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Dynamic coalition reformation for adaptive demand and capacity sharing

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ABSTRACT

To deal with volatile product demand and rapidly changing manufacturing technologies for sustainable returns, selective collaboration among companies in supply networks (SNs) is required. Recently, demand and capacity sharing among independent and non-competitive manufacturers, at the same horizontal layer in SNs, has been studied. Through an appropriate coalition for collaborative demand and capacity sharing, manufacturers can minimize their lost sales, as well as maximize production capacity utilization against lumpy real demand. In a previous study, we have developed the Collaborative Demand and Capacity Sharing (CDCS) protocol which addresses a long-term profitable and well-balanced collaboration for each manufacturer through distributed decision making. However, the uncertainty of circumstances calls for an effective and timely reformation of coalitions. In reality, there is a trade-off between frequent accommodation to changeable environments and high additional costs incurred by reformation. Hence, in this paper, we design the Adaptive CDCS protocol based on dynamic contract mechanism. In each period, our protocol suggests whether to reform existing coalitions or not based on theoretical analyses of long-term expected net profit. To evaluate its performance, a numerical experiment is conducted by comparing three models: no collaboration, static collaboration, and dynamic collaboration by Adaptive CDCS protocol. Dynamic collaboration results in more profits and its balanced redistribution by accommodating with changeable conditions.

1. Introduction

Due to the increased importance of sustainability issues, business managers have been under pressure to deliver sustainable supply networks (SNs) to foster effective sustainable planning and control (Cairns Jr., 2004; Diesendorf, 2000; Gagnon et al., 2009; Jiao, 2009; Sustainability, 2002; Willis, 2010). In such a situation, intelligent information sharing and collaboration among participants have been proposed as promising solutions (Seok and Nof, 2011, 2012, accepted for publication; Seok et al., 2012). A lot of research has been done in this field, but most of the works have only focused on the cases of internal and external vertical collaboration (Barratt, 2004; Renna and Argoneto, 2010a; Qianhan et al., 2010). Hence, a specific case of the external horizontal collaboration has been proposed—demand and capacity sharing among independent and self-interested manufacturers at the same horizontal layer of SNs (Seok and Nof, 2012, accepted for publication; Yoon and Nof, 2010). The meaning of "independent" is that each manufacturer has his/her own customer demand and production capacity; hence, he/she produces and delivers products himself/herself, i.e., there is no collaboration with other manufacturers. The meaning of "self-interested" is that each manufacturer only considers his/her own profit, i.e., they are not interested in maximizing global profit even if they are collaborating with others. Additionally, assume that manufacturers are not competitors; even though they produce similar or same types of products, they serve different markets/industries. Demand and capacity sharing has been frequently studied to enhance companies' competiveness by increasing their sustainability, augment customer satisfaction by minimizing lost sales, and to increase facility utilization by reducing idle capacity (Ip et al., 2000; Mazzola and Neebe, 1999; Roux et al., 1999; Vercellis, 1999). Demand and capacity sharing has been conducted in various industries such as semiconductor manufacturing, transportation industry, and food production industry (Chen et al., 2008). However, most of previous work has focused on the capacity sharing within an internal company and has missed the sustainability of this collaboration; they have only considered a short-term collaboration, and have not considered the necessity of balanced rewards. Hence, we have developed the Collaborative Demand and Capacity Sharing (CDCS) protocol to design effective collaborative coalitions, especially focusing on long-term benefits with considering collaboration costs and balanced distribution of profits among independent and self-interested companies (Seok

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and Nof, accepted for publication). The CDCS protocol aids each manufacturer individually, through the distributed interactions, to determine whether and with whom to effectively collaborate in order to increase long-term profits.

However, CDCS protocol has been designed to manage the collaboration when manufacturers' demand characteristics, e.g., mean and standard deviation of demand, are not changed. In reality, most of factors such as demand characteristics, price of products, and manufacturing cost can be changed over time, depending on both internal and external conditions. Hence, an appropriate and timely reformation of collaborative coalitions (partnerships) is critical to maintain a high level of effectiveness in collaboration. In general, coalition reformation entails an additional cost such as setup cost and compensation cost. Most of previous research about capacity sharing problem has not considered these costs (Roux et al., 1999; Vercellis, 1999; Tonshoff et al., 2000). They have only proposed decision models for a short-term collaboration without considering additional costs; in one model, coalitions are changed every period based on the demand at that time, but additional cost is not taken into consideration. In reality, such an unrealistic coalition/partnership reformation can harm the sustainability of collaboration in a long-term aspect, and make a negative profit by excessive reformation.

Hence, in this paper, we extend the CDCS protocol to reform a coalition in order to accommodate to environment changes over periods, but in a cost-effective way—we call this new advanced decision protocol the Adaptive CDCS protocol. This helps each manufacturer to make an appropriate decision on whether to join/leave/remain in existing coalitions, based on theoretical analysis of a trade-off between frequent coalition reformation and high collaboration/compensation cost. Specifically, each manufacturer can reselect sustainable and profitable partners over time based on updated condition. As a result, manufacturers can continuously reduce their lost sales and idle capacities, and increase their own profit under external changes by this appropriate demand and capacity sharing.

We discuss the background of the proposed solution in Section 2, and describe the mechanism of collaboration in our case and detail procedure of the Adaptive CDCS protocol in Section 3. After empirically demonstrating the performance of the Adaptive CDCS protocol in Section 4, we discuss the conclusion and necessary future work in Section 5.

2. Background

2.1. Capacity sharing problem

Researchers have discussed the collaboration by information sharing in SNs for sustainability improvement (Darmanata et al., 2010; Walton et al., 1998). Focusing only on improving manufacturing and management systems within internal company is no longer sufficient. In order to achieve higher sustainability in the long term, companies must try to coordinate proactively not only with their customers and suppliers, but also with other companies at the same level of network (Carter and Rogers, 2008; Walton et al., 1998). A lot research has been conducted with various perspectives of general supply chain collaboration (Aviv, 2007; Nyaga et al., 2010; Ramanathan and Gunasekaran, in press). In relation to this issue, our previous research has mainly focused on demand and capacity sharing problem in SNs (Seok and Nof, accepted for publication).

Master production planning and capacity allocation problems of multiple factories have been extensively studied in previous work; various methods have been developed, using binary linear programming, Lagrangian relaxation, genetic algorithm, and so on (Ip et al., 2000; Mazzola and Neebe, 1999; Roux et al., 1999; Vercellis, 1999). However, most of the research has considered capacity sharing within internal company; therefore, they used a centralized decision model under the assumption of complete cooperation. This is not applicable in case of collaboration among independent and self-interested companies.

Therefore, a decentralized/distributed decision making has been introduced and applied for the collaboration among independent companies. Tonshoff et al. (2000) have designed a type of conceptual decentralized decision model including a mediator which helps the coordination between task and resource owners by negotiation service (Tonshoff et al., 2000). In other research, a distributed decision model consisting of demand sharing protocol and capacity sharing protocol has been implemented for effective collaboration among multiple plants (Yoon and Nof, 2010). They have introduced the concept of reserved sharing capacity for partial collaboration, and developed the decision protocol that suggests an appropriate level of reserved capacity based on a theoretical model. As a result, this decision protocol achieves an increase of the demand fulfilment rate and total global profit. However, such previous works have two limitations related to sustainability aspects: (1) A real-time decision is made without considering excessive costs incurred from frequent change of partners; and (2) A well-balanced distribution of returning profits to participants has not been considered. The first limitation occurs because only short-term collaborations, in which partners are changed in every period depending on the actual demand at that time, has been considered. It can be acceptable only in case collaboration/communication costs are enough small to be ignored; however, this condition is unusual in reality. On the other hand, the second limitation can harm the reliability of collaboration in the long term because unbalanced distribution of profits can cause participants' complaints, and bring the collapse of their partnership. Several studies have considered the way of addressing balanced rewards. Chen et al. (2008) have modeled a price negotiation between two factories by using a constraint programming-based genetic algorithm. The mutual negotiation has been processed through a mediator, and profit distribution depending on various outsourcing costs has been analyzed and compared to that of centralized decision model. On the other hand, a game-theoretic approach to develop distributed cooperation mechanism has been used (Renna and Argoneto, 2010b, 2011; Argoneto et al., 2006); they used Nash bargaining to reduce the productive disequilibrium for all participants in a collaborative network. However, these are applicable for the collaboration between two participants only, and consider short-term profit only.

2.2. Adaptive coalition reformation

Hence, under the consideration of long-term aspects to avoid unnecessary collaboration/communication costs, and fair redistribution of profits among multiple participants, we have developed the Collaborative Demand and Capacity Sharing (CDCS) protocol (Seok and Nof, accepted for publication). This provides appropriate coalitions of multiple manufacturers, through a distributed negotiation process among them. In this paper, we extend the CDCS protocol to adapt to changeable environments by appropriate coalition reformation. Rational companies have to be able to timely form/reform a beneficial coalition in open, distributed, and heterogeneous environment (Arnold and Schwalbe, 2002; Klusch and Gerber, 2006). To the best of our knowledge, research theoretically dealing with coalition reformation in such a dynamic context has not been sufficiently conducted. Even though Yoon and Nof (2011) have developed affiliation/dissociation protocols for capacity sharing, they have not considered a dynamic condition and a long-term aspect. Also, the benefit of only individual enterprise or only collaborative coalition is considered depending