Research on the Vulnerability Assessment Framework of Urban Critical Infrastructures System

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Abstract: On the basis of summarizing research methods of the urban critical infrastructure system (CIS), confirm that the urban critical infrastructure system consists of eight parts which are power grid, transportation network, communication network, energy network, water supply network, drainage network, financial network and administrative network. The paper establishes the vulnerability assessment framework of urban critical infrastructure system under different interdependent with in urban CIS.

Keywords: complex network; critical infrastructure; multi-attributes analysis; vulnerability

1. Introduction

Since ancient times, the urban has been the colony of many people. As the political, economic and cultural center of the region and even the country, the urban has an important position in the national economic and social development with great strategic significance in the overall and long-term. In the urban, there is a Critical Infrastructure System (CIS) consisting mainly of functional networks such as power grids, transportation networks, water networks, drainage networks, and energy networks, which are related to national security, economic development, and people's daily lives. Close correlation is the material basis on which people depend for survival. In recent years, critical infrastructure system damage incidents caused by frequent disasters have occurred frequently, resulting in the lack of related services. If it is not able to get timely processing and control, under the influence of factors such as complexity, uncertainty and relevance, it is very likely to cause large-scale secondary derivative disasters, which will bring huge losses to the country and society. The necessary measures should be taken in a timely manner to strengthen the protection of critical urban infrastructure.

At present, the research methods of urban key infrastructure systems are mainly concentrated in the following three aspects: (1) Conceptual approaches: define and classify key infrastructure and related concepts, and give the main influencing factors [1], this is a basic study. (2) Empirical and knowledge-based approaches: This method can identify the frequency of events and major failure modes based on historical events or disaster data and expert experience analyzing critical infrastructure relationships. A quantitative correlation strength matrix assists in decision making, conducts risk analysis based on experience, and then provides a means to reduce risk [2]. Due to the different research priorities, the research direction of this method is divided into: frequency and major failure mode identification, quantitative analysis of related indicators and empirical risk analysis. However, due to the extremely low probability of recurrence of unexpected events and the fact that historical data is generally difficult to obtain, data is prone to dirty data or missing data during the archiving process, so the operability is not strong. (3) Model and simulation approaches: Using mathematical tools to study the relationship from a quantitative perspective to visualize the effects of failures, which is a commonly used research method. At present, there are four models to simulate and simulate the urban CIS relationship: Agent simulation system [3], system dynamics simulation [4], economic theory model [5] and Modeling method based on network structure characteristics [6]. Among them, economic theory modeling mainly relies on two types of economic theory: input-output model and computable general equilibrium theory.

2. Composition of Urban Critical Infrastructure System

Aiming at the scope of urban CIS, there is currently no consensus in the academic world. A large amount of research work aims to reveal the key components of the urban, which facilities and departments are essential for normal social operations. Some scholars believe that the grid is the most critical part of all infrastructure and it is worthy of careful study and should be prioritized in the urban CIS research process. Transportation and road traffic systems are also often identified as an important part of the infrastructure system. In recent years, China has incorporated water networks into the construction of key urban infrastructures, and is expected to invest 410 billion yuan in the construction and renovation of water network facilities in the 12th Five-Year Plan. In 2014, the National New Town Planning clearly pointed out: strengthen the protection of urban water source areas, increase the scale of urban water source construction, promote the transformation and construction of water supply facilities, and ensure the safety of urban water supply. It can be seen that water network is also an important part of urban CIS. In view of the key infrastructure types summarized by countries, combined with national policy guidance, urban CIS usually includes the following eight parts: power grid, transportation network, communication network, energy network, water supply network, drainage network, financial network and administrative network (composed of two parts: emergency management department and government functional department).

3. Interdependent Types

Rinalidi SM et al (2001) divided it into physical interdependent, network interdependent, geographic interdependent and logical Interdependent, gave definitions of four interdependent types [7]. Leonardo (2005) considers network interdependent as information interdependent [8]. Zimmerman (2001) proposes functional interdependent and spatial interdependent in a more general way [9]. Zimmerman believes that functional associative support for the operation of one infrastructure requires the normal operation of another infrastructure, which refers to the proximity of locations between two infrastructure systems. The classification method of Dudenhoeffer (2006) and others is similar to that of Rinalidi SM et al [10]. They propose and redefine the four types of physical connections, information interdependent, geographic interdependent, policy procedures and social connections, specifically point out that the interdependence of social dimensions refers to public opinion, confidence, fear, and cultural issues; De Porcellinis (2009) Others formally added the interrelationship of social dimensions to the fifth type [11]. Wallace and Lee (2003, 2007) give the relationship between infrastructure from the perspective of computer science, namely input, interaction, sharing, exclusivity and co-location [12-13]; Zhang and Peeta (2011) consider the economic factors, the infrastructure between Relationships are divided into functional interdependent, physical interdependent, budget interdependent, and market-economic linkages [1]. This paper adopts the classification method of Rinalidi SM.

4. Vulnerability Assessment Framework of Urban Critical Infrastructure System based on Interdependent

Multivariate interdependent is relative to only one related relationship scenario, which means that there are two or more heterogeneous Interdependent in the same disaster event for a period of time. Such scenarios can occur between the same critical infrastructure entities and between different critical infrastructure entities and there are certain causal relationships between different Interdependent. According to the heterogeneity of urban CIS Interdependent, it can be divided into geographic interdependent, physical interdependent, information interdependent and logical interdependent. The logical interdependent is not within the scope of this paper and the multiple Interdependent between the other three Interdependent are diverse. As shown in Figure 1, the three circles represent geographic Interdependent, physical Interdependent and information Interdependent. The overlapping part between the circles is a multi-relevant form. As can be seen from the figure, there are four overlapping parts with the labels 1, 2, 3, and 4 between the three circles and the four overlapping parts respectively represent four kinds of multi-interdependent patterns.

The first type is the geographical-physical interdependent means that there are two kinds of Interdependent of geographical interdependent and physical interdependent between the main infrastructures of the urban CIS in the same disaster event and two interdependent types interact. It has a certain impact on the development of disaster scenarios, such as the Dalian oil pipeline explosion mentioned in the previous article.

The second type of geo-information interdependent means that there are two kinds of Interdependent of geographical interdependent and information interdependent between the critical infrastructure entities in the urban CIS in the same disaster and the two interdependent interact. It has certain impact on the development of disaster scenarios. For example, a critical infrastructure failure may result in the destruction of communication networks in the vicinity due to geographical interdependent, which may lead to information interdependent or communication network failure. Other critical infrastructures in the vicinity are ineffective due to geographic interdependent while generating information interdependent.

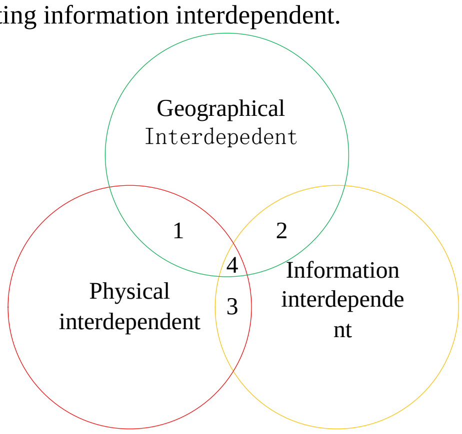

Figure 1. Mult-interdependent diagram of urban CIS

The third type of physical-information interdependent means that there are two kinds of interdependent of physical interdependent and information interdependent between the main infrastructures of the urban CIS in the same disaster event and the two interdependent interact. It has a certain impact on the development of disaster scenarios such as the 2003 Italian blackout. First, the grid failure causes the physical relationship to be interrupted and the power cannot be transmitted to the communication network, which causes the communication network to fail and the information interdependent relationship to be interrupted. Therefore, urban CIS failures can occur not only between different critical infrastructures but also between different types of relationships.

The fourth type of geo-physical-information interdependent means that there are three kinds of interdependent, such as geographical interdependent, physical interdependent and information interdependent, between the critical infrastructure entities in the urban CIS in the same disaster event, and the interaction between the interdependent. It has a certain impact on the development of disaster scenarios. Compared with the first three multi-relationships, this form of interdependent is the most complex of the multi-relationships and the most extensive one involving critical infrastructure. For example, in 2010, the Songhua River water pollution incident in Harbin was a cross-provincial disaster. It was caused by natural disasters and floods in Yongji County, Jilin Province, causing the chemical raw materials of certain chemical plants to be destroyed by floods and flow into the Songhua River. The role of pollution in drinking water in Harbin. Although Jilin Province quickly took measures to set up 8 lines of defense along the Songhua River for interception, the water quality of the Songhua River was not significantly polluted. However, due to related rescue work, the water supply network in Harbin was once interrupted and the traffic network was congested. Relationship failure or overload occurs; on the other hand, due to people's panic, the communication network collapses and the information interdependent is destroyed.

It should be noted that, in the above four multi-categories, the order of occurrence of the interdependent relationship is not limited, and multiple interdependent relationships may occur at the same time or one interdependent relationship may cause another interdependent relationship to occur, which has a certain time continuity. In particular, a single interdependent can be seen as a special form of multivariate interdependent. In order to more clearly show the linkages and differences of the four kinds of multiple Interdependent, they are now compared and analyzed, as shown in Table 1.

Table 1. Comparative analysis of multiple interdependent

Associated form	Existing relationship			Type of interdependent	Cause
	Geographic	physical	information		
Geographic -physical interdependent	√	√		2	The critical infrastructure principals are “geographically close” and have a form of transmission or sharing of the same kind of “physical resources”
geo-information interdependent	√		√	2	Occurs between the communication network and other critical infrastructure entities, "geographical proximity" and the transmission or sharing of "information resources"
physical-information interdependent		√	√	2	Occurs between the communication network and other critical infrastructure entities, and there is a form of transmission or sharing of “information resources”, and the two parties still have transmission or sharing forms for other “physical resources” other than “information resources”.
geo-physical-information interdependent	√	√	√	3	Occurs between the communication network and other critical infrastructure entities, "geographical proximity" and the transmission or sharing of "information resources" and the two parties still have transmission or sharing of other "physical resources" other than "information resources" form.

5. Conclusion

The assessment of the resilience of critical urban infrastructure systems requires a comprehensive consideration of multiple forms and scenarios. Based on the analysis of the composition of urban critical infrastructure systems and the types of associated relationships, this paper proposes a framework for assessing the resilience of urban critical infrastructure systems based on multiple interdependent. The framework includes geo-physical interdependent, geo-information interdependent, physics-information interdependent and geo-physical-information interdependent. The results of urban multi-assessment vulnerability assessments are more consistent with certain multi-attribute analysis methods actual. In the next step, multi-attribute analysis methods will be used to establish a model for assessing the vulnerability of critical infrastructure systems in cities under various associated scenarios.

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