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An ant colony based resilience approach to cascading failures in cluster supply network

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HIGHLIGHTS

- The mapping between ant colony SFZ and cluster supply chain network SFZ is presented.
- A new cascading model based on under-load failures is proposed.
- A SFZ-based resilience method against cascading failures is developed.
- The deviation of SFZ is used to measure the resilience to cascading failures.

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ABSTRACT

Cluster supply chain network is a typical complex network and easily suffers cascading failures under disruption events, which is caused by the under-load of enterprises. Improving network resilience can increase the ability of recovery from cascading failures. Social resilience is found in ant colony and comes from ant's spatial fidelity zones (SFZ). Starting from the under-load failures, this paper proposes a resilience method to cascading failures in cluster supply chain network by leveraging on social resilience of ant colony. First, the mapping between ant colony SFZ and cluster supply chain network SFZ is presented. Second, a new cascading model for cluster supply chain network is constructed based on under-load failures. Then, the SFZ-based resilience method and index to cascading failures are developed according to ant colony's social resilience. Finally, a numerical simulation and a case study are used to verify the validity of the cascading model and the resilience method. Experimental results show that, the cluster supply chain network becomes resilient to cascading failures under the SFZ-based resilience method, and the cluster supply chain network resilience can be enhanced by improving the ability of enterprises to recover and adjust.

1. Introduction

Cascading failures are common in most real complex networks. The researches on cascading failures mainly focus on the infrastructure networks, e.g., electrical power grids, the Internet, transportation networks. In electrical power grids, when a line goes down, its power is automatically shifted to the neighboring lines, which have to handle the extra load. In the Internet, traffic is rerouted to bypass malfunctioning routers, which may lead to an avalanche of overloads on other routers. In urban transportation networks, the vehicles will avoid the congested intersection, eventually leading to the traffic congestion at other intersections. In these networks, the cause of the failures of nodes./edges is that the node./edge

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load exceeds its capacity. Accordingly, some overload failure models are proposed to study cascading failures in most infrastructure networks [1–4].

Supply chain is a complex network of suppliers, manufacturers, distributors and retailers that provide products or services to customers. Recently, cascading failures in supply chain networks have attracted the interest of some scholars, who used the above overload failure models in their researches [5,6]. However, there is a drawback. Unlike the overload failures, the cascading failures in supply chain networks are caused by the under-load of the node enterprises, a node enterprise fails when it does not reach the minimum production requirements. Specifically, in supply chain networks, there is a supply and demand relationship between upstream and downstream enterprises. When an enterprise fails under disruptions, its downstream enterprises may not produce normally, because of insufficient supply of materials; its upstream enterprises may end operation, due to a drop in demand for their products.

Resilience is usually referred to as the ability of a system to return to its original state after disruptions. Increasing network resilience can promote resistance to cascading failures, and reduce the negative impacts of cascading failures [7,8]. At present, scholars have done a lot of work in supply chain resilience, such as: Hohenstein et al. [9] suggested that it is more beneficial to learn from disruptions and adapt to the new environment than to return to its original state, so supply chain resilience should also contain the ability to grow; Tukamuhabwa et al. [10] argued that, as an economic system, supply chains need to consider cost-effectiveness in supply chain resilience; Kim et al. [11] differentiated between node/edge-level disruptions and network-level disruptions, and they defined supply chain resilience as a network-level property to withstand disruptions that may be triggered at the node/edge level; Colicchia et al. [12] established a resilient supply chain model against internal risk of supply chain, and identified a series of methods to manage the risk and improved supply chain resilience through in-depth analysis of the vulnerability of supply process; Jüttner and Maklan [13] analyzed empirically the relationship between supply chain resilience, supply chain vulnerability and supply chain risk management, and their empirical study showed that supply chain risk management has a positive impact on supply chain resilience and supply chain resilience can decrease supply chain vulnerability; Carvalho et al. [14] elaborated on the importance of resilience in the supply chain operation with an instance of a three-tier supply chain and how to use simulation method to achieve supply chain resilient restructuring, and pointed out the key factors affecting the supply chain resilience; Wang and Ip [15] defined the node resilience as the ratio of the available and reliable suppliers over the demand, and the weighted sum of the node resilience is the supply network resilience; Zhao et al. [16] adopted availability, connectivity and accessibility to measure supply network resilience, and they proposed a growth model called degree and locality-based attachment to improve supply network resilience against disruptions; Munoz and Dunbar [17] used the "resilience triangle" to measure supply chain resilience, where the depth of the triangle represents the disruption severity, and the length of the triangle represents the recovery time. All the aforementioned studies on supply chain resilience are mostly concentrated on the discussion, analysis and measure of resilience, which consider the failure of a single enterprise from a static point of view, ignoring the interactions among enterprises and disruption propagation within the supply chain. In other words, the work about supply chain recovery under considering cascading failures is very limited. This gives the motivation of our present work.

There are many resilient phenomena in biology society [18,19], and some bio-inspired methods are proposed to solve practical problems [20,21]. Taking ant colony as an example, an efficient labor division can be recovered from disruptions, Backen et al. [22] attributed it to ant colony's social resilience. Specifically, the ants have limited areas of movement, termed spatial fidelity zones (SFZ) [23]. The location of an ant's SFZ is related to the tasks it performs. When the colony suffers great accidents (e.g., nest damage or colony emigration), the ants can rebuild their SFZ relative to one another and resume their different tasks, thus achieving the social resilience. And the social resilience is robust. Through social resilience ants recover their previous spatial structure and resume their familiar tasks, without any time and resources being wasted in worker re-specialization. As a result, the colony returns to a normal level of efficiency. Inspired by social resilience, Wang et al. [24] presented a flexible, robust and adaptable rapid response design approach, which is used to minimize the losses of infrastructural facilities caused by disaster; Wang and Xiao [25] established a resilient control structure to explore the social management.

In this paper, we start from under-load failures and study the resilient recovery of cluster supply chain network from cascading failures by leveraging on social resilience in ant colony. The remainder of this paper is organized as follows. Section 2 presents the mapping between ant colony SFZ and cluster supply chain network SFZ. Section 3 proposes a new cascading model for cluster supply chain network. According to ant colony's social resilience, this section also develops SFZ-based resilience method and index to cascading failures. In Section 4, a numerical simulation is conducted to verify the validity of the cascading model. In Section 5, a case study related to a laser cluster supply chain network is developed to verify the practicability of the resilience method to cascading failures. Finally, conclusions are discussed in Section 6.

2. The SFZ in cluster supply chain network

2.1. Spatial fidelity zones

Sendova-Franks and Franks [23] found that ants in colony of *Leptothorax*cannot move equally throughout the nest but have limited areas of movement, termed spatial fidelity zones (SFZ). SFZ is specific to ants. The position of an ant's SFZ is