Supply Chain Optimization Through Cooperative Negotiation by Using Backward Scheduling

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Abstract. In recent years, mass customization is an important issue in manufacturing industries. They may require a make-to-order (MTO) manufacturing system throughout the whole supply chain. Our previous researches proposed a basic three-layered supply chain model for dynamic configuration of supply chains including an MTO manufacturing system. The model consists of three model components named a client, a manufacturer, and a supplier. A negotiation process among the model components were proposed in order to enter into a lot of contracts. This paper presents a cooperative negation method between a manufacturer and a supplier. The objective is to provide a negotiation method for entering into a large amount of contracts with a client. A manufacturer adjusts the requirement of part order for a supplier by reallocating manufacturing operations backwards from the delivery time required by a client. We developed a prototype of simulation system for a three-layered supply chain. We carried out large number of computational experiments by changing experimental conditions and verified the effectiveness of the proposed negotiation method.

Keywords: Supply Chain Configuration, Make-to-Order (MTO) Manufacturing, Job-shop Scheduling, Backward Scheduling, Cooperative Negation.

1 Introduction

Mass customization is attracting the attention of manufacturing industries, since customers need various products. Conversion from an MTS (make-to-stock) manufacturing system to an MTO (make-to-order) manufacturing system is required for not only a single company but also a group of companies in a supply chain. Recent advantages in Internet technology have enabled a dynamic configuration of supply chains [1]. Independent but cooperative relationships between manufacturing companies can make large profits in the supply network.

We developed a dynamic supply chain model including an MTO manufacturing system [2, 3]. Without a specific leader such as an automobile final assembly company, all the companies in a supply chain should be cooperatively negotiated with each other in order for all the companies to obtain a large profit. The companies in a supply chain repeatedly send orders and offers to determine a suitable price and delivery time of the products which customers need.

Our previous researches proposed a negotiation method among the three model components. In this research, we improve the negotiation method between a supplier and a manufacturer in the supply chain model to obtain a large profit by entering into a lot of contracts. A manufacturer adjusts the required delivery time of parts by estimating a lower bound of the earliest starting time of manufacturing operations in the manufacturer's production schedule through backward scheduling.

2 Literature Review

Most of the existing researches about supply chain management deal with an MTS manufacturing system. In recent years, the supply chain models including an MTO manufacturing system are proposed by some researches, such as Robinson et al. [4], Sahin and Robinson [5], Li et al. [6], Aboolian et al. [7]. The MTO supply chain models proposed dynamic scheduling procedures. Decentralized negotiation processes control the entire supply chain without a specific leader company. A competitive negotiation approach such as a game theory is proposed to divide profits accurately in the supply chain. A cooperative negotiation approach should be considered not only to divide profits but also to increase profits for the entire supply chain.

3 Dynamic Supply Chain Model

3.1 Basic Model Components

In general, there are a large number of manufacturing companies in a supply network as shown in Fig. 1. Dynamic configuration of supply chains is considered for each order to create appropriate supply chains. Manufacturing companies, including MTO manufacturing systems, send and receive orders and offers of parts and products for entering into profitable contracts. Most companies in the supply network receive orders from lower-tier companies and create orders to higher-tier companies. On the other hand, the companies receive offers from higher-tier companies and make offers to lower-tier companies.

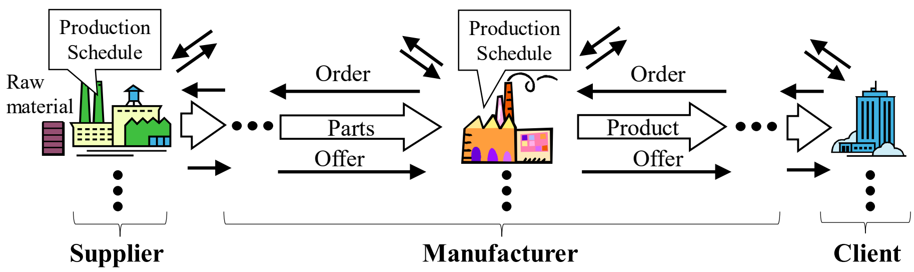

Fig. 1. A supply network includes a large number of manufacturing companies. Dynamic configuration of supply chains is considered for each order to create appropriate supply chains.

Our previous researches propose a basic dynamic supply chain model which consists three model components, those are a client, a manufacturer, and a supplier, as shown in Fig. 2. A client represents a customer which generates an order of a product. The order includes the information about the required delivery time and price of the product. It is sent to manufacturers. A manufacturer is a manufacturing company which machines and assemblies some parts to make a product. An order of a part is created based on the manufacturer's production schedule and the received order from a client. A supplier is a part manufacturing company which produce parts based on both its production schedule and the received orders from Manufactures.

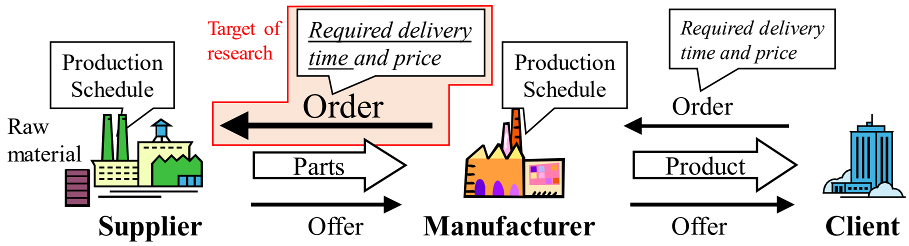

Fig. 2. A three-layered dynamic supply chain model consists of three kinds of model components which are a client, a manufacturer, and a client as a basic model.

3.2 Previous Negotiation Process among Model Components

A client can enter into a contract with a manufacturer, when an offer sent from the manufacturer is satisfied with an order from the client. The offered price of a product is equal to or less than the required one. In addition, the offered delivery time of a product is equal to or shorter than the required one. When the client accepts the offer from the manufacturer, the Manufacture can also enter into a contract with the supplier. The manufacturer accepts the offer sent from the supplier. Both the Manufacture and the supplier make a profit by the contract.

The supplier can reject an order from the manufacturer, if the supplier evaluates that the order cannot be profitable. The supplier should pay a penalty charge for delays in the delivery time. The manufacturer permits a delay of a part but requires a penalty charge for the delay. If the required delivery time suggested from the manufacturer is too early for all suppliers, no offer from the suppliers can be received by the manufacturer. In this case, the manufacturer cannot generate an offer to the client, and loses the chance of a contract. The manufacturer and client need to determine the required delivery times of parts and products respectively in consideration of their production schedules accurately, and suggest the penalty charge due to delays.

The manufacture estimates a feasible delivery time when the supplier can generate and deliver a part to the manufacturer. The estimated feasible delivery time *dt* of a part is used as the required delivery time which sent to the supplier. Furthermore, the manufacturer uses the estimated feasible delivery time as the earliest starting time *est* of a product for optimizing the manufacturer's production schedule. No manufacturing operations of a product can be allocated before the earliest starting time in the production schedule. Our previous researches proposed the following equation for determining the feasible delivery time by using the sum of the estimated processing times *spt* of parts in the supplier. The parameter *T* means a present time. A coefficient value α represents the margin of delivery time.

$$dt_n = T + \alpha \times \sum_{j=1}^{J} spt_{n,j} \leq est_n \tag{1}$$

The appropriate delivery time of a part should be determined and required as an order by the manufacturer to the supplier in order to enter into a lot of contracts in the supply chain. If the manufacturer specifies an early delivery time to the supplier, the supplier loses enough time to manufacture a part and it is difficult for the manufacturer to receive a beneficial offer from the supplier. On the other hand, in case where the supplier receives a late delivery time required from the manufacturer, the manufacturer cannot generate an acceptable offer for the client. However, it is difficult for the manufacturer to accurately estimate processing times of parts and to get information about a production schedule of the supplier, since they are different companies.

3.3 Adjustment of the Required Delivery Time

This research proposes a negotiation method for creating a profitable order from a manufacturer to a supplier. The order includes a delivery time suitable for both a manufacturer and a supplier in order to enter into a lot of contracts and improve the profits of the whole supply chain.

A manufacturer tightens or relaxes the required delivery time of a part to the lower bound in its production schedule, after the production schedule is optimized through the scheduling process. The adjustment process of the required delivery time is summarized as follows.

1. When a manufacturer receives a new order of a product from a client, the manufacturer estimates an earliest starting time of the product based on Eq. 1 and makes a production schedule by using a genetic algorithm. All manufacturing operations of the product are assigned after the earliest starting time in the production schedule.
2. The manufacturing operations in the production schedule are reallocated backwards from the delivery time required by the client. When the latest finishing time of the product is later than the delivery time required by the client, the manufacturer moves the manufacturing operations forward and tightens the required delivery time of a part, as shown in Fig. 3. On the other hand, the latest finishing time of the product is earlier than the delivery time required by the client, the manufacturer moves the manufacturing operations backwards without changing the loading sequences of the manufacturing operations in the production schedule. Then, the required delivery time of a part are relaxed from the initial condition.
3. The earliest starting time is modified and estimated by the reallocated manufacturing operations. Then, it represents a new value of the required delivery time sent by the manufacturer to the supplier.

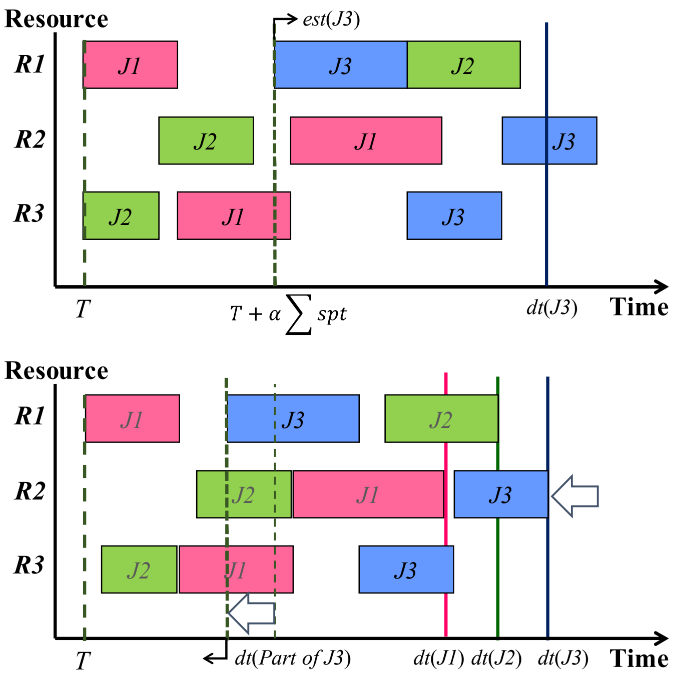

Fig. 3. A manufacturer's production schedule contains three jobs consisting of three manufacturing operations. After the schedule of the third job *J*3 is optimized, the manufacturing operations of *J*3 are moved forward from the delivery time required by the client.

When the delivery time required by the client is early, the manufacturer requires the supplier to deliver a part early. The supplier makes an effort to the requirement by improving its production schedule, and creates a beneficial offer for entering into a contract with the manufacturer. On the other hand, when the delivery time required by the client is late, the required delivery time of a part is relaxed by the manufacturer compared to the initial condition. The supplier can reduce the penalty charge for delay, and gain a profit. The manufacturer can receive a beneficial offer from the supplier, and enter into a lot of contracts with the client.

4 Computational Experiments

4.1 Development of a Supply Chain Simulation System

We developed a prototype of a supply chain simulation system by using an object-oriented language Smalltalk. The prototype system was implemented on a Windows-based personal computer having a 3.16GHz Intel Core2 processor with 2GB of RAM. Three model components, which were a supplier, a manufacturer, and a client, were described in the simulation system.

In the initial conditions, a manufacturer had a job-shop type production schedule consisting of 10 manufacturing resources, 20 jobs, and 200 manufacturing operations. A supplier had a job-shop type production schedule consisting of 5 manufacturing resources, 20 jobs, and 100 manufacturing operations. A client continuously gives 50 new orders to a manufacturer. The negotiation processes are repeated among the three components until the offers from a manufacturer are accepted by a client for the orders or a client cancels the orders.

4.2 Comparison of Experimental Results

We carried out computational experiments by using the previous negotiation method and the new one in order to compare the experimental results. A large number of experiments were carried out by changing experimental conditions to show the effectiveness of the new method. We changed a coefficient value α in Eq. 1 from 2 to 20 in 2 increments. Then, we changed the margin of feasible delivery time which a manufacturer estimated in the experiments. Furthermore, we changed the margin of required delivery time which a client determined by using the following equation. A coefficient value β in Eq. 2 was changed from 2 to 6. The processing times *mpt* of a product *n* are estimated by a manufacturer.

$$T + \beta \times \sum_{j=1}^{J} mpt_{n,j} \tag{2}$$

Experimental results of the previous negotiation method are summarized in a bar chart as shown in Fig. 4. The variation of α is arranged in the horizontal direction, and the variation of β is arranged in the depth direction. The vertical axis represents the average number of contracts which are additionally accepted by a client. Each bar shows the average number of contracts obtained by 10 experiments under each condition. The experimental results show that the number of contracts decrease as the coefficient value α increases especially when the coefficient value β is small. For example, most of the orders from the client cannot enter into contracts on the condition that α is about 20 and β is about 2. The reason is that the manufacturer has relaxed the requirements for delivery times of parts to the supplier, even though the client has shortened the required delivery times of products to the manufacturer. These results mean that the profit in the whole supply chain decreases when a manufacturer estimates the longer margin of processing times of a supplier.

Figure 5 summarizes experimental results of the newly proposed negotiation method. The average number of additional contracts through 10 times of experiments under each condition is represented on the vertical axis. The experimental results show that both the manufacturer and the supplier can enter into a lot of contracts independent of the variation of the coefficient value α. For example, even if the value α is about 20, many orders from the client can enter into contracts. These results mean that the profit in the whole supply chain is stable even if a manufacturer estimates the longer or shorter margin of processing times of a supplier without considering the processing times accurately. A manufacturer does not need to know the exact processing times of suppliers. This negotiation method can be one of the useful approach for operating an MTO decentralized supply chain which each company in the supply network can make decisions independently under the limited information sharing.

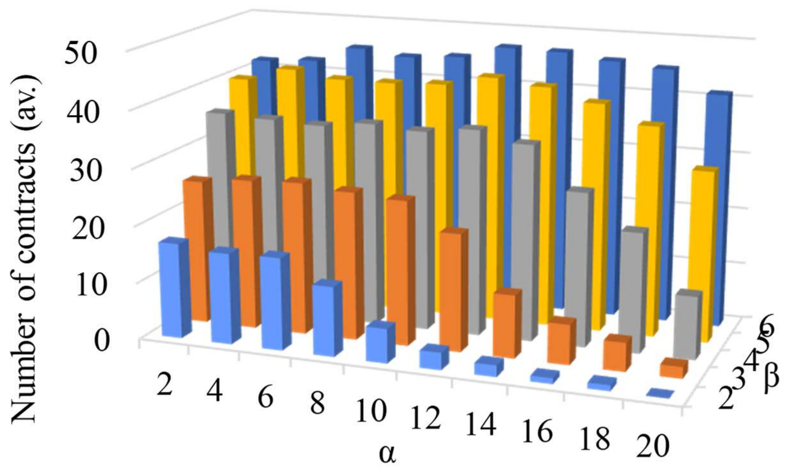

Fig. 4. This bar chart summarizes experimental results by using the previous negotiation method which determines the required delivery time of parts based on the sum of the estimated processing time of a supplier by a manufacturer.

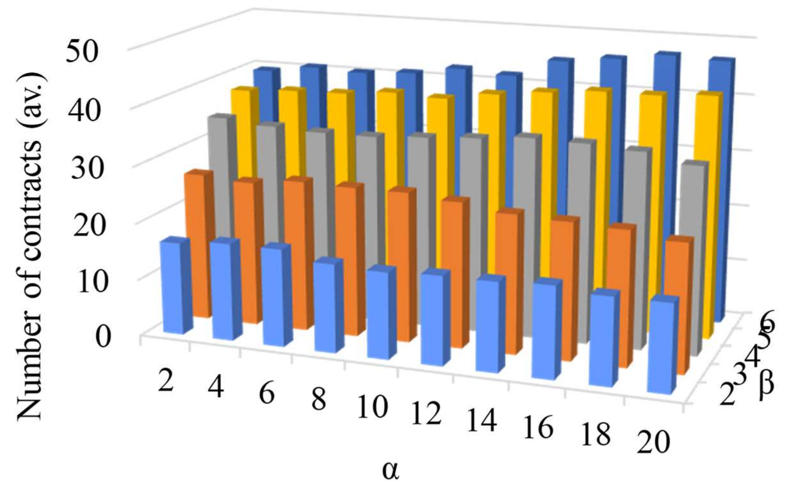

Fig. 5. This bar chart shows experimental results by using the proposed negotiation method which determines the required delivery time of a part by reallocating manufacturing operations backwards in the manufacturer's schedule from the required delivery time by the client.

5 Conclusion

This research proposed a cooperative negotiation method between a supplier and a manufacturer. A manufacturer adjusts the required delivery time of a part by reallocating manufacturing operations backwards in a manufacturer's production schedule from the delivery time required by the client. Experimental results showed that the supply chain can enter into a lot of contracts under the limited information sharing.

In future work, we will investigate what strategic companies can continue to make profits and survive in the supply network. We will compare the proposed cooperative method to the other non-cooperative methods by computer experiments to verify their effectiveness in the supply network. The relaxation process of the proposed method can be further improved, as the experiments have shown that the number of contracts can increase if there is sufficient time to deliver the product required by the client. The cooperative negotiation method for MTO manufacturing systems may be extended to advanced negotiation methods that consider both MTO and MTS manufacturing systems at the same time.

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