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Collaborative Agent Based Supply Chain Planning for Functional Product Markets

Hosang Jung[1‡] · Bongju Jeong[2] · Chi-Guhn Lee[3]

[1]Grado Department of Industrial and Systems Engineering, Virginia Tech, Blacksburg, VA 24061, USA
[2]Department of Information and Industrial Engineering, Yonsei University, Seoul, 120-749, Korea
[3]Department of Mechanical and Industrial Engineering, University of Toronto, Ontario M5S3G8, Canada

기능성 제품시장을 위한 협업 에이전트 기반 공급사슬계획

정호상[1] · 정봉주[2] · 이치근[3]

[1]Virginia Tech 산업시스템공학과 / [2]연세대학교 정보산업공학과 / [3]University of Toronto 기계산업공학과

We propose a new supply chain planning methodology for both a manufacturer and a distributor in order to find a global supply chain plan for functional product markets. Functional products as opposed to innovative products include the staples that people buy regularly from their nearby places to satisfy basic needs. In the functional product market, the distributor has an initiative of supply chain control and planning with a freedom to request any profit maximizing order quantities until the manufacturer refuses, whereas the manufacturer may not provide more than requested. In this paper, two independent agents on behalf of the manufacturer and the distributor are introduced, and supply chain planning can be conducted by collaboration between them. In addition, mathematical models and a numerical example are presented to show the possibility of the proposed methodology.

Keywords: supply chain planning, collaborative agents, functional product markets, supply chain management

1. Introduction

With the vast distribution network directly related to the customer contacting, distributors constantly enhance their ability from solely a distribution task to the coordination of a whole supply chain. According to Andersen Consulting Co.(Gattorna, 1998), many distributors will be changed into more powerful supply chain coordinators in the near future.

Such a situation is often encountered with functional products, as opposed to innovative products that are supplied by many sellers. Functional products include the staples that people buy regularly from their nearby places to satisfy basic needs. They show stable, predictable demand and long life cycles. Their stability invites competition, which often leads to low profit margins and little room for sellers to negotiate around, especially in terms of price, i.e., the price of functional products is

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‡ Corresponding author : Dr. Hosang Jung, VA 24060 Grando Department of Industrial and systems Engineering, Virginia Tech, Blaksburg, USA, Fax : +1-540-231-3322, E-mail : hsjung@vt.edu
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set by the market(Fisher, 1997). The only option for sellers is either meeting the whole demand at the given price or rejecting the part or the whole demand.

Although, there has been a large body of research on the supply chain planning in various contexts(Kim and Lee, 2000; Kang *et al.*, 2004), supply chain planning for functional product markets has not caught much attention from the research community. Most studies focus on the integrated functions of a supply chain, especially for production and distribution(Thomas and Griffin, 1996; Vidal and Goetschalckx, 1997; Erenguc *et al.*, 1999; Barbarosoglu and Ozgur, 1999; Sarimento and Nagi, 1999; Dhaenens-Flipo and Finke, 2001; Jayaraman and Pirkul, 2001; Park, 2005). Moreover, they assume rather complete sharing of information between departments or entities in a supply chain. This usually gives rise to a centralized optimization problem where a single decision maker has the full authority to operate the whole supply chain, which might not be perfectly realistic.

Decentralized models and approaches for supply chain planning problems have been raised by some researchers, and most of their papers are based on two different approaches, such as mathematical decomposition methods(Barbarosoglu and Ozgur, 1999) and auction theoretic methods(Ertogral and Wu, 2000). Their research, however, assumes the presence of an extra coordinator with complete control over the whole supply chain.

In this paper, we propose a new supply chain planning methodology considering the functional product market, and we also introduce two collaborative agents that represent the manufacturer and the distributor respectively. By collaboration between agents, a global supply chain plan is generated. In addition, the proposed supply chain planning methodology attempts to address the limitations of past research in that 1) both the manufacturer and the distributor reveal only minimum information regarding their own private business between each other; and 2) the supply chain planning procedure converges to a feasible supply chain plan without the extra coordinator.

The rest of this paper is organized as follows. Section 2 introduces our supply chain planning problem by focusing on the functional product market. Section 3 presents the proposed supply chain planning methodology with two collaborative agents. Section 4 gives the numerical example for demonstrating the possibility of the proposed methodology. Finally, Section 5 summarizes conclusions and future research directions.

2. Supply Chain Planning Problem for the Functional Product Market

As mentioned in the previous section, the distributor leads the supply chain planning procedure by setting the order quantities for each production facility of the manufacturer over a given planning horizon. The manufacturer passively reacts to the request of the distributor by committing to meet either the full or the partial orders. Large wholesalers can forecast the demand of functional products, and decide the proper order quantity that will be fulfilled by the manufacturer. The order quantity is the results of profit maximizing efforts of the distributor with consideration of transportation costs, inventory carrying costs, inventory holding capacity at distribution centers, size of markets, sale price of products in each market, wholesale price of products from each of the production facilities, etc. Once the order quantity is submitted, the manufacturer has to decide how much of the order quantity should be satisfied in order to maximize the profit. The manufacturer just reacts to the request of the distributor passively by supplying the requested products since the distributor initiates the overall supply chain planning as a planning leader. Thus, sometimes the manufacturer may supply less than requested due to production shortage, but may not do more.

The profit-maximizing manufacturer should consider product specific production costs, inventory capacity, production capacity at different production facilities, and inventory carrying costs. These costs vary at different locations and change over time.

Throughout the supply chain planning procedure led by the distributor, neither the distributor nor the manufacturer wants to reveal their private information such as cost and capacity related information. The distributor simply submits order quantities, and the manufacturer meets the requested demand to the extent that it maximizes the profit.

Also, the following assumptions are employed in our supply chain planning problem.

- Products are delivered to markets via only distribution centers without direct shipping from production facilities to markets.

- The profit of the supply chain occurs when the product is transferred from the distribution center to the market.
- The sales price of the distributor and the wholesale price of the manufacturer are assumed to be set by negotiation between the manufacturer and the distributor initially, and can be adjusted periodically. Also, the price discount per the size of the order quantity is not considered.
- Production lead time and transportation time between locations are negligible due to the long or mid time bucket characteristics. A basic time unit can be a week or a month.
- The proposed mathematical models are based on the linear programming and its properties(e.g., continuous variable, etc.).

3. Collaborative Agent Based Supply Chain Planning

Two collaborative agents are introduced for the proposed supply chain planning procedure. On behalf of the distributor, a distribution agent (DA) generates a distribution plan for multiple products over a given planning horizon that maximizes the profit of the distributor, whereas a production agent (PA) generates a production plan, in response to order quantities submitted by DA, for multiple production facilities that produce multiple products over the given planning horizon in order to maximize the profit of the manufacturer.

The basic supply chain planning procedure with two agents can be summarized as follows:

Step 1: The order quantity is determined from DA as a result of distribution planning for multiple products over a given planning horizon.

Step 2: DA submits the determined order quantity to PA.

Step 3: PA generates a production plan for the given order quantity to maximize the profit of the manufacturer, and calculates any shortage amounts of each product from each production facility over a given planning horizon.

Step 4: PA submits the shortage quantity against the order quantity to DA.

Step 5: The supply chain planning procedure is terminated, if there is no shortage reported by PA. The detailed analysis regarding the termination of the procedure will be presented in Theorem 1 of Section 3.4. Otherwise, DA regenerates a distribution plan so that the order quantity of each product at each production facility does not exceed the committed supply quantity of the product at each production facility. DA resubmits the new order quantity from the distribution plan to PA and then returns to Step 3.

Before proceeding to a local planning model of each agent, we investigate the centralized supply chain planning(CSCP) model. The CSCP model assumes that all the necessary information can be collected from overall supply chain and processed freely in the central joint planning department between the manufacturer and the distributor. Unless the whole production network and the distribution network are controlled by a single owner, all the necessary information may not be available to a supply chain planner. To formulate the model, the following parameters and decision variables are required:

Parameters

F: Set of production facilities

D: Set of distribution centers

M: Set of markets

N: Set of all locations(i.e., $N = D \cup F \cup M$)

P: Set of products

T: Set of time periods

D_{kmt}: demand for product k in market m in period t

p_{kmt}: distributor's sales price per one unit of product k sold in market m in period t

w_{kft}: wholesale price of product k manufactured at produc- tion facility f in period t

r_{kft}: unit production cost of product k at production facility f in period t

T_{kijt}: cost of transporting one unit of product k from location i to location j in period t

h_{kft}: unit inventory carrying cost of product k in production facility f in period t

$\hat{h}_{kdt}$: unit inventory carrying cost of product k in distribution center d in period t

H_{ft}: inventory capacity in production facility f in period t

$\hat{H}_{dt}$: inventory capacity in distribution center d in period t

C_{ft}: production capacity in production facility f in period t

c_{kf}: production capacity required to produce one unit of product k in production facility f

v_k: storage space required for one unit of product k

Variables

x_{kft}: production volume of product k at production facility f in period t

y_{kijt}: transportation volume of product k from location i to location j in period t

I_{kft}: inventory level of product k in production facility f in period t

$\hat{I}_{kdt}$: inventory level of product k in distribution center d in period t

Now, the CSCP model is given as follows:

$$\text{Max} \sum_{k\in P,t\in T,m\in M}\left(p_{kmt}\sum_{d\in D}y_{kdmt}\right)- \sum_{k\in P,t\in T}\left\{\sum_{i\in N,j\in N}T_{kijt}y_{kijt}+\sum_{d\in D}\hat{h}_{kdt}\hat{I}_{kdt}+\sum_{f\in F}\left(w_{kft}\sum_{d\in D}y_{kfdt}\right)\right\}$$
$$+\sum_{k\in P,f\in F,t\in T}\left\{\left(w_{kft}\sum_{d\in D}y_{kfdt}\right)-(r_{kft}x_{kft}+h_{kft}I_{kft})\right\} \quad (1)$$

Subject to

$$I_{kft}+x_{kft}-\sum_{d\in D}y_{kfdt}=I_{kft+1} \quad \forall k\in P,f\in F,t\in T \quad (2)$$

$$\hat{I}_{kdt}+\sum_{f\in F}y_{kfdt}-\sum_{m\in M}y_{kdmt}=\hat{I}_{kdt+1} \quad \forall k\in P,d\in D,t\in T \quad (3)$$

$$\sum_{d\in D}y_{kdmt}\le D_{kmt} \quad \forall k\in P,m\in M,t\in T \quad (4)$$

$$\sum_{k\in P}v_k\hat{I}_{kdt}\le \hat{H}_{dt} \quad \forall d\in D,t\in T \quad (5)$$

$$\sum_{k\in P}v_kI_{kft}\le H_{ft} \quad \forall f\in F,t\in T \quad (6)$$

$$\sum_{k\in P}c_{kf}x_{kft}\le C_{ft} \quad \forall f\in F,t\in T \quad (7)$$

$$x_{kft}, I_{kft}, \hat{I}_{kdt}, y_{kijt}\ge 0 \quad \forall k\in P,f\in F,d\in D,i\in N,j\in N,t\in T \quad (8)$$

As mentioned in the above, the CSCP model is based on the assumption that the central joint planning department knows everything about all of the production facilities, including production capacities, inventory capacities, production costs, and inventory costs in all periods in the given planning horizon; in addition, the central joint planning department knows all such information of the whole distribution network, including future demands in all markets, transportation costs, and inventory capacities in all distribution centers over all periods in the given planning horizon. In fact, the manufacturer would be very reluctant to reveal such information to their business partners and vice versa. In the above model, the objective function (1) tries to maximize the total profit of the distributor(i.e., sales revenue minus the total cost of the distributor) and the manufacturer(i.e., the payment from the distributor minus the total cost of the manufacturer) simultaneously. Constraints (2) are inventory balance equations for production facilities, while constraints (3) are flow conservation equations between production facilities and markets via distribution centers. Constraints (4) ensure that the distributor may not provide more than market demands. Constraints (5) and (6) are to make sure inventory carrying capacity is not violated. Constraints (7) are to limit the production volumes less than or equal to production capacity in each of the production facilities.

3.1 A distribution Planning Model for DA

We propose a linear programming model for the profit maximization of DA. To define a distribution planning model for DA, we define a new parameter in addition to those introduced before as follows:

Parameters

$\hat{C}_{ft}$: production capacity at production facility f in period t as perceived by DA based on the shortage reported by PA. $\hat{C}_{ft}$ are initially set at ∞ until PA reports a shortage for product k at production facility f in period t.

A distribution planning problem of DA is given as follows:

Max

$$\sum_{k\in P,t\in T,m\in M}\left(p_{kmt}\sum_{d\in D}y_{kdmt}\right)- \sum_{k\in P,t\in T}\left\{\sum_{i\in N,j\in N}T_{kijt}y_{kijt}+\sum_{d\in D}\hat{h}_{kdt}\hat{I}_{kdt}+\sum_{f\in F}\left(w_{kft}\sum_{d\in D}y_{kfdt}\right)\right\} \quad (9)$$

Subject to

$$\hat{I}_{kdt}+\sum_{f\in F}y_{kfdt}-\sum_{m\in M}y_{kdmt}=\hat{I}_{kdt+1} \quad \forall k\in P,d\in D,t\in T \quad (10)$$

$$\sum_{d\in D}y_{kdmt}\le D_{kmt} \quad \forall k\in P,m\in M,t\in T \quad (11)$$

$$\sum_{k\in P}v_k\hat{I}_{kdt}\le \hat{H}_{dt} \quad \forall d\in D,t\in T \quad (12)$$

$$\sum_{k \in P}\sum_{d \in D} y_{kfdt} \le \hat{C}_{ft} \qquad \forall f \in F, t \in T \tag{13}$$

$$\hat{I}_{kdt}, y_{kijt} \ge 0 \qquad \forall k \in P, d \in D, i \in N, j \in N, t \in T \tag{14}$$

The objective function (9) is to maximize the sum of all sales revenue minus transportation costs between production facilities and distribution centers($\sum_{k,t,d,t} T_{kfdt}y_{kfdt}$), between distribution centers and markets($\sum_{k,d,m,t} T_{kdmt}y_{kdmt}$), the total inventory carrying costs at distribution centers($\sum_{k,d,t}\hat{h}_{kdt}\hat{I}_{kdt}$), and the total purchase cost paid to PA based on the wholesale prices set prior to the negotiation($\sum_{k,f,t}\left(w_{kft}\sum_d y_{kfdt}\right)$). Constraints (10)~(12) are from the constraints (3)~(5) of the CSCP model. Constraints (13) are to limit the order quantities less than or equal to production capacity in each of production facilities where PA reports a shortage. How to set the order quantity(i.e., the requesting quantity to the manufacturer) with the output(i.e., y_{kfdt}) of solving the above model will be discussed again in the section 3.3. Notice that the value of $\hat{C}_{ft}$ is set based upon the shortage reported by PA, while all the others are the private information of DA.

3.2 A Production Planning Model for PA

PA plays a passive role in the proposed agent based supply chain planning. Responding to the orders submitted by DA, PA checks to see if the producing ordered quantity at each production facility is going to maximize the profit of the manufacturer. PA will meet the demand up to the point at which the profit is maximized, and then will report the shortage to DA.

We propose a linear programming model for PA by which the manufacturer can maximize the profit for the given order quantity. In addition to those introduced before, we define a new decision variable as follows:

<u>Variables</u>

b_{kft} : supply shortage volume of product *k* at production facility *f* in period *t*

A production planning model of PA for the given order quantity O_{kft}(order for product *k* from production facility *f* in period *t*) is given as follows:

$$\text{Max} \sum_{k \in P, f \in F, t \in T}\left\{\left(w_{kft}\sum_{d \in D} y_{kfdt}\right) - (r_{kft}x_{kft} + h_{kft}I_{kft})\right\} \tag{15}$$

Subject to

$$I_{kft} + x_{kft} - O_{kft} + b_{kft} = I_{kft+1} \quad \forall k \in P, f \in F, t \in T \tag{16}$$

$$\sum_{k \in P} v_k I_{kft} \le H_{ft} \qquad \forall f \in F, t \in T \tag{17}$$

$$\sum_{k \in P} c_{kf} x_{kft} \le C_{ft} \qquad \forall f \in F, t \in T \tag{18}$$

$$x_{kft}, I_{kft}, b_{kft} \ge 0 \qquad \forall k \in P, f \in F, t \in T \tag{19}$$

The objective function (15) is to maximize the profit of the manufacturer, which is the payment from DA ($\sum_{k,f,t}\left(w_{kft}\sum_d y_{kfdt}\right)$) minus production and inventory carrying costs combined($\sum_{k,f,t}(r_{kft}x_{kft} + h_{kft}I_{kft})$). Constraints (16) are inventory balance equations, and they ensure that PA may not supply more than requested, but may refuse to meet the full quantity. Constraints (17)~(18) are from the constraints (6)~(7) of the CSCP model.

3.3 Communication between DA and PA

The communication between DA and PA enables the proposed planning models to generate a feasible global supply chain plan because each agent only focuses on its local profit maximization. The proposed communication logic is designed to allow participating agents to reveal only minimum business information to their partners. The minimum information that DA has to forward to PA is the order quantity, and the minimum information that PA has to provide to DA is the supply quantity. As per common practice between any buyer and seller, the supply quantity may not exceed the order quantity but there is no practical mechanism to prevent the supplier(or seller) from untruthfully reporting its lack of capacity to meet the whole order quantity. Therefore, our communication process allows PA to report the shortage, not for the lack of production capacity, but for the profit maximization of the manufacturer.

In each of the planning iterations, DA submits to PA the order quantity for each product type from each production facility in each period. Such information is a result of solving the problem given in equations (9) through (14). In the linear program, $\sum_d y_{kfdt}$ is the order quantity for product *k* from production facility *f* in period *t* that is to be submitted to PA and then to be used as O_{kft} in PA. On DA's submission of the order quantity, PA builds the production planning problem shown in equations (15) through (19) to find a profit maximizing production plan. The production plan specifies the production volume of each product at each production facility in each time period. The production volume in the production plan can be less than the corresponding order quantity, and PA has to report the shortage amount(b_{kft}), if any, to DA. With the reported shortage amount received from PA, DA will adjust its perceived production capacity of production facility f in period t. That is, the new distribution planning problem of DA in the next planning iteration will assume $\sum_k (O_{kft} - b_{kft})$ as a new production capacity($\hat{C}_{ft}$) at production facility f in period t. If no shortage is reported at production facility f in period t, DA maintains the same capacity limit from the previous planning iteration. Notice that the production capacity at production facility f in period t should remain unlimited until PA reports any shortage for that particular combination for the first time.

3.4 Analysis of the Proposed Supply Chain Planning

In this section, we will examine whether communication between DA and PA terminates with a feasible supply chain plan: a feasible production plan for the manufacturer and a feasible distribution plan for the distributor. Typically, when a centralized planning problem is decomposed into two subproblems, which are locally optimized iteratively, convergence is often not guaranteed, and a planning procedure may continue indefinitely. Thus, convergence of the proposed collaborative agent based planning with a feasible supply chain plan should be clarified, and we introduce the following theorem.

Theorem 1. Communication between DA and PA always terminates with a feasible supply chain plan at convergence.

Proof. The feasible supply chain plan required that both a distribution plan of DA and a production plan of PA are feasible, and that there is no conflict between the order quantity of DA and the supply quantity of PA(i.e., $b_{kft} = 0$ for $\forall k,f,t$).

First, it is straightforward to see that the communication process in all planning iterations produces a pair of feasible local plans to DA and PA, since ordering nothing in DA and producing nothing in PA are obvious feasible plans to the two problems: the production planning problem and the distribution planning problem.

Next, we should show the proposed communication process is convergent in b_{kft} as zero for $\forall k,f,t$, as planning iterations proceed. From equation (16), b_{kft} is directly affected by the order quantity of DA, O_{kft} (i.e., $\sum_d y_{kfdt}$) which should be under $\hat{C}_{ft}$ as shown in equation (13). Therefore, if a sequence of $\hat{C}_{ft}$, $\{\hat{C}^i_{ft}\}$, becomes convergent as a planning iteration i increases, then b_{kft} will become convergent. The sequence, $\{\hat{C}^1_{ft}, \hat{C}^2_{ft}, ..., \hat{C}^i_{ft}\}$ is a non-increasing sequence as planning iterations proceed, since $\hat{C}^i_{ft}$ of DA has the value of either $\sum_k (O^{i-1}_{kft} - b^{i-1}_{kft})$ or $\hat{C}^{i-1}_{ft}$ after each PA runs. However, $\hat{C}_{ft} \geq 0$ for $\forall k,f,t$, in all iterations, and delivering nothing from production facilities(i.e., $y_{kfdt} = 0$) is obviously a feasible plan of PA. Consequently, $\{\hat{C}^i_{ft}\}$ is non-increasing, but it is bounded from below. This proves that a sequence of b_{kft}, $\{b^i_{kft}\}$, is convergent as planning iterations proceed(or as $i \rightarrow \infty$) by the monotone convergence theorem(Lay, 1990). $\hat{C}_{ft}$ will decrease along planning iterations until the terminating condition of communication between DA and PA is satisfied, since the terminating condition is that all b_{kft} values are zero for $\forall k,f,t$.

4. Numerical Example

To show how the proposed methodology generates a feasible supply chain plan, we conducted the simple experiments with a numerical example. The main contribution of this research is not to provide a new heuristic for solving supply chain planning problems, but to propose a new approach based on the collaboration between two independent agents by focusing on the minimum information sharing. Thus, we try to investigate the performance of the proposed supply chain planning methodology by comparing it with the CSCP model. Since most supply chains for functional product markets are decentralized, the proposed approach can be a more realistic choice for a supply chain planner if its performance is similar to the CSCP model.

4.1 Design

For this example, we consider a mid-size supply chain with 4 product types, 10 production facilities, 5 distribution centers, 10 markets, and 12 planning periods, and we randomly generate 10 problem instances for experiments. The gap between maximum profits from the CSCP model and from the proposed collaborative agent based planning is investigated. Remember that the CSCP model assumes a complete sharing of information, whereas the proposed collaborative agent based planning allows for the minimum information exchange between DA and PA.

The market demand is randomly generated from U (1500,3500). As for the production capacity, the sum of demands for all products is 130% of the sum of the production capacity, and we applied a similar method to generate the inventory capacities for both production facilities and distribution centers. In addition, costs have been determined in the following way. The inventory carrying cost at production facilities over two periods is of the same level as its production cost. The production cost is chosen from U(45,55). The sum of the inventory carrying cost at a distribution center and the transportation cost from a production facility to a customer zone might be as expensive as the production cost of a product. Finally, the distributor's sales price and the wholesale price of the manufacturer for one unit of product are set properly in consideration of the total production or distribution related cost, respectively.

The proposed collaborative agent based supply chain planning process is coded and solved with the script language of ILOG OPL Studio 3.1. Also, the solution of the corresponding CSCP model is derived using ILOG OPL Studio 3.1. The computation is executed on a PC containing Pentium IV-M process running at 2.20 GHz with 512 MB RAM.

4.2 Results

With the prepared data in the previous subsection, the result of the proposed collaborative agent based planning is summarized in <Table 1>. The CASCP of <Table 1> stands for the proposed collaborative agent based supply chain planning, and the deviation of the last column can be calculated with the total profits of CSCP and CASCP.

The above results show that the distribution and production plans at the end of planning iterations are on average only 4.31% below the solution of the CSCP model based on full information sharing. In addition, as expected from analytical proof in Section 3.4., a feasible supply chain plan is found at convergence with no supply shortage(i.e., $b_{kft}=0$) in all problem instances although we set an additional stopping rule such as $\forall b_{kft} < \epsilon$($\epsilon$ is a small number) to avoid a very slow converging. At the first iteration, DA generates a distribution plan and obtains an initial maximized profit on the assumption that PA can fulfill all order quantities without reporting any shortage. In response to the order quantity of DA, PA generates a production plan and reports the shortage against the request of DA as the result of maximizing the profit of the manufacturer. Until the production shortage is not reported from PA, DA continues the planning iteration by submitting to PA the modified order quantity that reflects the shortage reported from PA in the previous iteration.

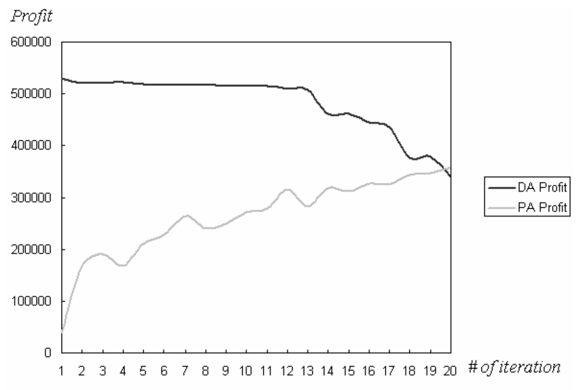
Table 1. Experimental results

	DA Profit		PA Profit		Total Profit		Dev.
	CSCP	CASCP	CSCP	CASCP	CSCP	CASCP	%
1	343560	337783	377376	359938	720936	697721	3.22
2	345216	338593	378828	360288	724044	698881	3.47
3	348440	343259	383542	365453	731982	708712	3.17
4	346740	328536	381180	353580	727920	682116	6.29
5	347500	339154	382244	358956	729744	698110	4.33
6	349820	344197	384844	366864	734664	711061	3.21
7	346640	330528	381040	350907	727680	681435	6.35
8	343500	337508	377940	363030	721440	700538	2.89
9	347620	336034	382395	358370	730015	694404	4.87
10	353156	337641	388648	364642	741804	702283	5.32

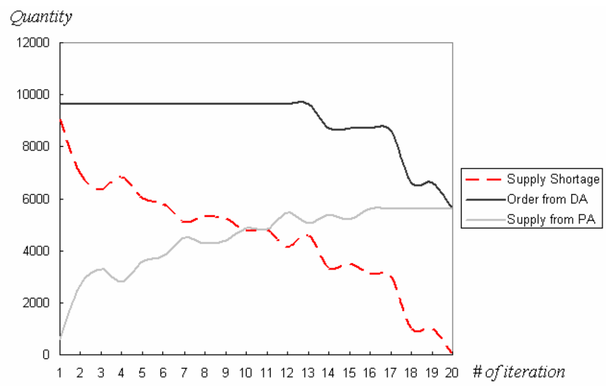
Table 2. Number of planning iterations

Experiment Number	Number of Iterations
1	22
2	19
3	19
4	22
5	20
6	16
7	19
8	18
9	16
10	18

<Table 2> shows the number of planning iterations to reach a final supply chain plan in the experiments. The average number of planning iterations in all problem instances is 18.9.



(a) Convergence of the profits of DA and PA



(b) Convergence of the order quantity from DA and the supply quantity from PA

Figure 1. Example graphs on the convergence of the proposd planning process.

Lastly a graphical illustration of the proposed planning process is given in <Figure 1>, where the supply shortage quantity(i.e., unmet orders) reported by PA, the requested order quantity by DA, and the profits of DA and PA in each of the planning iterations are plotted for the experiment number 5. As shown in <Figure 1-(a)>, the total profit of DA has decreased since the initial order quantity of DA has adjusted accordingly by the reported shortage of PA as planning iterations proceed. In other words, the initial ideal distribution plan of DA, assuming the infinite product supply, has changed into a more realistic one throughout planning iterations by communication with PA. Conversely, the total profit of PA has gradually increased since DA sends a more realistic request considering the shortage reported by PA. In addition, the order quantity from DA and the supply quantity of PA have reached the same quantity point at the end of iterations through the communication between DA and PA as shown in <Figure 1-(b)>.

5. Concluding Remarks

This paper deals with the collaborative agent based supply chain planning for functional product markets by focusing on the operational side of supply chain planning efficiency from a decentralized perspective. Especially, only minimum information sharing between the distributor and the manufacturer is considered as the most important factor to implement a fully decentralized environment. The proposed methodology can generate feasible supply chain plans with a good solution quality by exchanging only information on order and supply quantities, excluding private information such as unit costs or available capacities. Through experiments with the numerical example, we show that the proposed collaborative agent based supply chain planning terminates with a feasible supply chain plan at convergence as investigated in the analytical proof.

Since the distributor usually leads the supply chain planning procedure for the functional product markets, the proposed collaborative agent based supply chain planning can be a more realistic choice. Also, it can be used as a basic reference model for any distributors and manufacturers seeking collaboration for the functional product markets.

This research is currently being undertaken as an on-going project to build a complete supply chain planning system for real world cases. Simultaneously, extensive experiments for validation using random and real data are being designed and performed. After completion of all experiments and development of the system, further analyses of the proposed methodology will be conducted and reported. In addition, the following issues can be further investigated: 1) to extend the current models considering other supply chain participants(e.g., vendors) and/or various specific options in negotiation(e.g., price discount, profit rewards, etc.); 2) to introduce multiple manufacturers in the current models, even though this research only deals with the one-to-one relationship between the distributor and the manufacturer; and 3) to analyze communication loads that directly affect extra cost problems regarding network traffic, and to develop the advanced stopping rule of the planning procedure using the size of the supply shortage amount for reducing the communication loads.

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정 호 상
연세대학교 산업시스템공학 학사
연세대학교 컴퓨터 산업시스템공학 박사
현재: 미국 Virginia Tech 산업시스템공학 Post-Doc.
관심분야: Distributed decision making, Collaborative manufacturing and service system, Real-time enterprise

정 봉 주
서울대학교 산업공학 학사
서울대학교 산업공학 석사
미국 Pennsylvania State University 산업공학 박사
현재: 연세대학교 정보산업공학과 교수
관심분야: Modeling and analysis of manufacturing systems, Supply chain management

이 치 근
서울대학교 산업공학 학사
한국과학기술원 산업공학 석사
미국 University of Michigan 산업공학 박사
현재: 캐나다 University of Toronto 기계산업 공학과 교수
관심분야: Logistics management, financial theories applied in manufacturing and service sectors