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Modeling and simulation of supply network evolution based on complex adaptive system and fitness landscape ☆

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Abstract

A supply network (SN) is a complex adaptive system, and its structure and collaboration mechanism evolves over time. However, most literature views SN as a static system and the study on the evolution of SNs is very limited. Based on complex adaptive system and fitness landscape theory, this paper first proposes an evolution model of SNs in order to understand the general principle of SN evolution. Then the paper conducts a multi-agent simulation on the evolution model, and discloses that the SN emerges and evolves from firms' dynamic interaction under the dynamic environment. Dominated by the environment and firms' internal mechanism, the evolution is highly sensitive to the initial condition, and it is path-dependent and difficult to predict precisely. Although the dynamics of environments is different, a SN enjoys the stable structure in different environments. Higher level of structure stability and fitness of the SN are achieved when the firms in the SN adopt the long-term collaboration strategy rather than the short-term strategy. Finally, a China case is explored which validates the self-organization evolution of SNs.

Keywords: Operations management; Supply networks; Self-organization; System modeling; Simulation; Case study

1. Introduction

A supply network (SN) is referred to as a complex network of organizations that synchronizes a series of inter-related business processes, such as procurement, manufacturing and distribution, to create values to final customers in the form of one or more families of related products or services (Christopher, 1992; Min & Zhou, 2002). In spite of growing interest in the management of supply networks (Choi, Dooley, & Rungtusanatham,

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2001; Lamming, Johnsen, Zheng, & Harland, 2000; Stuart, Deckert, McCutcheon, & Kunst, 1998), researchers are still in an early stage of understanding how a SN behaves and evolves. Some studies investigated the factors that influence the SN evolution in different environments. For example, Hur, Hartley, and Hahn (2004) identified six factors that have influence on the structure of SNs in different industries. Choi and Hong (2002) found that the SN of Honda was controlled centrally by the final assembler, while the SN of DaimlerChrysler was decentralized. Choi et al. (2001) and Chung, Yam, and Chan (2004) proposed that a SN emerged and evolved in a way of its own. The emergence of cooperation networks was largely an endogenous process driven by the complex and dynamic interplay between institutions, products, technologies, markets and innovative actors (Bruce, 2000). What are the salient factors and the general principles that shape a SN? No one can answer this question with any degree of certainty (Harland, Zheng, Lamming, & Johnsen, 2002). This is due to the lack of our understanding of evolutionary aspects of SNs (Surana, Kumara, Greaves, & Raghavan, 2005).

This study will investigate the general principles involved in the evolution of SNs. It proposes a SN evolution model based on CAS (complex adaptive system) (Holland, 1995) and fitness landscape theory to model the dynamic behavior of the SN evolution with the dynamic interaction among the firms and the environment. This approach underscores the importance of the model in which different entities in the SN operate subject to their own local strategies, constraints and objectives. With the simulation of the evolution model based on multi-agent, the dynamic behavior of the firms and the SN can be analyzed from a variety of organizational perspectives. It finds that the evolution of SNs is a self-organization, and identifies the salient factors that control the evolution. Also, a case study which explores the evolution of a SN in China for more than 30 years validates the findings. Finally, some managerial insights are proposed in the paper.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the system model and simulation of SN evolution based on CAS and fitness landscape theory. The principles and some salient factors that influence the SN evolution are discussed. In Section 4, a China case study is presented to validate the findings in Section 3. In Section 5, we present some propositions and managerial implications about the evolution of SN. Finally, concluding remarks and future research directions are pointed out in Section 6.

2. Literature survey

A useful paradigm for supply chain management, taking into consideration of the dynamic interaction of the firms in the supply chain, is to view it as a supply network (Surana et al., 2005). Most of the researches in the past decades viewed the SN as a static system. Analytical models, simulation methods and empirical approaches have been employed to enhance the knowledge of SNs and optimize the system decision (Pathak, Dilts, & Biswas, 2007a). Based on analytical and simulation methods, most of researches focused on the "design" and "optimization" of SNs. They tended to assume that a SN is an integrated and static organization (Gunasekaran & Ngai, 2005; Min & Zhou, 2002; Whang, 1995). Empirical studies were employed to understand the strategic issues, managerial perceptions, and measurements of key operational issues of SNs (Choi & Hong, 2002).

Although the structures and collaboration mechanisms of a SN are static in a short term, they evolve in the long run. The optimal network structure and collaboration mechanism for a SN which takes researchers' many efforts based on the assumption of static structure may become invalid as the SN evolves. To better facilitate the management of SNs, we need to understand more about the dynamic behaviors of the firms and SNs. For example, how can different firms form a SN structure? How does the SN evolve over time? To answer these issues, we need to understand the evolution dynamics of the formation, adaptation and evolution of SNs.

There exists a body of literature that deals with the supply chain as a dynamic system. These approaches are often based on various simulation methods to examine the dynamic behavior of SNs. They can generate results about large-scale systemic behavior in ways that are analytically intractable, and find how various improvement efforts affect the dynamical behavior. Forrester (1961) was the first one who examined system dynamics within a supply chain by the simulation method. Illuminating results have been generated from this line of approach (Berry, Naim, & Towill, 1995; Larsen, Morecroft, & Thomsen, 1999; Marquez & Blanchar,