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Application of social network theory to prioritizing Oil & Gas industries protection in a networked critical infrastructure system

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ABSTRACT

As a typical process industry, the Oil & Gas industries play a key role within a networked critical infrastructure system in terms of their interconnection and interdependency. While the tight coupling of infrastructures increases the efficiency of infrastructure operations, interdependency between infrastructures may cause cascading failure of infrastructures. The interdependency between critical infrastructures gives rise to an infrastructure network. In this paper, we apply social network analysis, an analytical tool used by social scientists, to study human interactions and to analyze characteristics of the critical infrastructure network. We identify Oil & Gas, Information & Communication Technologies (ICT), and Electricity as three infrastructures that are most relied upon by other infrastructures, thus these may cause the greatest cascading failure of the infrastructures. Among the three, we further determine that Oil & Gas and Electricity are the more vulnerable infrastructures. As a result, priority toward critical infrastructure protection should be given to the Oil & Gas and Electricity infrastructures since they are most relied upon but at the same time depend more on other infrastructures.

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1. Introduction

As a social technical system, critical infrastructures are vulnerable in many respects (Little, 2004; Woo & Vicente, 2003), in particular, the Oil & Gas system. Oil & Gas related accidents have happened frequently, both in China and throughout the world, and have posed threats to human well-being and to other living things. For example, a gas release in Chongqing, China in December 2003 spread toxic hydrogen sulphide across mountain villages, killing 243 people in one of China's deadliest industrial accidents. More than 41,000 villagers were forced to evacuate their homes and thousands of survivors suffered lung damage and burns to their eyes and skin. More recently, in 2007, over 113,000 Oil & Gas related accidents occurred in China, and approximately 229,000 residents were either rescued or evacuated. Also, in the United States (US), 32,022 Oil & Gas related events were reported in 2007 (NRC, 2008).

Apart from the usual wear and tear, the optimum functioning of a critical infrastructure is also subject to various political and economic pressures (McEntire, 2001). In addition, critical infrastructures are becoming increasingly complex and interlinked, both internally and externally, and effective operation of an infrastructure relies more and more on normal operation of other infrastructures, presenting a danger of cascading failure of infrastructures (Comfort, Ko, & Zagorecki, 2004; Patterson & Apostolakis, 2007). The cascading breakdown of infrastructures often magnifies the cost and casualties of a single and, at times, minor, infrastructure breakdown to an astronomical scale. In the year 2000, a protest over fuel price increases, which disrupted fuel supply, cost the United Kingdom (UK) £250 million a day as a result of the cascading impacts of fuel shortage (Hills, 2005).

Given the increased vulnerability of critical infrastructures due to infrastructure interdependency, further efforts are being made to understand the nature of infrastructure interdependency (Canada, 2005). One way to study the vulnerability of critical infrastructure interdependency is through the analysis of the infrastructure network. Depending on the type and degree of interconnections between critical infrastructures, each infrastructure network possesses its own unique characteristic, and suffers different degrees of vulnerability. In this paper, the method of social network analysis, which is used predominantly to analyze social interactions, is applied to analyze the network vulnerability of critical infrastructures, in terms of cascading failure caused by Oil & Gas.

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The infrastructure that contributes most to cascading failure is identified through this analysis.

2. What is critical infrastructure?

Apprehension over the potential sabotage of critical infrastructures in the US, which was heightened during the aftermath of the Oklahoma City bombing in 1995, prompted President Clinton, through the issuance of the Executive Order 13030, to establish the President Commission on Critical Infrastructure Protection in 1996 to advise and assist the President on national strategy for the protection of critical infrastructures from physical and cyber threats. In the Executive Order, critical infrastructure is defined as "certain national infrastructures" that "are so vital that their incapacity or destruction would have a debilitating impact on the defense or economic security of the United States" (United States, 1996). In this definition, "defense" and "economic security" are the chief national concerns. As the critical infrastructure protection programme expands, the items on the watch list grow. For instance, in the Critical Infrastructure Protection Act 2001, infrastructures that cater for public health and safety, such as hospitals, are also included as critical infrastructures. Increasingly, infrastructures that symbolize a nation's moral standing, such as the Statue of Liberty, are also being considered as critical infrastructures (Cogwell, 2003, pp. 1–31).

As concern over the safety of critical infrastructures spreads, more and more countries are taking steps to single out critical infrastructures for extra protection. In the UK, apprehension over the interdependency between critical infrastructures intensified as a result of the year 2000 protest against rising fuel prices (Hills, 2005). Today, critical infrastructures in the UK are often referred to as critical national infrastructures (CNI). These are infrastructures which comprise those assets, services and systems that support the economic, political and social life of the UK whose importance is such that loss could: a) cause large-scale loss of life; b) have a serious impact on the national economy; c) have other grave social consequences for the community and; d) be of immediate concern to the national government (United Kingdom).

Neighboring the US, Canada is quick to follow in their footsteps and makes protection of critical infrastructures one of its national priorities. Currently, the Department of Public Safety and Emergency Preparedness Canada defines critical infrastructure as: "physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of Canadians or the effective functioning of governments in Canada" (Canada).

Based on the definitions used by different governments, five criteria can be identified as the basis for the determining of critical infrastructure. They are: health, safety, economic well-being, continuous functioning of government, and national morale. These criteria, in combined effect, gear toward the stability and well-being of a society.

3. Critical infrastructure interdependency

The optimal operation of a single critical infrastructure often relies on the effective functioning of several other infrastructures. This gives rise to infrastructure interdependency. While the coupling of critical infrastructures is necessary for efficient running of these infrastructures, their interlinking, especially when they are tightly coupled, also contributes to the danger of cascading failure of infrastructures (Liu, Li, Tu, and Zhang, 2011). For example, on 13 November 2005, in the bi-benzene plant of the Jilin petrochemical branch of PetroChina, nitrobenzene rectifying tower T102 exploded because of an operational fault, causing a nearby installation and storage tank to explode. Eight people died, one was severely wounded, and another fifty-nine people were hurt. The direct loss to the economy totaled 690.828 million RMB. Initial emergency procedures were not carried out promptly and appropriately after the accident and, furthermore, subsequent pollution of groundwater took place. Such pollution not only endangered local people but also had an effect internationally.

While individual infrastructures have their inherent vulnerabilities, the power outage on 14 August 2003 in the north-east of the US points to additional vulnerability as a result of infrastructure interdependency, for instance, the shutdown of water pumps causing potential water contamination. Four million residents in Detroit were advised to boil their water until 18 August. All trains running into and out of New York were also canceled. Some regional airports were closed due to the unavailability of a passenger screening facility, and certain flights were canceled even after the power had been restored due to the inaccessibility of electronic tickets. Transportation woes were further exacerbated by the closure of petrol stations as fuel pumps were not working. Production at oil refinery plants was also stopped, causing petrol prices to rise by approximately three cents per liter. In addition, cellular communication was interrupted, and landlines became congested. The manufacturing sector was also severely affected as a result of the disruption in raw material supplies caused by traffic slowdown at the border because of electronic checking systems being affected, for instance, at the Ambassador Bridge between Detroit and Windsor. Factories that relied on "just-in-time" supply systems were especially affected (Wikipedia). The protection of critical infrastructure, as a result, must take into account the potential domino effect of infrastructure failure.

4. Types of critical infrastructure interdependency

Rinaldi, Peerenboom, and Kelly (2001) identify four types of critical infrastructure interdependency. They are: physical, cyber, logical, and geographic. Physical interdependency is related to material flows between infrastructures. An example of this type of interdependency is between power plants and transportation. A gas- or coal-fired power plant relies on transportation systems to ship in raw materials while the transportation system itself requires a continuous supply of electricity for uninterrupted operation of traffic signals and lights. The second interdependency, cyber interdependency, is formed as a result of electronic connectivity. The SCADA system, for instance, while allowing electronic information exchange among infrastructures, at the same time ties these infrastructures together. Disruption of the SCADA system inevitability terminates electronic information exchanges that are crucial to the smooth running of various connected infrastructures. The third type of interdependency, geographic interdependency, refers to interconnectedness as a result of physical proximity, such as electrical cables that run along a bridge. There is no material or information flows between the bridge and the electrical cable but both are interdependent as the bridge needs electricity to light bridge lights while the electrical cable is attached to the bridge. And finally, logical interdependency refers to other types of interdependency that are not caused by the other three types of interdependency. An example of this type of interdependency would be a cost-cutting drive that reduces frequency of water quality monitoring at a water treatment plant, thereby increasing the chances of drinking water contamination.

5. Prioritizing critical infrastructure protection

In critical infrastructure protection, interdependency within and between critical infrastructures is of major concern to

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