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An analysis of the structural complexity of supply chain networks

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ABSTRACT

Each enterprise in a supply chain network needs quantitative indicators to analyze and manage its interactions with different business partners in the network. Supply chains exhibit the characteristics of complex systems. In a supply chain network, a large number of firms cooperate simultaneously with many suppliers and customers, and interact through a variety of information and material flows to achieve a balance between supply and demand. However, the complexity of a supply chain is not a simple linear structure where a small change often results in a chain reaction. When supply chain complexity increases, monitoring and managing the interaction between different elements of the chain becomes more difficult. An entropy model based on information theory provides an appropriate means of quantifying the complexity of a supply chain system by delivering information required to describe the state of the system. The entropy measure links uncertainty and complexity so that, as a system grows in uncertainty, it becomes more complex and more information is required to describe and monitor it. In this paper, we propose an entropy-based measure for analyzing the structural complexity in relation to the structure and system uncertainty. The method provides guidelines for estimating the complexity throughout the supply chain structure.

1. Introduction

Because of the competitive nature of the global markets, enterprises must be able to adapt quickly to variations in supply and demand. Effective responses require the integration of the internal and external resources of the supply chain. Coordinating operations, cooperating with other members, and sharing information throughout the supply chain facilitate optimum production and operating efficiency, and also improve the overall quality of customer service. A supply chain consists of a supply side, a production side, and a customer side, which together create a "multi-stage" environment. Each stage has more than one site, so it becomes a "multi-site" environment. The combination of "multi-stage" and "multi-site" environments yields the production environment of a supply chain network, as shown in Fig. 1.

The interaction between the various information flows and logistics of the supply chain partners is a key characteristic of a complex system [1]. Generally, the relationships between network participants, from upstream suppliers to downstream customers, are not single line connected. Because of their complexity, supply chain networks are difficult to understand, describe, predict and control. To reduce the level of uncertainty in such networks, it is necessary to understand the diverse roles of the supply chain's members, their interactions, and the transaction models they use to interact with one another.

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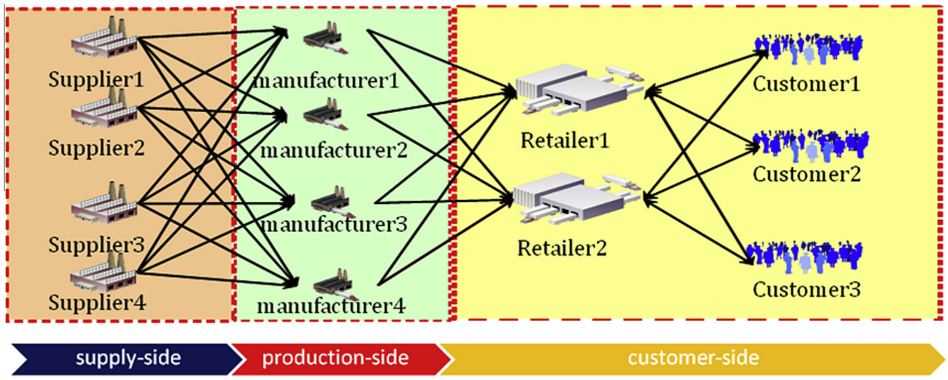

Fig. 1. A supply chain network.

In recent years, several methods have been proposed for evaluating the complexity of supply chain networks in order to control the level of uncertainty. For example, Huan et al. [2] developed the Supply Chain Operations Reference (SCOR) model, which emphasizes the complex features of supply chain networks, and supports managers' decisions by establishing a supply chain structure from the perspective of workflow efficiency. Perona and Miragliotta [3] investigated how uncertainty affects manufacturing companies and the efficiency of their supply chains. They showed that companies use complex methods to manage operation systems, which affect their performance. The authors also classified the sources of complexity and methods of control, and proposed a theory about the relationship between management skills, work content and work efficiency. Their complexity model shows that the skill with which complexity is controlled is a core competitive capability that can be exploited to improve a supply chain's efficiency and effectiveness. Mills et al. [4] reviewed the relevant research on supply chains and suggested that future studies should consider the relationship between the upstream and downstream parts of the supply chain, i.e., the relationship between supply and demand, and compare different supply chain network structures.

System complexity can be classified as (1) structural complexity, which is related to the uncertainty of a static system; and (2) operational complexity, which is related to the uncertainty of a dynamic system. Systems with a higher degree of uncertainty will have a higher level of complexity. In this work, we focus on and analyze static structural complexity.

For static networks, Arteta [5] used Petri Net to construct an enterprise's operational structure, applied Shannon's [6] information theory of entropy quantification, and analyzed the complexity of the enterprise's process structure. Ulanowicz [7] utilized the entropy function of information theory as a quantification index of the stability of an ecological network, and determined that ecological networks with smaller Average Mutual Information (AMI) scores are more stable. A supply chain system can be described as transition probabilities of exchanged goods or products from upstream to downstream, and the AMI could be computed by inputs and outputs entropy of each supply chain nodes. Therefore, low AMI could indicate a stable supply chain system considering uncertainty. Persona [8] used Ulanowicz's entropy index of ecological networks to classify supply chain networks and ecological networks. Using ecological networks as prototypes with which to construct supply chain networks, Persona devised an index of the efficiency of supply chain systems. Allesina et al. [9] used the entropy model to develop a complexity analysis index of supply chain networks, quantified the complexity of supply chains under different supply chain management strategies. However, Allesina et al.'s [9] analysis of supply chain network complexity only uses AMI as a complexity index, without considering the diversity of the structural types of supply chain members. By contrast, Sivadasan et al. [10] used entropy to quantify difference of information flow between the logistic networks. Isik's [11] analysis of the complexity index uses the entropy function distributed by the difference in the quantified flow of supply chain members to demonstrate that the complexity index increases as the difference in the supply chain flow increases.

In this study, we adopt the entropy model in information theory to analyze the static structural complexity of supply chain networks and derive a quantified complexity index of the supply chain. The remainder of the paper is organized as follows. In the next section, we review related works on supply chain complexity and information theory. In Section 3, we present a structural complexity model of the supply chain; and in Section 4, we use different networks to validate the proposed model. Section 5 contains some concluding remarks.

2. Literature review

2.1. Complexity of supply chain networks

Supply chain systems comprise the supply members—upstream suppliers and downstream customers, as well as the material logistics and information flow among supply chain members that create a network structure. Various supply chain members can simultaneously interact with one another in various channels via various information flows and logistics, making the entire network a complex system [12]. The uncertainty of this complex system may create internal conflicts; thus,