Multi-agent Based Supply Chain Management with Dynamic Reconfiguration Capability

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Abstract

Supply chain management (SCM) has received increased attention in a globally challenging environment as companies face the necessity to improve customer service and maximize profit. Therefore, dynamic reconfiguration capability is vital for supply chain management to respond to changing customer requirements and operating environments. On the other hand, for its flexible and autonomous characteristics, multi-agent systems are a viable technology for SCM, and have been widely applied in SCM. To this end, dynamic reconfiguration in agent-based SCM systems is proposed from Autonomy Oriented Computing point of view. The performance of agent-based SCM with dynamic reconfiguration is evaluated under a modified TAC SCM scenario. With a dynamic reconfigurable SCM system, new products and processes can be introduced with considerably less expense and ramp-up time.

1 Introduction

Supply chain management (SCM) is becoming more and more important as companies face the necessity to improve customer service and maximize their own profits. There are also multiple challenges in modern supply chain management like customer demand uncertainty and changing market.As a result, it cannot be expected that supply chains preserve their structure over a long horizon because each company or factory may risk loosing its competitiveness or face internal collapse for the changing customer demands and operating environments. Therefore, appropriate mechanisms for supporting reconfigurability should be embedded in supply chain configuration decisions [2].

According to the widely accepted definition of agents [7], agents have the features of autonomy, social ability, reactivity, and pro-activeness. It is identified that components in supply chains, like manufacture, have the same characteristics as agents [1]. Therefore, agent-based systems are well suited to model supply chain management. Actually, multi-agent systems have been widely applied in supply chain management and have attracted much attention from the supply chain management community [1]

More generally, supply chain configuration research has attracted significant attention in scientific literature outside agent community. Chapter 3 in reference [2] provides a detailed review on supply chain configuration. 91 papers dealing with supply chain configuration are listed. Among them, only one paper is using agent-based approaches.

To promote the application of multi-agent technology in modern supply chain management, the Supply Chain Management track of the international Trading Agents Competition (TAC SCM) was introduced in 2003. TAC SCM scenario provides a challenging test-bed for automated trading agents that act in dynamic supply chains[1]. Current trends in TAC SCM research are inclined to develop various supply chain agents with intelligent strategies applied at various stages of the process to reduce cost and improve service levels [5]

In those applications of using multi-agent systems in supply chains, there are no reports on agent-based SCM with support of dynamic reconfiguration. Whereas this is of paramount importance in modern supply management as pointed out in [2]. To this end, we introduce a mechanism for supporting reconfigurability in agent-based SCM.

Furthermore,based on the basic TAC SCM Simulator called AgentWare[2], the design and evaluation of a multi-agent based supply chain management system (called MySCM) with reconfiguration ability is presented in this paper. An emerging computational paradigm called Autonomy Oriented Computing (AOC) [4] is utilized to model the dynamic reconfiguration in agent-based supply chain management. Based on the experimental results, agent-based SCM with dynamic reconfiguration has the following ad-

[1]http://www.sics.se/tac
[2]http://www.sics.se/tac/page.php?id=16

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vantages:

(1)Robustness: The manufacture is able to withstand external and internal shocks such as loss of suppliers because suppliers can be replaced, manufacturing can be switched to alternative facilities. (2)Flexibility: Changing customer requirements can be accommodated by finding less expensive parts suppliers, and introducing modified products. (3)Agility: New business opportunities can be captured by engaging in relationships with innovative supply chain partners.

The rest of the paper is organized as follows. Section 2 briefly outlines MySCM scenario. Section 3 presents the overall architecture of agent-based supply chain management model with reconfiguration ability. Section 4 shows the dynamic reconfiguration model in MySCM. Experiments provided in Section 5. Section 6 concludes this paper.

2 MySCM Scenario

TAC SCM provides an international forum and a benchmark environment to promote and encourage high quality research into SCM problems.

Compared with TAC SCM [3], MySCM scenario includes the following changes:

(1)The number of suppliers as well as their quoted prices is changing dynamically every day in MySCM. While in TAC SCM, both of them are stable. (2)Unstable component supply is allowed. One supplier may close down or cannot supply components in time due to unpredictable problems. (3)Customer requirements are allowed to change in MySCM, which is not permitted in TAC SCM.

In such a MySCM scenario, neither typical static supply chain management models nor the strategies of good players in TAC SCM game are appropriate. In those models and strategies, the dynamic changing situations are not allowed. To tackle such dynamic changes in supply chains, dynamic reconfiguration capability is essential for agent-based SCM systems.

The focus of this paper will be on how to embed the dynamic reconfiguration capability into MySCM, which is discussed in the following two sections.

3 The Architecture of MySCM and Related Definitions

MySCM is composed of three principal modules (Figure 1): the Supply Manager module, the Demand Manager module, and the DR (Dynamic Reconfiguration) Manager module.

The primary tasks of the Supply Manager include:(1)Send RFQs to Component Suppliers; (2)Send orders to one supplier based on the suppliers' replies; (3)Send reconfiguration requests to DR Manager based on the suppliers' operation information.

The Demand Manager deals with all the issues related to customers. The main tasks are:(1)Bid on customers RFQs(Request for Quote); (2)Deliver computers to customers; (3)Send requests to DR Manager when receiving the order change requests from customers.

The DR Manager is the core for supporting dynamic reconfiguration of manufacturing agent. The main tasks of DR Manager include: (1)Receive and organize the registration information of Component Suppliers; (2)Process reconfiguration requests, and determine whether to start a reconfiguration behavior or not; (3)Do some assistant work for reconfiguration (e.g. send acknowledgement message to the Demand Manager or Supply Manager).

In the next section, we will discuss how to model the dynamic reconfiguration in agent-based SCM systems using an emerging computational paradigm–Autonomy Oriented Computing (AOC) [4]. Before we proceed, some definitions related to the dynamic reconfiguration under the modified scenario are given below.

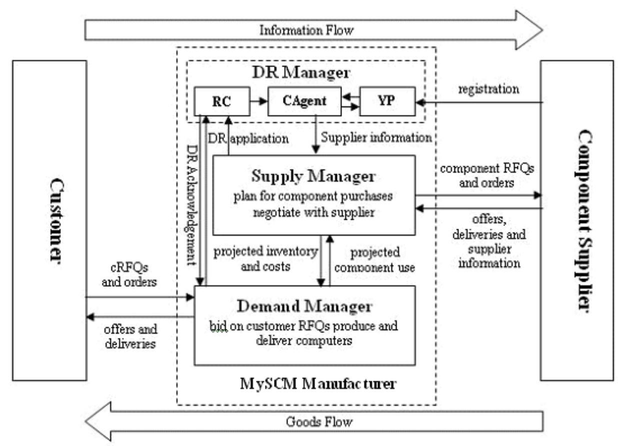

Figure 1. MySCM Architecture

In MySCM, the daily production and supplier price may be slightly different between original suppliers (who have long term relationship with manufacturer) and supplementary suppliers (who do not have long term relationship with manufacturer).The actual production capacity C_d^{ac} for some component on day d is determined by formula (1):

where C_{typ}^{nom} denotes the supplier nominal capacity. For example, if $typ = tacscm$, then $C_{tacscm}^{nom} = 550$ components/day. Otherwise, if $typ = myscm$, then $C_{myscm}^{nom} = 350$ components/day.

Note that $C_d^{ac} = 0$ means one supplier may in an abnormal production status for some unpredictable factor. If the number of zero production days exceed a given threshold δ (e.g. $\delta = 5$ days), the manufacturing agent may start a reconfiguration for its own benefit.

$$C_d^{ac} = \begin{cases} max(0, C_{d-1}^{ac} + random(-0.5, +0.5)C_{typ}^{nom} + 0.01(C_{typ}^{nom} - C_{d-1}^{ac})), & if\ supplier\ is\ normal. \\ 0, & if\ supplier\ is\ abnormal. \end{cases} \quad (1)$$

On any day d, the offer price of some component c that is due on day $d+i+1$ (which must be produced by day $d+i$) is given by formula (2):

$$P_{d,i} = P_{c,typ}^{base}(1 - \delta \frac{C_{d,i}^{avl'}}{iC_d^{ac}}) \quad (2)$$

Where $P_{d,i}$ is the offer price on day d for an RFQ due on day $d+i+1$. δ is the price discount factor. $P_{c,typ}^{base}$ is the baseline price for components of type c and supplier type typ. Generally, the baseline price of supplementary suppliers ($typ = myscm$) is 10% higher than that of original supplier ($typ = tacscm$). C_d^{ac} is the supplier's actual capacity on day d as given in equation (1). $C_{d,i}^{acl'}$ is the same as that defined in reference [3].

Customer demands are expressed as requests for quotes (customer RFQ or cRFQ)(Definition 1).

Definition 1: *cRFQ=*(o, *pt, q, due,* ρ, r, x)

Where o is the ID of order requested to change; pt is the component type that should be changed to (for the specific parameter settings, refer to [3]); q is the changed component quantity; due is the due date of one component. It can be calculated as: $due = d + random(due_{min}, due_{max})$ (where d is the current day); ρ is the reserve price ; r is the additional benefit for the agreement of order changed; and x is the penalty.

The DR Manager can process two kinds of requests– $cDRP$ and $sDRP$. $cDRP$ is from the Demand Manager for customer order change. The semantic expression is given below.

Definition 2: *cDRP=*(d, d_{ord}, *due*, due_{ord})

Where d is the current day; d_{ord} is the ordered day of original order; due is the changed component due date calculated by $due = d + random(due_{min}, due_{max})$; d_{ord} is the due date of components in original order.

The DR Manager uses formula (3) to decide whether to perform reconfiguration.

$$\begin{cases} d - d_{ord} \le \nu \\ due - due_{ord} \ge \sigma \end{cases} \quad (3)$$

Where ν and σ are thresholds of time. ν is the time period from one order been entered to this order been produced by factory. σ is an anticipated value of components delivery. Factories incline to select applications with bigger σ for less risk.

The second type of request is $sDRP$, which is from the Supplier Manager for suppliers reconfiguration. Definition 3 below gives a semantic expression.

Definition 3: *sDRP=*($type$, $delay$, dep_{typ}, con_{typ})

Where $type$ is the component type of the supplier that will be replaced; $delay$ is the number of deferred days of this component; dep_{typ} is the inventory level of this component; and con_{typ} is the mean value of daily consumption of this component.

Generally, the DR Manager uses formula (4) to decide whether to perform reconfiguration:

$$\lfloor \frac{dep_{typ}}{con_{typ}} \rfloor - 2 < delay \quad (4)$$

Note that if $delay = dep_{typ} = con_{typ} = 0$, dynamic reconfiguration will happen immediately because a new type of component is needed.

4 Dynamic Reconfiguration Model in MySCM

The key to embed the dynamic reconfiguration capability in agent-based SCM is to model dynamic reconfiguration in SCM properly. Autonomy Oriented Computing (AOC) can be used to tackle this problem.

AOC is an emerging computational paradigm that draws on the principles of self-organization and complex systems[4]. A formal framework of AOC consists of a population of autonomous entities and the rest of the system referred to as the environment.

Using AOC framework to model dynamic reconfiguration of agent-based systems from manufacturer point of view, we need to clearly describe what are the environment, primitive behaviors and behavioral rules of autonomous entities (here agents), and the interactions between agents and their environment. The dynamic reconfiguration of agent-based systems is then reduced to the self-organization of AOC systems.

Figure 2 shows the dynamic reconfiguration embedded in the DR Manager module of MySCM. In the model, there are five different types of agents: Construct Agent (CAgent), Yellow Page Agent (YP), Reconfiguration Controller Agent (RC), Member Agent (MAgent, representing component suppliers), and Employee Agent (EAgent, representing suppliers selected by manufacturer). CAgent undertakes the task for searching appropriate MAgents. In MySCM, more than one CAgent can be ordered by manufacturing Agent parallel searching and negotiating with suppliers to decide which suppliers are appropriate for the manufacturer.

EAgents are those who carry out tasks. They are the suppliers who have been selected by the manufacturer. YP can perform some basic functions, such as registering MAgents and organizing the registration information. RC monitors and controls the reconfiguration behavior of the whole agent system.

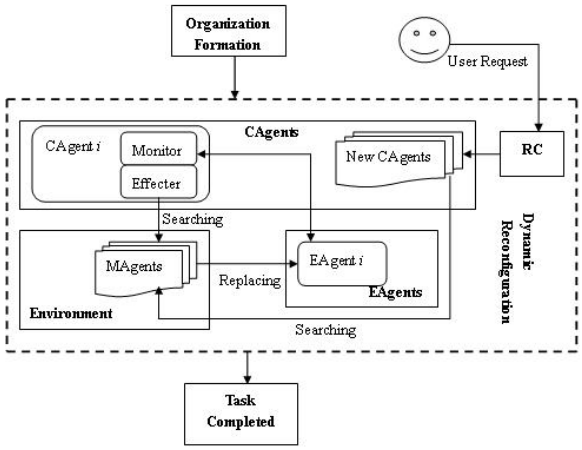

Figure 2. Dynamic Reconfiguration Model in MySCM

Due to the limit of space, the definition of key component CAgent, its primitive behaviors, and logical environment E please refer to reference [6].

5 Experiments and Evaluation

In order to evaluate MySCM model, a competition between MySCM and AgentWare has been conducted. In this experimental competition, suppliers will shut down randomly to simulate the abnormal suppliers in real world, and customers may modify their order randomly. Figure 3 shows the result of this experimental competition (the results are average value after running 10 times). From this figure, we can see that MySCM has less debt than AgentWare. This indicates that dynamic reconfiguration mechanism can provide better support for supply chain management.

6 Conclusions

Supply chains are keeping change in nature, while agent technology is good at supply chain management. Therefore, dynamically reconfiguring agent-based SCM systems is extremely useful for today's economy.

To this end, a framework of agent-based supply chain management with dynamic reconfiguring ability has been

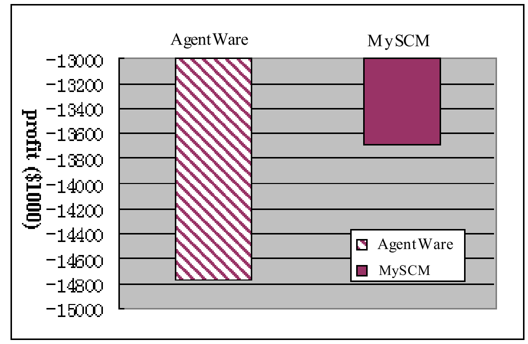

Figure 3. Experimental Competition Results

proposed from AOC point of view. An agent-based SCM system with dynamic reconfiguration capability (MySCM) was implemented and tested. The experimental results show that MySCM has the advantages of robustness, flexibility and agility.

In the future, we will try to improve the performance of agent-based supply chain reconfiguration systems from other perspectives other than manufacturer's point of view.

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