A multi-agent-based novel framework for flexible and tailorable modeling and smart simulation for supply chains

QINGQI LONG *
School of Information, Zhejiang University of Finance & Economics
Hangzhou, Zhejiang, CHINA
longqingqi1116@163.com

SHULIANG LI [a,b]
[a] Westminster Business School, University of Westminster, 35 Marylebone Rd, London, UK
[b] School of Economics & Management, Southwest Jiaotong University, Sichuan, China

ADRIAN HOPGOOD
Sheffield Business School, Sheffield Hallam University, Sheffield, UK
a.hopgood@shu.ac.uk

Abstract: - To achieve competitive advantage in today's global markets, supply chains need to be reconfigured in order to respond to unpredictable changes. Aiming to enable and deliver agile responses and rapid reaction, we propose a multi-agent framework for flexible modeling and simulation of supply chains using reconfigurable production cells. Our novel approach will enable the structural model and the controller model to be considered separately, and enable high quality simulation models to be rapidly built and reconfigured using relevant production cells. To accomplish these capabilities, a four-layered conceptual modeling framework is proposed, which provides an adaptable and tailorable mechanism to support simulation model reconfiguration. In addition, two categories of reconfigurable production cells can be extracted from the bottom layer of the framework to help users to quickly create a conceptual model using functional "building" blocks or templates.

Key-Words: - intelligent software agent; flexible modeling; tailorable models; smart simulation; supply chain; reconfigurable production cells

1 Introduction

One of the major problems faced by enterprises in supply chains is how to provide customers with the fast delivery and the most competitive price as well as how to respond rapidly and cost-effectively to unpredictable changes that take place in today's global markets. To remain competitive, enterprises need to communicate and coordinate their logistics and information flow and even reconfigure their supply chains. The traditional analytical methods are mainly static, relying on mathematical formalizations of supply chains and the obtained models necessitate simplicity and approximations, usually restrictive, and are limited for taking into account of time [5]. Therefore, they have no capability in keeping up with the pace of changes. In order to overcome the weaknesses of the analytical methods, simulation and agent-based simulation in particular [6], has been widely used in supply chain evaluation as a decision-making tool. This has been motivated by the fact that the performance of supply chains is determined by its structure and flow control.

Supply chains have such significant features as hierarchy, dynamics, and rapid reconfiguration with its adaptation to the markets, which is a new challenge for research on agent-based supply chain modeling and calls for a new adaptive simulation modeling approach. However, undeniably, the recent researches about agent-based modeling of supply chains have their deficiencies in hierarchical structure modeling, separation of structure model and controller model, supply chain reconfiguration, and time problem.

In order to deal with the above-mentioned issues, a multi-agent-based framework for adaptable and tailorable modeling and simulation of supply chains through utilising reconfigurable production cells is proposed in this paper. Our approach has the capacity to flexibly model supply chain systems, structure, control logic, and associated logistics and information flow.

*Corresponding author: longqingqi1116@163.com

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2 Related Work

Agent-based modeling and simulation of supply chains has boomed over the past decade and it has become an international hot issue. Swaminathan et al. [8], Bruzzone et al. [2], Labarthe et al. [5], and Jiang et al. [4] have respectively proposed their methodological frameworks for agent-based supply chain modeling and simulation. However, the hierarchy of supply chain structure and associated simulation modeling approach has not been considered adequately.

A flexible approach with a mechanism that captures and represents the structure and the controller of supply chains separately can support reconfigurable modeling to a large extent. However, little of the literature takes into account the structure and controller of supply chains simultaneously. For example, the studies of Zhang et al. [10], van der Zee [9], and Anosike and Zhang [1] note that the structure and controller should be considered simultaneously in supply chain simulation modeling, but they do not explicitly aim to achieve the separation and independency of the two. Moreover, a non-methodological framework for supply chain simulation modeling is established to separate the structure and controller, which offers a great opportunity to study an agent-based simulation modeling approach for supply chains to achieve the separation of structure and controller, and in turn to improve reconfigurability.

A simulation project includes several phases, among which the initial phase, simulation modelling, is the most important, complicated and time-consuming, as demonstrated by Santa-Eulalia et al. [7] and Govindu and Chinnam [3]. Therefore, an approach capable of supporting efficient, rapid and flexible simulation modelling is of great necessity to reduce complexity, time and improve quality of simulation models.

3 The Proposed Approach

3.1 Overview

A multi-agent-based flexible and tailorable simulation modeling approach for supply chains using reconfigurable production cells is shown in Fig.1. Firstly, domain knowledge must be acquired from the real supply chain domain experts and is then stored in a domain knowledge base for the next step. Secondly, on the basis of domain knowledge, a conceptual model with knowledge about the enterprises, their structural relationships, and coordination for logistics and information flow in supply chains is built up. Thirdly, the conceptual model is converted into a conceptual agent model, which is called agentification. Then, in order to be implemented in a simulation platform, the conceptual agent model must be translated into an agent-based simulation model. The most important process in this step is instantiation, including agent instantiation, structural relationship instantiation and control logic instantiation. As the main part of the agent-based simulation modeling process, the simulation model after instantiation still cannot immediately be executed and will need to be integrated into a simulation platform and fit into its simulation environment before execution. Finally, the simulation model is executed as a multi-agent system in the simulation platform and its simulation results are gathered for real-time statistical analysis and visual interaction.

In order to support the modeling process mentioned above, the proposed approach provides modelers with more effective tools including a four-layered conceptual modeling framework and two categories of reconfigurable production cells. This allows modelers to carry out the top-down hierarchical decomposition and bottom-up aggregation to create conceptual models with the consideration of separation of structure and control logic in each layer, which greatly enhances the model reusability and scalability. The reconfigurable production cells, extracted from the bottom layer of the framework, are the finest classes and no longer decomposed. As the basic modules for conceptual modeling, these cells support building conceptual models flexibly and rapidly by using themselves as building blocks or templates. In order to fulfill the conversion from conceptual models to agent-based simulation models, these cells are mapped into cell agents.

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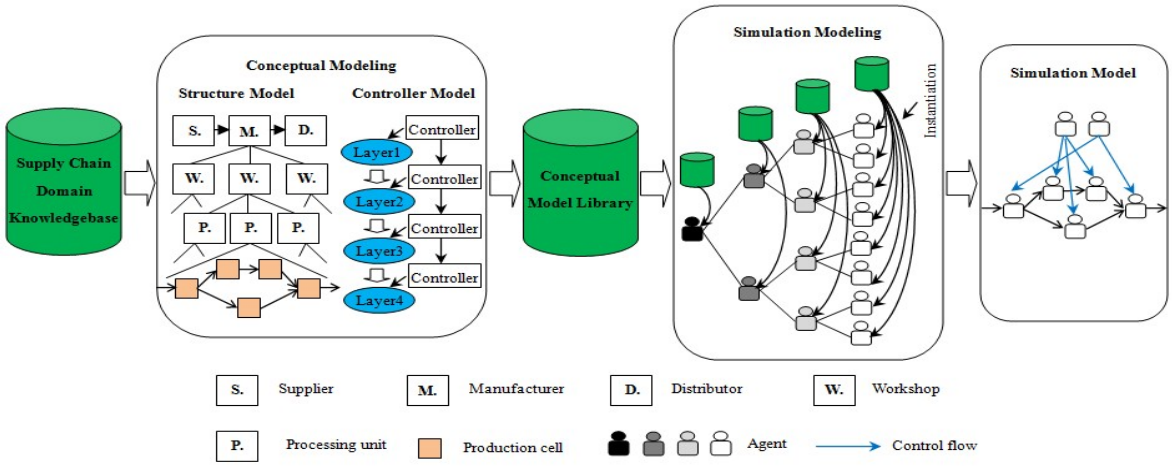

Fig.1 The proposed multiagent framework

3.2 A four-layered conceptual modeling framework

The complex and hierarchical supply chains require simulation modeling approaches not only to meet the requirement for function modeling of supply chains (called validity), but also to take model reconfiguration into account (called flexibility).

According to the requirements of supply chain simulation modeling, a four-layered conceptual modeling framework for supply chain is proposed to back up and realize conceptual modeling on the basis of a domain knowledge base. This framework defines supply chain as four layers, namely the supply chain layer, the enterprise layer, the workshop layer and the processing unit layer. The supply chain layer describes the knowledge which comes from domain knowledgebase, referring to the enterprises, their structural relationships and the coordination for logistics and information flow. The enterprise layer describes knowledge and information of each workshop in the enterprise. The workshop layer has descriptions of the internal process, production line or product structure of the refined model for the enterprise. The processing unit layer includes sub-process segments which are composed of the production cells, such as machine, buffer and so on. The reconfigurable production cells are basic modules for bottom-up conceptual modeling. The model in any upper layer can be decomposed into cell groups and their structural relationships in the bottom layer, while the cells in the bottom layer can be assembled into an aggregation model in any upper layer. Several sub models can compose a larger model.

In order to support high reconfigurability, each layer has two basic components, its structure and its controller. The structure defines the elements and their structural relationships. While the controller is used for presenting logistics and information flow in the supply chain and guides the elements how to make their operations to achieve the function of the layer in the required manner. The tasks and the scheduling policies of the controller in the upper layer are broken down into those of the controller in the lower layer. In particular, the controller in the lowest layer has the largest number of the tasks and their scheduling policies which provide the guides for operations of production cells. Therefore, each layer can be described as an integrated model of its structure and controller, guided by the tasks and their scheduling policies from its controller to achieve its function. The modeling approach with separation of supply chain structure and control logic significantly improves the model reusability, scalability and flexibility.

3.3 Reconfigurable production cells

3.3.1 The reconfigurable production cells

According to the characteristics of the supply chain and the modeling requirements, three kinds of entity cell agents are defined: buffer/inventory agent, machine agent and transport agent.

Machine agent (MA): This agent simulates a certain production process in an actual enterprise. Raw materials are extracted from forward buffers to be further machined into semi-finished products or finished products.

Buffer/inventory agent (BA/IA): The buffer or inventory agent is responsible for storing all kinds of products and responding to machine agent or transport agent for product requirements.

Transport agent (TA): This agent refers to vehicles in logistic transportation or forklifts in a production line. It takes responsibility for delivering raw materials or products from one inventory to another.

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The machine agent and transport agent mentioned above are guided by tasks from controller cell agents: machining task agent and transport task agent to undertake and fulfill their functions in simulations. These two kinds of tasks: machining task and transport task are extracted from customers' orders.

Machining task agent (MTA): The machine task agent provides the machine agent with machining policies.

Transport task agent (TTA): This agent provides the transportation policies for transport agent.

3.3.2 Controller-entity hierarchy

The controller-entity hierarchy task lists are represented by controller cell agents. Entity cell agents must request their controllers for tasks and carry out a series of defined behaviors guided by the tasks leading to emergence of a macro-phenomenon of the supply chain. Therefore, a controller-entity hierarchy is used in this paper, which provides agent simulation capabilities for the infrastructure entities in the supply chain. As shown in Fig.2, this hierarchy is an application-authorization based task scheduling model in charge of the controller cell agents. The controller cell agents provide the whole life-cycle task management to the entity cell agents. In this hierarchy, entity cell agents are active to submit their requests, while the controller cell agents are reactive to respond to these requests. This kind of hierarchy has great advantages: (a) order-driven; (b) matching with characteristics of supply chains; (c) the separation and independency of control policies and infrastructure entities enabling the configurable modeling; (d) flexibility for modifying tasks or policies to support what-if analysis without changing model structure; and (d) beneficial to balance the load of machines and transport tools for obtaining a higher utilization.

Within our framework, agent interaction, communications and functional tailorability across cells and layers can be achieved and implemented using the multi-agent inter-communicating method [11, 12], flow and fit approach [13], and DARBS (Distributed Algorithmic and Rule-based Blackboard System) which has been developed by Hopgood's team as a framework for the collaborative interaction of hybrid agents [14, 15].

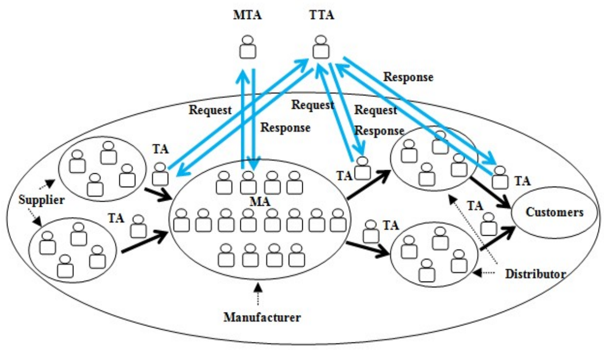

Fig.2 Controller-entity hierarchy

Software toolkits such as Chimera agents [11] can be employed to develop and create a software system for the framework proposed in this paper.

4 Conclusions

The main aim of our project has been to deliver an efficient, flexible and adaptable multi-agent-based simulation modeling approach that would enable supply chains to gain competitive advantages by reconfiguring themselves to respond to customer orders, coordinate the operations of enterprises, and thereby improve awareness and responsiveness to the dynamically changing environments. We have designed a four-layered conceptual modeling framework and two categories of reconfigurable production cells, blocks or templates. This approach can enable enterprises in supply chains to continuously seek ways to coordinate other companies to enhance the performance of whole supply chains and adapt to the changes in the market environments with flexibility and creativity.

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