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A review of agent-based modeling approach in the supply chain collaboration context

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Abstract. Collaboration is considered as the key aspect of supply chain management (SCM) success. This issue has been addressed by many studies in recent years, but there are still few research employs agent-based modeling (ABM) approach to study business partnerships in SCM. This paper reviews the use of ABM in modeling collaboration in supply chains and inform the scope of ABM application in the existing literature. The review reveals that ABM can be an effective tool to address various aspects in supply chain relationships, but its applications in SCM studies are still limited. Moreover, where ABM is applied in the SCM context, most of the studies focus on software architecture rather than analyzing the supply chain issues. This paper also provides insights to SCM researchers about the opportunity uses of ABM in studying complexity in supply chain collaboration.

1. Introduction

Collaboration between companies along a supply chain is believed as the core driver to achieve a long-term business success. In supply chain management (SCM) concept, a success collaboration practice is characterized by the integration of all operations from the upstream channel (the suppliers of raw materials) to the downstream side (end consumers) of the supply chain. Nevertheless, this ideal collaboration is hard to achieve. Most enterprises claim that integrating supply chain planning and operations activities is a complex issue although the alignment is only at a corporate level[1]. The challenge becomes more complicated when the integration involves other organization in the supply chain.

Agent-based modeling (ABM) is one of the simulation approaches that is increasingly employed to study behavior complexity in strategic partnerships, such as conducted by Robertson and Caldart [1] in strategic management research and Axelrod [2] in social science. Even though it has been considered as an innovative approach to study business relationships, the implementation of ABM in SCM context is still less popular than the other research field, particularly in strategic management.

This paper aims to explore the application of ABM in supply chain collaboration with a view to identifying the nature of their use. The nature of use is defined in terms of the aspect of collaboration, which considers supply chain functions. The contribution provided by this work is twofold. First, it documents the scope of supply chain collaboration issues that have been considered in the current literature. Secondly, the review provides an insight about potential uses of ABM in the future, in the context of studying partnership complexity in supply chains.

The remaining sections of this paper is structured as follows. In the next section, the literature review of supply chain collaboration and ABM work in SCM are presented. Then it is followed by a description

of the review approach adopted, the findings and discussion of the review. Finally, Section 4 concludes the paper and presents suggestions for further studies.

2. Review on collaboration studies

Here is the brief literature review that provides the existing collaboration studies in both SCM and ABM field. The first subsection describes how ABM approach is appropriate in studying collaboration in supply chains, and the second subsection lists the current ABM work in supply chain collaboration.

2.1 Supply chain collaboration

Much research has discussed supply chain collaboration problems by applying analytical approach. Several examples of these studies are as follows. Cachon and Lariviere [3] study revenue sharing contracts by incorporating the newsvendor model for the collaboration approach. Dimitriou, Robinson, and Kotiadis [4] investigate the performance of newsvendor model under the bounded rational decision. Wu and Chen [5] perform a laboratory experiment to investigate rationally bounded behavior in newsvendor settings under several theoretical supply chain contracts. However, these studies only focus on inventory and logistics policy. Moreover, they tend to model collaboration issue in the form of supply chain contract, which is only appropriate to implement in the downstream level of the supply chain rather than for supply chain partnerships in general.

Other SCM studies apply empirical approach to view collaboration issues in a more comprehensive scope than inventory and logistics decisions. Holweg, Disney, Holmström, and Småros [6] consider the geographical dispersion of customers and supplier plants, demand pattern of products, and product characteristics as the key factors that drive supply chain collaboration. Cao and Zhang [7] study the nature of supply chain collaboration to explore its impact on company's performance. They took U.S. manufacturing enterprises as case studies. Purwaningrum and Evers [8] also find that culture has a significant effect on the mechanism of supply chain collaboration. However, none of these works explores how these complexities emerge from interactions between firms during their collaboration.

Studying complexities is hard to perform by using both analytical and empirical approach. Analytical models are mostly available for operational level problems where data can be obtained and follows a certain statistical distribution. Nevertheless, analytical solutions only work in a circumstance with a low complexity level. Meanwhile, empirical approach enables observation of many factors. However, exploring the impacts of sensitive factors in strategic partnerships through what-if analysis is difficult to conduct in the real world. It potentially causes problems of research ethics and consumes a great amount of time. Thus, simulation can be the best approach to study complexities that cannot be explained by both analytical and empirical approaches, particularly when the research aims to explore the impact of individual behavior on the supply chains.

2.2 ABM studies in SCM

ABM employs a bottom-up modeling, which starts with defining the individual agent. Then, the agents interact with each other and create a resulting emergent behavior at system level. ABM is a non-aggregated method that allows system perspective analysis to the emergent results [9].

The earliest and most popular ABM simulation in SCM is the beer game [9] although it is more popular to be modelled in system dynamics approach. The beer game simulates the increase of demand volatility as it moves further up a supply chain, which is known as the bullwhip or whiplash effect. This effect emerges because each company inside the supply chain is a rationally bounded entity and does not coordinate with each other in their decision-making process.

SCM research that employs ABM in analyzing the collaboration issue is still limited. Several studies consider supply chain collaboration as firm's integration. For instance, Xue, Li, Shen and Wang [10] employ ABM to address collaboration issue in construction supply chain, but they concentrate on the information flow and negotiation. Zhang, Anosike, Lim, and Akanle [11] present an ABM as an approach for e-manufacturing to provide flexibility, robustness, and adaptability to the rapid changes. Zhu [12] also models supply chain collaboration, but it does not consider the collaboration as integration between firms; the study focuses on investigating the impact of information sharing in a single *two-echelon* supply chain. Chen, Ong, Tan, Zhang, and Li [13] conduct a literature review on the use of

ABM in supply chain risk management (SCRM). They consider that SCRM is a result of collaboration success in a supply chain.

Other studies consider supply chain collaboration only in the scope of inventory decision, such as Dimitriou, Robinson, and Kotiadis [4] and Robinson, Dimitriou, and Kotiadis [15]. The study examines the effect of bounded rational decisions in a classical inventory model for perishable products (the Newsvendor inventory model) by combining ABM and multiple linear regressions.

Trust between collaborating firms has also modelled and investigated by using ABM, but not many studies can be found in this topic so far. Only Mohamed, Omar, and Wei [15] examine this issue in SCM context through an empirical approach in Malaysian industries.

Meanwhile, other works focus on modeling and analyzing collaboration issue in the downstream level of supply chain, such as conducted by Caridi, Cigolini, and De Marco [16]. They review the literature on ABM applications in managing supply chain processes, particularly in collaborative planning, forecasting, and replenishment (CPFR). In SCM, CPFR involves procedures and guidelines for sharing sales and forecast information between buyer and seller.

With regards to all ABM studies in supply chain collaboration, they concentrate mostly on software architecture than investigating the problem. These studies tend to employ ABM as a part of intelligent system in decision making rather than exploring the firm behavior. The following are several examples of these studies described in brief. Swaminathan, Smith, and Sadeh [17] utilize ABM as a multi-agent approach to develop a supply chain modeling framework. It addresses supply chain configuration, coordination, and contracts issues, which deal with inventory decisions. Julka, Srinivasan, and Karimi [18] propose an ABM framework for developing a decision support system prototype to integrate supply chain processes in a refinery supply chain. However, the goal of the system is optimizing a firm's performance, not the supply chain's performance. Jiao, You, and Kumar [19] applies an ABM system to develop a framework of collaborative negotiation in a supply chain. The framework incorporates supply chain network and inventory decisions. Zarandi, Pourakbar, and Turksen [20] employ ABM to reduce the bullwhip effect by coordinating all entities along the supply chain to minimize the total costs. Cheng [21] proposes an agent-based supply chain collaboration model that studies production and logistics processes at enterprise-level. The model comprises a single two-stage supply chain, which involves a manufacturer and a supplier. Kwon, Im, and Lee [22] propose an agent-based web approach to support supply chain collaboration in e-business. It models a three-stage supply chain that consists of suppliers, manufacturers, and retailers. The framework focuses on inventory decisions and allows flexibility in coping with partnerships changes. Santos, Coutinho, Cretan, and Jardim-Goncalves [23] develop a prototype of an agent-based framework for negotiation. The system is intended to support a supply chain collaboration network by improving the interoperability in the single supply chain. Hsieh and Lin [24] proposes ABM model with multi-agent system (a distributed agent-based modeling) to manage collaborative workflows and schedule the activities within a firm.

Besides supply chain collaboration, ABM has been widely applied in many SCM issues. Most of them focus on simulation software development instead of adopting ABM to analyze the supply chain problem. This is because they are conducted under the research area of computer science, not operational research and management science or SCM. For example, Barbuceanu, Teigen, and Fox [25] model a supply chain system that focuses on the information architectures, and Shen and Norrie [26] survey the application of agent distributed computing in supporting the mechanism of manufacturing systems.

3. The research approach, findings and discussion

The findings in this paper is based on a review of journal articles that mainly apply ABM in supply chain collaboration. The literature review performed follows two phases: identification of the journal articles, and categorizing the papers by the collaboration issues addressed. SCM involves a wide variety of topics, and this causes difficulties in categorizing the nature of the papers. A readily classification of supply chain collaboration issues was not available in the existing literature. Moreover, each paper uses different terms, such as production planning is used in place of inventory management. Therefore, the papers are classified based on author's own interpretation and judgment on the main information provided in each article.

A summary of previous research on competition and collaboration in SCM is presented in Table 1. The table outlines the scope of application for each research, which are classified into 12 issues: supply chain planning, bullwhip effect, network/supply chain configuration, scheduling, trust, inventory, product development, logistics, supply chain risks, information sharing, supply chain financial aspect, and negotiation. This categorization represents the scope of supply chain problems that is popularly discussed in SCM literature. According to the area of applications, it can be seen that most of these research defines collaboration aspect in supply chains based on the supply chain operations.

Table 1. Previous ABM work in supply chain collaboration.

Author(s)	Scope											
	Plan	Bull	Netw	Sche	Trus	Inve	Pro	Log	Risk	Info	Fina	Neg
[10]		✓				✓						
[11]												✓
[12]											✓	
[13]										✓		
[14]									✓	✓		
[5,15]						✓						
[16]					✓							
[17]	✓	✓				✓						
[18]			✓			✓						
[19]						✓		✓				
[20]			✓			✓						
[21]		✓										
[22]							✓	✓				
[23]						✓						
[24]			✓									
[25]				✓								

Note:

Plan	:	Supply chain planning	Pro	:	Product development
Bull	:	Bullwhip effect	Log	:	Logistics
Netw	:	Network/supply chain configuration	Risk	:	Supply chain risks
Sche	:	Scheduling	Info	:	Information sharing
Trus	:	Trust	Fina	:	Supply chain financial aspect
Inve	:	Inventory	Neg	:	Negotiation

From the literature review, it can be interpreted that ABM approach has been well implemented in SCM studies. However, as shown in Table 1, it is obvious that the number of ABM work in supply chain collaboration is still limited. All of these studies observe a particular single supply chain with a limited attempt to explore the effectiveness of the collaboration approach under supply chain competition. Moreover, the perspective used in the literature still tends to side with one company rather than improving and maintaining the whole supply chain performance for the long-term. Furthermore, most ABM research in SCM is conducted through computer science research, so the works tend to focus on software architecture rather than analyzing a problem of the proposed topic. This indicates that analyzing

collaboration dynamics by using an ABM approach can be a potential SCM research topic in this field. In other words, there is many opportunities to apply ABM in collaboration in supply chains.

Furthermore, ABM has a unique feature to model and observe a problem. ABM employs a bottom-up approach that enables researchers to understand an emergent behavior at macro level by investigating the behavior at the micro level of individual agent. This approach is appropriate to model a phenomenon that is difficult to explain empirically and analytically.

4. Conclusion

The findings of this work provide evidence on the extent use of ABM approach in SCM, particularly in collaboration issues. The nature of use is defined based on the popular topics on supply chain collaboration found in this review, which are classified into 12 issues: supply chain planning, bullwhip effect, network/supply chain configuration, scheduling, trust, inventory, product development, logistics, supply chain risks, information sharing, supply chain financial aspect, and negotiation. The review also offers new ideas and insights about the application of ABM in studying partnerships in supply chains as well as the potential uses of ABM in collaboration issues. A review of ABM approach in supply chain collaboration has never been conducted in the existing literature both in SCM and ABM studies, so this paper is useful to motivate SCM researchers to benefit ABM to enrich the current body of knowledge, in terms of exploring complexity in supply chain partnerships.

This paper employs a literature-based approach to classifying the collaboration aspects modelled using ABM, and it does not consider other factors or criteria in business collaboration. Future work will be performed by taking a more specific scope of supply chain environment, such as partnerships under a competitive market.

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