordination and resource integration in emergency situations, and effectively reduces the risk of poor communication between organizations. This is in line with the conclusions of Du et al.(2020) that centralized management systems may be more conducive to emergency response than decentralized management systems in emergency situations. In addition, with the development of COVID-19, the mechanism and prevention and control methods of the epidemic have gradually become clear, the decentralized network became more conducive to inter-organizational communication and emergency operations under multi-task. This is consistent with opinion that decentralized network is more conducive to information interaction to support decision making in the study of Guetzkow and Simon (1955). Therefore, in the COVID-19 emergency, centralized and decentralized networks are complementary. In the actual emergency response to public health emergencies, the advantages of centralized emergency network and decentralized emergency network should be reasonably used according to the evolution of the event, and emergency communication strategies should be dynamically adjusted in phases.

5. Conclusion

This article studied the COVID-19-EIOCN in Wuhan, Hubei, China from the perspective of time dynamics. First, the various organizations involved in the COVID-19 emergency were identified, and then the interaction between them was extracted. Finally, the dynamic evolution of ECN, organizational position and organizational communication supported tasks are analyzed through SNA.

The results of this study are helpful to guide emergency management of public health emergencies. First of all, emergency communication of public health emergencies needs to consider dynamics. The positions and tasks of emergency organizations at each stage should be clarified, information and resources should be dynamically integrated according to the evolution of specific events, and the position and interaction of participating organizations should be dynamically adjusted to meet the emergency needs of different phases. Secondly, under the centralized management emergency system, the internal communication of the government system is relatively active, which is conducive to rapid coordination and resource integration in urgent situations, but the emergency interaction between the government system and the non-governmental system is limited. Therefore, we should promote communication between different types of organizations such as GOs, RIs, POs, and NPOs. At the same time, in the design of emergency communication structure for public health emergencies, it is necessary to take NGOs into consideration and set up reasonable channels for them to participate in emergency communication, so as to avoid obstructing the communication between GOs and NGOs at the system level. Finally, for future emergencies of similar public health events, we should make rational use of the advantages of centralized emergency networks and decentralized emergency networks based on the phased characteristics of event evolution, and dynamically design communication and collaboration networks to form reasonable emergency plans to meet emergency needs.

This study still has some limitations. First, the analysis of this article helps us to have a general understanding of the communication between emergency organizations under the public health emergency in China, but only a single case is used. Future research may focus on the analysis of multiple cases, such as analyzing COVID-19 ECNs at other urban, provincial and national levels. In addition, in the future, we will consider integrating network data, questionnaire surveys, interviews and other data. Questionnaires can be sent to managers of non-governmental organizations and the private sector to collect data at different levels.

Declarations

Acknowledgements

This study was financially supported by “safety Risk Assessment Method of Consumer products”: National Key Research and Development Project (2017YFF0209604-2).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Figures

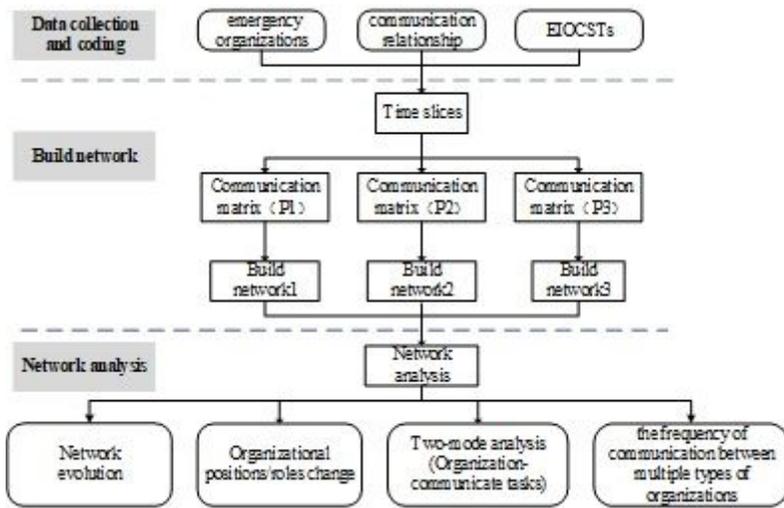


Figure 1

Research framework.

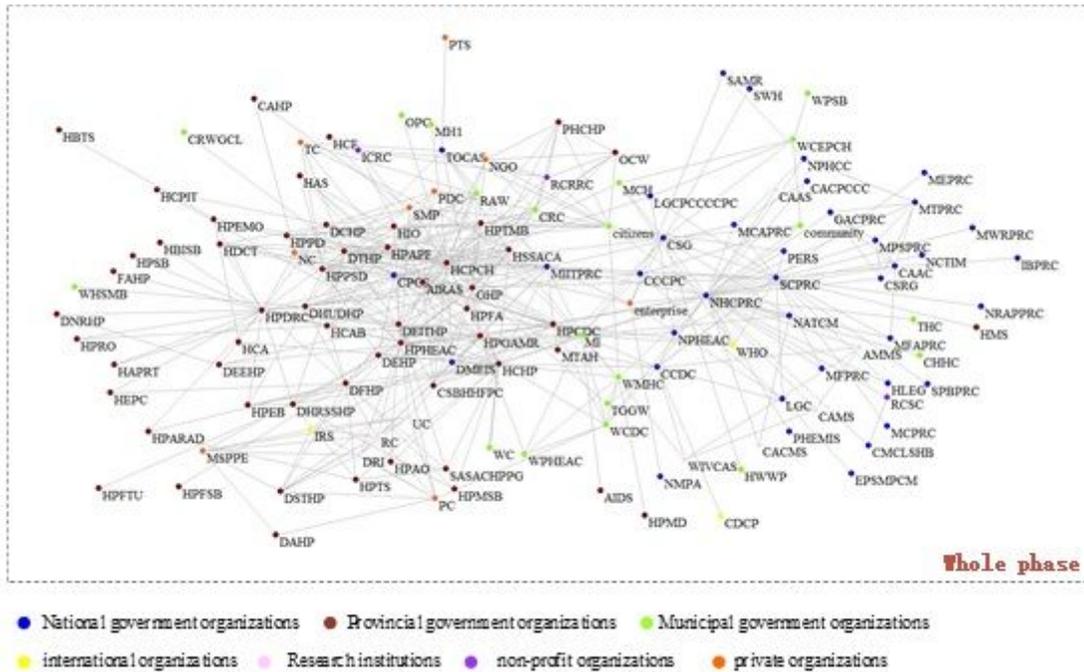


Figure 2

The whole emergency inter-organizational communication network of COVID-19. Note: The size of nodes set by degree centrality. The Organization's full names in Fig.2 are listed in Table A1 of Appendix A.

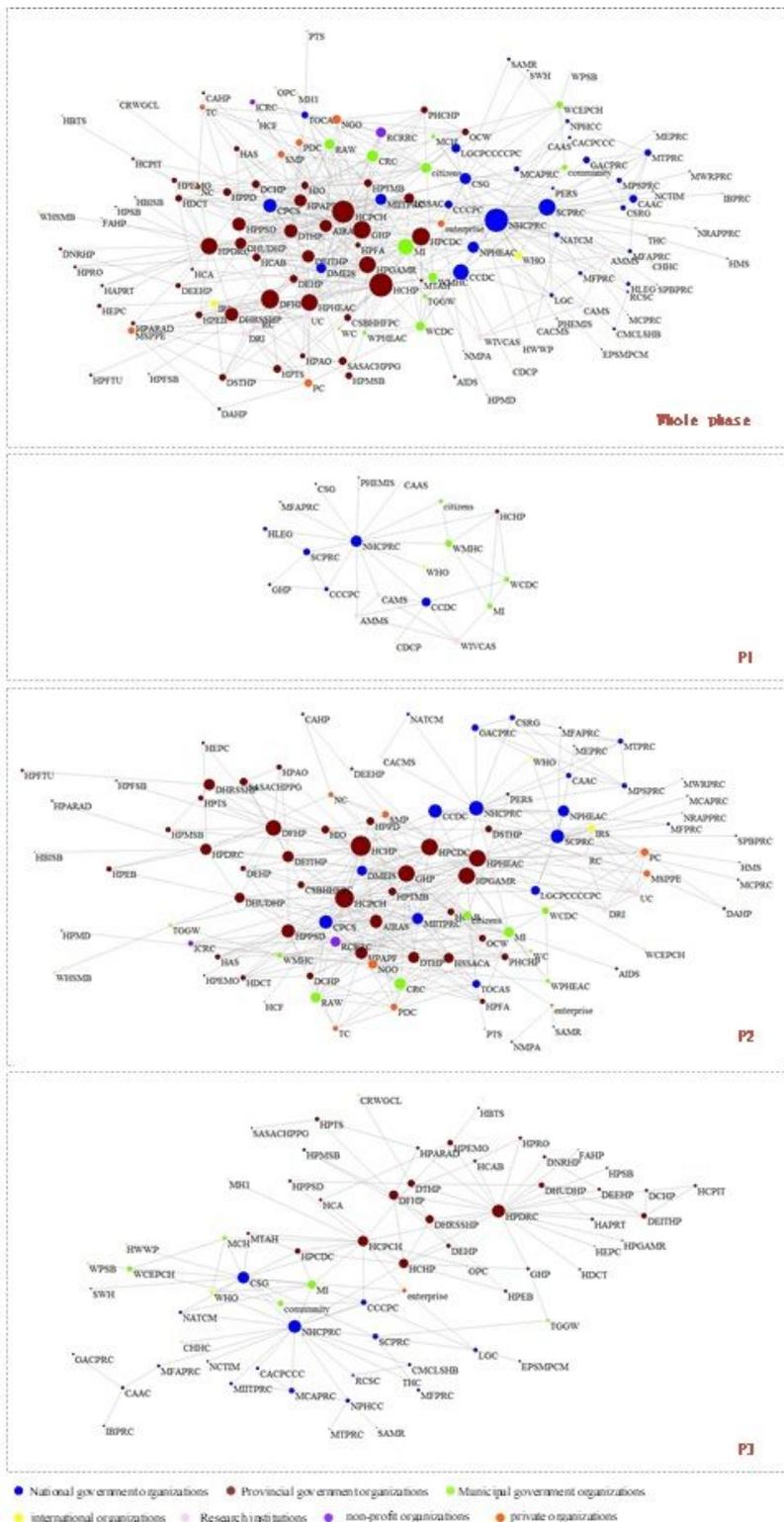


Figure 3

Four COVID-19-EIOCN in different stages Note: The size of nodes set by degree centrality. The Organization's full names in Fig.3 are listed in Table A1 of Appendix A.

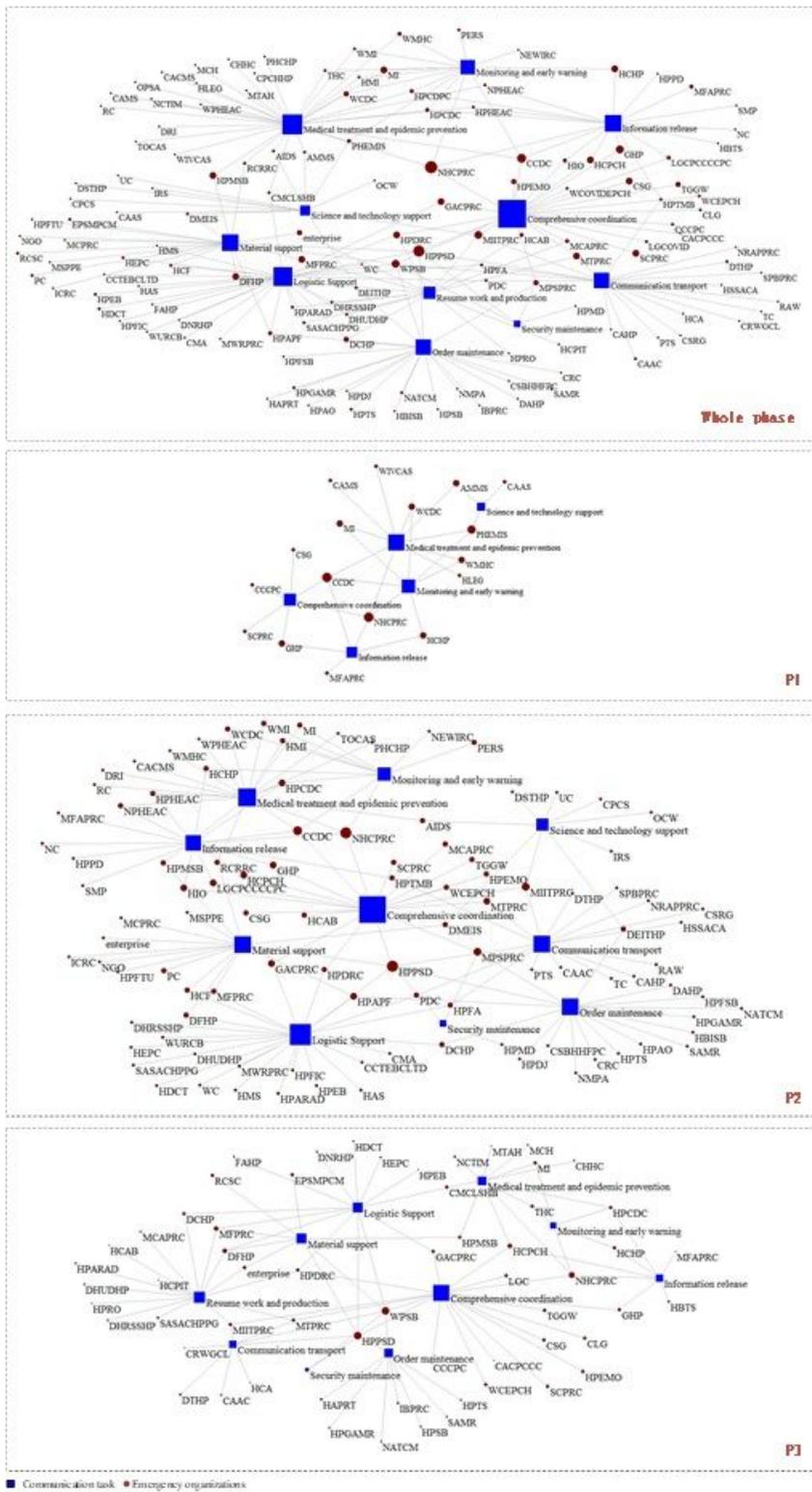


Figure 4

Emergency Organization-Task Two-Mode Network Topology Diagram Note: The size of nodes set by degree centrality. The Organization's full names in Fig.4 are listed in Table A1 of Appendix A.

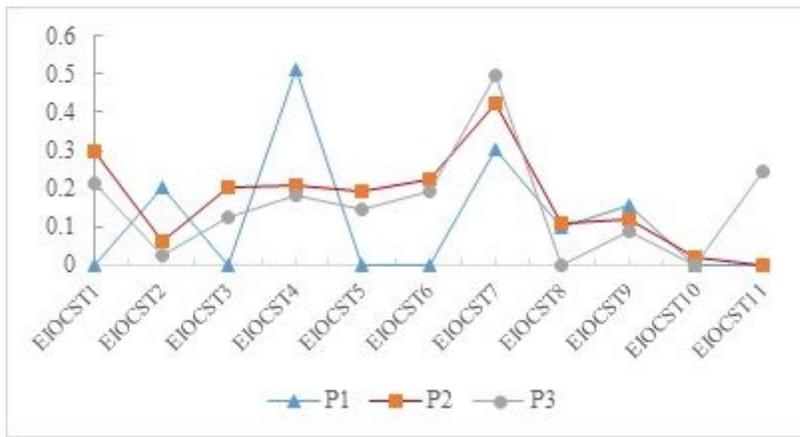


Figure 5

Measurement of betweenness centrality of tasks supported by emergency communication

Supplementary Files

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- [AppendixA.pdf](#)