Chaos, Solitons and Fractals 116 (2018) 72–78

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

The complexity measurement and evolution analysis of supply chain network under disruption risks

Hua Wang[a], Tao Gu[a], Maozhu Jin[a,*], Rong Zhao[a], Guanxiang Wang[b]

[a] Business School, Sichuan University, Chengdu 610065, China
[b] Tsinghua-Berkekey Shenzhen Institute, Shenzhen 518000, China

ARTICLE INFO

Article history:
Received 27 August 2018
Revised 8 September 2018
Accepted 11 September 2018

Keywords:
Complexity
Supply chain
Complex network
DSM
Disruption risks

ABSTRACT

Based on the study of the complexity of supply chain network, this chapter mainly analyzes the complexity of supply chain network structure in the context of disruption risk, and proposes a quantitative measurement method for the complexity of supply chain network based on DSM model. On this basis, this measure method is used to measure the complexity and evolution of ER random networks, small-world networks, and BA scale-free networks. Finally, the internal relationship between the complexity value, network size and connection probability is analyzed, which provides a theoretical basis for the structural design of supply chain network under the disruption risks.

1. Introduction

Among practitioners and scholars, the complexity of the supply chain is one of the most pressing issues in the modern supply chain and a major obstacle to performance [1]. The high degree of complexity of the interrelated flows of materials, funds, and information between firms is not only attributed to reducing supply chain efficiency, but is also seen as a key precursor to disruptions in supply chains [2,3]. For example, Toyota's product recall crisis is at least partially due to the proliferation of supply chain complexity.

The complexity of the supply chain network is reflected in many aspects, including the complexity, openness, emergence, and dynamics of the structure. From the perspective of the composition of the supply chain, it involves members of various roles, including suppliers, manufacturers, distributors, retailers, etc. From the perspective of topology structure, different types of supply chains exhibit different topological structures due to the different characteristics of products.

The analysis of the complexity of the supply chain using complex science-related methods is a research trend in the supply chain field. However, in most of the existing research literature, there is little to start from the structural characteristics of the supply chain network, lack of in-depth analysis of the structure, such as not considering the diversity of the role of the node, ignoring the locality of the node selection range and the connection Preference is too simple to deal with, and most of the proposed structural models have a certain gap with the real supply chain system. On the other hand, although complexity is discussed in many different areas, most of them focus on the complexity of the engineering field. The complexity of the supply chain context is only described in terms of its complexity or elemental analysis of the complexity of the supply chain system. , did not propose how to measure the complexity of the supply chain network. The complexity of the structure of the supply chain network is one of the main reasons leading to the complexity of the process of the supply chain interruption risk. Therefore, this paper analyzes the complexity of supply chain network structure and its measurement methods under the background of supply chain interruption risk.

The structure of this dissertation is organized as follows: In the next section, we reviewed the relevant literature on DSM methods, complexity measures, and supply chain disruption risks. The third part proposes a method to measure the complexity of supply chain network. The fourth part analyzes the complexity of several complex networks, their connection probability, and the variation between nodes. Finally, the conclusions of this paper and the prospects for future research are given.

2. Literature review

The Design Structure Matrix (DSM) is a project management tool used to represent and analyze relationships. DSM was developed by Warfield in the 1970s. Research was conducted during the

* Corresponding author.
E-mail address: jinmaozhu@scu.edu.cn (M. Jin).

https://doi.org/10.1016/j.chaos.2018.09.018
0960-0779/

design process in 1990. DSM breaks the system down into relationships between multiple parts to study the sum of its complexity. DSM can represent the structure of the supply chain system in the network and the interaction between node enterprises. It has prominent advantages in the decomposition of complex network structure and the expression of the relationship between system elements such as dependence, constraints, etc. It is a quantitative analysis of the supply chain. An effective tool for complex network structures [4].

If a system contains many related elements, this system is considered to be complex. System complexity was divided into structural, dynamic, and organizational complexity. Structural complexity is a characteristic of the basic system architecture. Dynamic complexity deals with the dynamic behavior of the system during transient or steady-state operations. Organizational complexity deals with the interactions between various elements of the organization . As the system becomes more and more complex, its development and operation become more difficult. In order to reduce the development time and cost of the engineering system, the complexity must be reduced, and certain types of metrics that can measure the complexity of a given system are needed .

Many scholars have studied the complexity indicators. In the software industry, various indicators have been proposed since the 1970s. Some well-known indicators are the measures of circle metrics proposed and the connectivity-based metrics developed by Kafura and Henry (1981) [5] . In general, the indicators proposed in software engineering use code lines, algorithm test paths, programming workload, and information flow to estimate overall complexity.El-Haik and Yang (1999) introduced a complexity index based on Boltzmann entropy to express the design complexity associated with the size of the design problem, the relevance of the design parameters, and the sensitivity of the functional requirements when the design parameters change [6] . A set of effective measurement attributes of evaluation complexity established by Weyuker (1988) [7] , compared with some of the previous complexity indicators. It embodies the complex attributes of three different aspects of the complex system system architecture, and the complexity evaluation is more objective, more comprehensive, and more accurate.

In social sciences, Simon (1962) gave the definition of complexity as follows: If a social technology system consists of a large number of parts that interact in a very simple way, the system is complex [8] . Later, many scholars conducted in-depth research on this structure and behavior. (Perrow, 1984 [9]). The former is often referred to as structural complexity and refers to the number and type of elements that define the system. The latter is often referred to as dynamic complexity and refers to the interaction between system elements. In practice, these aspects are often closely related because the greater the number of different elements, the greater the possible number of interactions. Therefore, the system may exhibit different behaviors and states. (Bozarth et al. 2009 [1]; Skilton and Robinson, 2009 [10] ; Manuj and Sahin, 2011 [11]).

Supply chain network complexity has been used as a reason to reduce operational performance (Bozarth et al. 2009 [1]), making decision making complex (Manuj and Sahin, 2011 [11]) and impacting operations (Craighead et al. 2007 [12] ; Narasimhan and Talluri, 2009 [2]). There are two unique perspectives on the study of supply chain complexity. A research perspective is to study the supply chain as a complex adaptive system that has the ability to learn and adapt to environmental changes (Choi et al., 2001 [13] ; Pathak et al., 2007 [14]). The second research perspective is to view the supply chain as a complex social network and use social network analysis methods to understand how relationship relationships are formed and how these relationships affect the relationship between nodes and nodes in a supply chain system (Borgatti And Li, 2009 [15] ; Kim, 2014 [16] ; Lomi and Pattison, 2006 [17]).

The complexity of factors such as supply chain interruption risk source, propagation carrier and propagation path, and the randomness and uncertainty of supply chain interruption risk determine the complexity of supply chain interruption risk. The complexity of supply chain networks increases the risk of disruptions in supply chain networks [18] . When the complexity is out of the tight rope of control, it is difficult for the organization system to effectively predict the operational status of the supply chain [19] , so reducing complexity is the strategic goal of the company's operations [20] .

3. Supply chain network complexity measurement

In the supply chain network, each node represents a member enterprise in the supply chain network. The associated edge between the nodes represents the various interactions between each node enterprise such as business flow, logistics, information flow, and capital flow. Therefore, the complexity of the supply chain network is mainly reflected in the complexity of the nodes, the complexity of the associated edges, and the complexity of the supply chain environment. Based on the complexity of the three aspects of the supply chain network to measure the complexity of the supply chain network structure.

The complexity of the supply chain network mainly includes the complexity of the organization and the overall complexity of all supply chain node enterprises. The complexity of the supply chain network mainly depends on the number of different node enterprises and their connectivity structure, which is a measurable system feature. The complexity measurement index includes the value of the complexity of the supply chain network node enterprise, the complexity associated with the supply chain network node enterprise connection, and the complexity value generated by the topology structure between supply chain network nodes, ie, the complexity of the supply chain network structure. The measure formula can be expressed as:

$$C = C_1 + C_2 \cdot C_3 \tag{1}$$

In Formula 1, C represents the total complexity value of the supply chain network; C_1 represents the sum of the complexity values of the nodes in the supply chain network; C_2 represents the sum of the complexity values of the associated edges of the node enterprises in the supply chain network; C_3 represents the complexity of the network topology.

3.1. Node complexity value measurement

The complexity of each node enterprise in a supply chain network can vary across the entire supply chain system (for example, the complexity of the manufacturer is much more complex than the complexity of the retailer) and is measured by the complexity of each node's enterprise [21].

Sadin et al. (1988) [22] used the level of technical readiness of the components that make up the system as a proxy for complexity, with the complexity level of all components set to . In the case of structural complexity measurement, for the absence of component data, the complexity of the component was evaluated using the ratio of the subjective evaluation method used by the experts.

In a complex supply chain network, it is clear that the importance of node enterprises is greater, and the greater the impact of disruption risks. Therefore, this paper regards the ædegreeg of each node as a surrogate index of complexity. The complexity level of all nodes is set as the degree of each node's enterprise , then the complexity value of each node's enterprise can be calculated according to the following formula:

$$\alpha_i = 5 \cdot \frac{d_{max} - d_i}{d_{max} - d_{min}} \tag{2}$$