

MACE-SCM: A multi-agent and case-based reasoning collaboration mechanism for supply chain management under supply and demand uncertainties

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Abstract

The importance of collaboration in the supply chain has led scholars to suggest diverse approaches for problems in the collaboration process. Questions still remain about which method is best when coordinating and sharing information in the presence of various supply and demand uncertainties. Hence, this paper aims to propose an integrated framework based on multi-agent collaboration and case-based reasoning that can resolve various collaboration issues in the supply chain. To show the framework's feasibility, we implemented a prototype system: MACE-SCM. MACE-SCM provides more flexible and extensible solutions to help address emerging uncertainties. The validation results reveal the importance of intensive collaboration for maximum efficiency in the supply chain.

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1. Introduction

Firms today increasingly consider supply chain management (SCM) to be a major vehicle to gain a competitive advantage in turbulent markets. While firms have traditionally acted as sole economic entities in the market, they have begun to form strategic alliances with other firms, integrating their business processes, and consolidating their resources. According to the Global Supply Chain Forum, SCM is defined as

... the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders (Lambert & Cooper, 2000).

The advancement of information technology (IT) has allowed firms that participate in SCM to share information across organizational boundaries, bringing about substantial performance increases. For example, the collection of sales information at the point-of-sale and the sharing of that information via an electronic data interchange (EDI) have lowered costs in the ordering processes.

Supply chain scholars have championed various complementary perspectives in order to resolve problems in collaboration and information sharing, including optimization-, simulation-, and multi-agent-based. Prior research focused primarily on optimization-based techniques and mathematical modeling of operational aspects of information sharing (Maturana & Norrie, 1997). Management Science/Operations Research (MS/OR) researchers have used this approach extensively to identify optimal solutions for given situations subject to specific assumptions. This approach is strong in addressing focused sets of problems, such as inventory management, logistics optimization, and production

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scheduling. Simulation-based approaches allow dynamic modeling of behaviors of supply chain firms with varying degrees of constraints and policies, dealing with diverse contingencies caused by supply and demand uncertainties. However, they cannot generate the design itself, and can only run models with pre-specified parameters and conditions (Harrison, 2001).

Scholars have recently begun to focus on multi-agent-based approaches to address collaboration and information sharing problems (Swaminathan, Smith, & Sadeh, 1998). Supply chain firms are typically modeled as software agents, which pursue their own goals under certain constraints.

Prior research has addressed diverse aspects in the supply chain, but questions still remain concerning the best method of addressing and resolving collaboration and information sharing problems. Traditionally, scholars have focused on the problem domain in which supply and demand uncertainties are low. In this context, the best strategy is to implement “efficient supply chains” (Lee, 2000; Lee, So, & Tang, 2000) by lowering costs. However, a supply chain may experience uncertainty both in a high supply and in a high demand. In high supply uncertainty, the supply chain suffers an evolving supply process in which manufacturing technology is emerging, and the supply base is unstable. The traditional approaches may have limited applicability in this context, because calculating analytical solutions are prohibitive—even impossible—as these uncertainties create increased complexities, resulting in a model that becomes overly complicated (Shapiro, 2001).

The present research asks the following question: *How can multi-agent and case-based reasoning be applied to facilitate collaboration and information sharing in the presence of high supply and demand uncertainties?* We propose a framework based on a combination of multi-agent and case-based reasoning (MACE-SCM). This unique combination provides a model with several advantages. The multi-agent structure allows us to easily model different components in the supply chain. It also provides a flexible structure in handling emerging situations. For example, it can easily reflect on any changes in the agents’ roles or the structure of the supply chain. In addition, CBR mechanisms can be used to model different levels of collaboration; for example, intensive collaboration in which the partners share sensitive marketing information by tracking the history of problems and solutions. We first design three levels of collaboration among the partners: Autonomy, Integration, and Enhanced Integration. At the Autonomy level, the agents do not collaborate at all. At the Enhanced Integration level, the agents collaborate extensively; also, a central coordinator agent, MACE, which is equipped with the case base, provides additional support. We then expose the three to various uncertainties. The uncertainty contingencies considered are: (1) demand uncertainty; (2) supply uncertainties with regard to lead time, production capacity, change in the suppliers, and risk pooling. The validation results using six experiments demonstrate the importance of intensive collaboration for maximum performance.

This paper is organized as follows: (1) briefly review existing literature on supply chain collaboration and information sharing; (2) present the architecture and detailed mechanisms of the model; (3) describe the implementation details and validation results of the prototype system; and (4) conclude with a brief discussion of the model’s implications.

2. Background

2.1. Supply chain collaboration

Dramatic advances in IT have enabled supply chains to integrate various functions into their total processes within e-business settings (Cagliano, Caniato, & Spina, 2003; Vakharia, 2002). In addition, supply chain strategies are reorganized through information integration, flow coordination (Sahin & Robinson, 2003), and inter-organizational cooperation (Sanchez & Perez, 2003). IT allows a greater amount of data to be distributed with increased accuracy and frequency along the supply chains, and for their activities to be synchronized. As a result, the firms in supply chain are able to efficiently coordinate their business decisions and activities and become integrated (Frohlich, 2002; Sahin & Robinson, 2003). A tightly integrated supply chain leads to superior performance and improved competitiveness for each firm in the supply chain (Frohlich, 2002), and many innovative firms have adopted SCM and its integrating mechanisms as a top strategic priority. Supply chain integration is characterized by three dimensions (Lee, 2000; Lee et al., 2000): information integration, coordination, and organizational linkage. Of these, information integration is considered the basis of supply chain integration.

2.2. Related works

Supply chain scholars have taken various complementary perspectives when investigating coordination and information sharing within a supply chain, including optimization-based, simulation-based, and multi-agent-based. Each approach has unique strengths, but also has some limitations when the problem context for collaboration and information sharing adds complexities and contingencies to existing problems.

Optimization-based approaches employ mathematical programming techniques, such as linear and integer, dynamic, and stochastic. MS/OR researchers have used this approach extensively to identify the best possible solutions for given situations, subject to specific assumptions. These approaches are generally applicable to focused problems, such as inventory management, logistics optimization, and production scheduling. However, if the assumptions of optimization-based solutions are not met, the results of these techniques can lead to excess inventories, poor customer service, and higher-than-expected

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