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Home Health Care vulnerability assessment using graph theory and matrix methods

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Abstract: The accumulation of factors like climate variability, epidemics and the increasing mobility of people around the world have increased the devastator impact of disasters. Furthermore, people have become more aware and exigent especially in terms of healthcare. Hence, a lot of pressure has been exercised on the healthcare system. Home Health Care (HHC), as a vital component of the healthcare system is facing manifolds crisis that can undermine its activities. This paper addresses the question of HHC vulnerability assessment. We use digraph presentation and matrix operations in order to synthetize indexes that infer the severity of crisis situations that a HHC facility could face, based on the predefined criteria. We introduce dynamic vulnerability assessment that takes into account cascading events over time. Vulnerability Priority Index (VPI) has been proposed to support decision-making related to the design of countermeasures and mitigation policies.

Keywords: Home Health Care, care networks, performance evaluation, massive influx, vulnerability, resilience, robustness, cascading events, graph theory, matrix methods.

1. INTRODUCTION

Today, the accumulation of risks associated with factors such as increasing urbanization, climate variability, epidemics, increasing mobility of people and goods around the world, has increased the disruptive impacts of various disasters. Besides, being aware of the recent events (terrorist attack all over the world, new epidemics such as Ebola and Zika, floods, etc.), we have noticed the lack of proactivity in our health system to anticipate its responses to unpredictable crises, due to the lack of knowledge on crisis situations, insufficient preparation and finally, a daily routine usually experienced in emergency and not in serenity. All these factors, have intensified the pressure on the health care sector.

Home health care has become a vital component of the health care system (Rest and Hirsch 2015). During the last decades, HHC has known a rapid growth. Nonetheless, the fact that HHC facility has its patients geographically decentralized and engages a lot of stakeholders (nurses, deliverers, doctors, hospitals, etc.) makes its management burdensome especially in times of crisis, and subsequently more vulnerable. Our research focus is the vulnerability assessment for HHC facility facing health crisis. We are working in collaboration with the 3rd biggest French HHC structure that denoted as HHC X.

In order to better manage crisis and mitigate the consequent losses, we need to measure the impact of this crisis on the daily running of HHC X in terms of vulnerability.

The need for Vulnerability assessment is undeniable since it is one of the most important task of the risk assessment process. It takes into account not only the system components, the layout, and the interactions between different actors but, also their failure modes based on a set of threats scenarios (Baker, 2005). The main goal of this phase is to assess the system's preparedness while facing a crisis situation.

In general, the assessment phase is lined with managers and technical staff (Baker, 2005). Assessors need a set of criteria or indexes to make their judgments so that they can evaluate the situation and take further decisions. A good index system should be easy to interpret, facilitates the evaluation task and makes it reasonable (Deng and Zheng, 2006; Tian and Yang, 2008; Ju et al., 2012).

In HHC, several actors, exchanging a lot of informational and material flows, interact with each other. In a context of vulnerability assessment, it is worth taking into account all these particularities.

In this paper, we aim at developing a set of vulnerability assessment indexes related to each component (actor and flow) for the purpose in analysing the criticality of the crisis situation. We propose an approach to assess the vulnerability of HHC facility (actors and flows) taking into account several criteria and the different dependencies and influence between the actors. The approach is based on graph theory and matrix operations.

The paper brings the following contributions:

- Define a set of criteria for vulnerability assessment of each actor and flow facing different types of crisis.
- Provide indexes to assess the vulnerability of actors and flows based on actor resilience and flow robustness, using matrix operations that do not necessitate a big computational effort.
- Define the notion of dynamic vulnerability that takes into account the cascading events over a defined horizon of time.
- Define the Vulnerability Priority Index (VPI).

The remainder of the article is organized as follows. The present section introduces the paper and defines the general

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framework. In section 2, we make an overview of the related literature. Section 3 will be dedicated to the development of the approach through a scenario. Finally, section 4 concludes the paper.

2. LITERTURE REVIEW

2.1 The use of Graph theory in vulnerability analysis

In the literature, several works focused on the use of digraph representations and matrix methods in order to investigate the vulnerability analysis and assessment. Supply chain attracted a lot of interest in terms of risk and customer sensitivity, risk management drivers, agility measurement and quantification of risk mitigation (Faisal et al., 2006a, 2006b, 2007a, 2007b). Other authors tackled the same problem using graphs and matrix methods. Wagner and Neshat (2010) developed an approach to assess the vulnerability of supply chains based on the vulnerability drivers and their relative importance and interactions. They generated a unique index called supply chain vulnerability index (SCVI) that gives an idea on the severity of the situation. Soni et al. (2014) addressed the concept of supply chain resilience measurement using a deterministic approach. They proposed a survey to identify a set of supply chain resilience enablers and took into account the interactions between them using the permanent matrix representation in order to calculate a resilience index. Attri et al. (2014) used a digraph approach to assess the robustness of barriers in a context of Total Productive Maintenance (TPM). Khakzad and Reniers (2015) and Khakzad et al. (2016) used graph metrics such as degree, centrality, betweenness and proved their usefulness to analyze the vulnerability of process plants taking into account the cascading effects. Their results were verified by Bayesian Network analysis.

Recently, several researches coped with complex infrastructure vulnerability assessment and analysis. Kamissoko et al. (2011) presented a state of the art of structural vulnerability in the literature and proposed a general model to assess the infrastructure network vulnerability. In another work, they investigated the question of technological networks in terms of resistance and resilience assessment. They also defined a function of vulnerability assessment of a network based on the resilience and the robustness of each component of the infrastructure (Kamissoko et al. 2013). Besides, they used complex system in a context of vulnerability analysis and proposed a model based on 5 layers (spatial, framework, stake, flow, environment, and network structure) that takes into account the notion of flow circulation while conducting the vulnerability analysis (D. Kamissoko, Pérès, Zaraté, & Gourc, 2015). Other authors used graph theory techniques to tackle the vulnerability of water supply networks (Yazdani and Jeffrey 2012; Gutiérrez-Pérez et al. 2013; Soldi et al. 2015).

2.2 Home Health Care vulnerability analysis

It is worth noticing that the literature that deals with HHC vulnerability analysis is too scarce. To the best of our knowledge, Rest et al. (2012) were the pioneer to investigate this question. They defined a set of potential threats that can impact the HHC in rural and urban areas based on National Association for Home Care and Hospice directives (NAHC,2008), and highlighted the need for anticipatory risk management in HHC facing health crisis. Rest and Hirsch (2015) made a vulnerability analysis in HHC. Besides defining a set of success factors for HHC services (nurses number, transport trafficability, communication availability, etc.), they pointed out the impact of the harmful crisis scenarios (blackout, natural disasters, epidemics, etc.) on the success factors. Note that, no vulnerability assessment in terms of metrics and indices has been clearly addressed. Lee et al. (2011) studied the vulnerability of Medical devices in home health care based on a set of criteria mainly related to the information exchange, security and privacy. Other related works have been done that deal with vulnerability analysis of hospitals facing earthquakes using Leontief model and rapid seismic vulnerability assessment (Miniati and Iasio, 2012) and detailed risk assessment for health crisis (Melching and Pilon, 2006; Johanson and Galea, 2009; Berariu et al., 2015)).

None of the works cited above addresses clearly the problem of HHC vulnerability assessment. No metrics or functions have been developed in order to assess the real impact on the HHC facility. One need to measure the impact based on metrics in order to manage it. To the best of our knowledge, the concept of dynamic vulnerability that expresses the evolution of the network vulnerability over time taking into account the different interconnections, has not been clearly addressed in the literature. Some related researches took into account the cascading events, but they were dedicated to acyclic graphs (Khakzad and Reniers, 2015; Khakzad et al. 2016). Feng et al. (2014) tackled the vulnerability propagation in relation with causal relationships of risk factors using Bayesian Network in a context of security analysis for information systems.

3. VULNERABILITY ASSESSMENT APPROACH

3.1 Digraph modelling

Digraph modelling of a network allows a visual presentation that describes the reality and represents the involved actors, their exchanges and interactions. The vulnerability of the system is not only a result of the vulnerability of these actors, but also the vulnerability of the flows exchanged between them.

In Home Health Care, the digraph G = (A, F), with A= $A_0 \ldots A_n$ represent the actors involved in the HHC supply chain, and F=F_{ij}, with i,j=0…n. F_{ij} represents the flow delivered from actor A_i to actor A_j. This flow implies the duality of influence/dependency in the network. Flows are prominent for the good functioning of each actor and can be material or informational. Therefore, the digraph G, comprises all the critical assets (actors and flows) for the good functioning of HHC that can be undermined in time of crisis.