Hierarchical-Game Based Multi-Attribute Negotiation of Supply Chain Network

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Abstract: This paper focuses on hierarchical-game based multi-attribute negotiation between multiple MAs (Manufacture Agents) and multiple MSAs (Material Supplier Agents) of SCN (Supply Chain Network). The attributes of the wholesale price of the product, the quantity of the order and the lead time of the order are negotiated simultaneously. A modified hierarchical-game based negotiation protocol is proposed based on the previous work. It is a changeable hierarchical game. It is a two-layer game when all the orders are in abilities of all the MSAs. However, it is a three-layer game when there are some orders out of abilities of some MSAs. The second layer game is not necessary, it is triggered to find coalitions only if the order is out of ability of MSA. The third layer game is used to determine the final quotation of the negotiation. Then, the first layer game is aimed to find the optimal allocation scheme to maximize the total profit of SCN based on the results of the second and the third layer games. Numerical example is provided to illustrate the proposed protocol.

Key Words: multi-agent system, negotiation, supply chain, game theory.

1. Introduction

Multi-agent system has attracted a lot of attentions from intersecting itself with supply chain management in the last decade. Recently, it becomes more formal borrowing from operations research, game theory and other facets from distributed decision making [1].

Multi-attribute negotiation protocol has been widely studied and represents a promising field since most of negotiation problems in the real-world are complex ones including multiple issues ([2],[3]). In reality, attributes are constrained each other. It is a common situation that people must negotiate multi-attribute simultaneously, for example, the quantity, price, and delivery time in a supply contract. Moreover, it is also beneficial for people to introduce multi-attribute in negotiation when they have different preferences on the attributes, because they may achieve benefits by trading off multi-attribute. Schelling [4] indicated that when there are two objects to negotiate, the decision to negotiate them simultaneously or in separate forums or at separate times is by no means neutral to the outcome. Thus, the simultaneous negotiation and sequential negotiation are the major negotiation settings in multi-attribute negotiation, where the previous one negotiates the issues together as a package and the latter one negotiates the issues one by one. Researches on multi-attribute negotiation have been conducted in the fields of game theory and artificial intelligence. Game theory is a powerful tool for analyzing situations in which the decisions of multiple agents affect each agent’s payoff [5]. It has become a primary methodology used in supply chain network related problems. This research focuses on game theory based multi-attribute negotiation. The goal of the work in game theory is to find the optimal quotation and corresponding equilibria under different negotiation settings [6]. However, game theorists propose to negotiate multi-attribute sequentially and assume the utility functions of agents are linear additive [6]. Bac et al. [7] considered issue-by-issue negotiation with two pies and incomplete information. Lai et al. [8] proposed a model that can help agents negotiate multi-attribute simultaneously with complex utility functions and incomplete information, but still maintains Pareto optimality. Ito et al. [3] proposed an auction-based multiple-issue negotiation protocol among nonlinear utility agents. However, all these researches are not from the application in SCN (Supply Chain Network).

This research focuses on intersecting SCN with multi-agent system, and all the organizations of SCN are defined as agents. It tries to find a solution for the game theory based multi-attribute negotiation between multi-MAs (Manufacturing Agents) and multi-MSAs (Material Supplier Agents). In previous researches, single attribute negotiation between one MA and multi-MSA [9], and single attribute negotiation between multi-MA and multi-MSA [10] have been discussed. Both of them assumed that the quantity of the order of MA was fixed. However, in the real market, the quantity of MA is not fixed and it related to the demand of market. Thus, this research generalizes the results to multi-attribute negotiation between multi-MA and multi-MSA, where the quantity of the order is based on the demands of market. Furthermore, it mainly focuses on the situation where the orders of MAs are out of abilities of MSAs.

The remainder of the paper is organized as follows: section 2 describes the negotiation model and settings used in this research; section 3 describes the modified hierarchical-game based negotiation includes the determinations of coalitions, final quotation and final allocation scheme; numerical example and analysis are given in section 4 to illustrate the proposed protocol. In conclusion, the contributions and the directions of the future work are commented.

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(Received June 14, 2012)
(Revised October 4, 2012)
2. Negotiation Model and Settings

2.1 Nomenclature

I: number of MAs, i is the index of MA
J: number of MSAs, j is the index of MSA
k: index of the round of the negotiation
\( \alpha_{i}^{\text{max}} \): maximum percentage of the profit of i
\( \beta_{j}^{\text{max}(\text{min})} \): maximum (minimum) percentage profit of j
\( \gamma_{j} \): productivity of j
\( \delta \): concession function of wholesale price w of i
\( \delta_{j}^{M} \): concession function of wholesale price w of j
\( \delta_{Q}^{M} \): concession function of the Q of i
\( \delta_{Q}^{O} \): concession function of the quantity Q of j
\( \delta_{LT}^{M} \): concession function of the lead time LT of i
\( \delta_{LT}^{O} \): concession function of the lead time LT of j
\( \theta_{LT}^{R} \): \( z^{th} \) threshold value of LT related to w of MSA
\( \theta_{Q}^{R} \): \( z^{th} \) threshold value of w related to quantity of MSA
\( \theta_{Q}^{W} \): \( z^{th} \) threshold value of w related to lead time of MSA
\( \theta_{Q}^{M} \): maximum (minimum) value of quantity of MSA
\( \theta_{Q}^{O} \): threshold value of quantity related to w of MSA at k
\( \phi_{i}^{M} \): discount of \( s_{j|i} \)
\( \phi_{j}^{M} \): profit of j at k
\( \phi_{i}^{S} \): profit of j at k takes quotation of its own (MA)
\( \phi_{j}^{C} \): profit of j at k takes quotation of its own (MA)
\( a_{i} \): maximum demand of i
\( \psi_{j} \): ability of j at i at k
\( A_{j|i}^{C} \): combined ability of \( s_{j|i} \) at k
\( h_{C} \): coefficient of variation related to selling price of i
\( c_{F} \): fixed cost per order of i
\( c_{S} \): cost of i to save or extend the lead time per day
\( c_{P} \): cost of j to save or extend the lead time per day
\( c_{I} \): unit production cost of i
\( c_{P}^{j} \): unit production cost of j
\( c_{S}^{j} \): set-up cost per order of j
\( c_{LT} \): shortage cost of i
\( D_{j|i}^{I} \): demand of i at k
\( f_{j|i} \): judging function of the quantity of j
\( b_{M} \): holding cost of i
\( b_{S} \): holding cost of j
\( L_{j} \): order list of j
\( LT_{i}^{M} \): lead time of \( s_{j|i} \) at k
\( LT_{j|i}^{M} \): lead time of i at k
\( PC_{j|i} \): minimum price of \( s_{j|i} \)
\( PCA_{j} \): maximum price of \( s_{j|i} \)
\( PSA_{j} \): maximum price of j
\( PI_{j} \): minimum price of i
\( PSI_{j} \): minimum price of j
\( ps_{j|i}^{s} \): selling price of i at k
\( Q_{j|i}^{C} \): quantity of \( s_{j|i} \) at k
\( O_{j|i}^{C} \): quantity of i at k
\( Q_{j|i}^{M} \): quantity of j at k
\( O_{j|i}^{M} \): quantity of j at k
\( Q_{S}^{j|i} \): the allocation of quantity of \( s_{j|i} \) at k
\( s_{j|i}^{c} \): salvage value per unit of unsold product of i
\( f_{j|i}^{c} \): \( k^{th} \) coalition of j for i
\( TN \): deadline of the negotiation
\( w_{j|i}^{M} \): wholesale price of \( s_{j|i} \) at k

2.2 Negotiation Model and Settings

A model consists of two tiers of decision makers/agents (MAs and MSAs) is shown in Fig. 1.

MAs try to negotiate with MSAs about the quotation of the product they want to buy based on market demand. This research mainly focuses on the situation that the orders of MAs may be out of abilities of MSAs. Researchers are prone to letting MAs split the orders and then allocate them to different MSAs ([11]–[13]) when the order is out of ability of MSA. However, it wastes time to decompose the orders into pieces and allocate to different MSAs when MA has diversified products to order. In previous work [9], we tried to let MSAs establish coalitions when the orders are out of their abilities, which can maintain the integrity of the order. It has been verified that the proposed protocol using coalition formation is better than the protocol to split the order. Furthermore, it assumed that the quantity of the order of MA was fixed. However, in the real market, the quantity must be related to market demand, and the market demand normally related to the selling price of MA. Thus, this research tries to extend the negotiation under fixed demand to the negotiation under the situation where the demand depends on the selling price of MA. Furthermore, single-attribute negotiation is extended to multi-attribute negotiation between multi-MA and multi-MSA. The agreement cannot be reached by only considering one attribute in the multi-attribute negotiation. A weighted summation of all the attributes is taken into account. Assumptions are given as follows before discussing details of the negotiation protocol:

Assumption 1: The negotiation environment is static and all the MAs announce their orders at the same time.

Assumption 2: Only one kind of product is involved in the proposed SCN model.

Assumption 3: MSAs are allowed to find coalitions if the orders are out of their abilities.

Assumption 4: The market demand of MA i at the certain lead time is in an additive form as eq.(1) without upper bound.

\[ D_{j|i}^{l} = a_{i} - b_{i} p_{s_{j|i}} \]  \hspace{1cm} (1)

Equation (1) indicates that the demand decreases as the selling price increases.
MA must consider the price of the product, the quantity of
the order and the lead time of the order during the negotiation
with MSAs (coalitions). Therefore, in this research, we assume
that MAs and MSAs mainly care three attributes: the wholesale
price of the product, the quantity of the order, and the lead time
of the order.

3. Modified Hierarchical-Game based Negotiation

A hierarchical-game based negotiation protocol was
proposed in the previous work [10], where the quantity of MA
was fixed. In this research, a modified hierarchical-game based
negotiation protocol is proposed based on [10], where the quantity
of MA depends on the market demand. It is a changeable hi-
erarchical game. It is a two-layer game when all the orders are
in abilities of all the MSAs. However, it is a three-layer game
when there are some orders out of abilities of some MSAs. The
first layer game is between multi-MA and multi-MSA (coalitions)
and it aims to find the optimal allocation scheme to max-
imize the total profit of SCN. The second layer game is not
necessary, and it is triggered to find coalitions among MSAs only
if the order of MA i is out of ability of MSA j. The third layer
game is between quotations of MA and MSA (coalition) to de-
termine the final quotation of the product. These three layer
games constitute the hierarchical-game.

The structure of the modified hierarchical-game based nego-
tiation is shown in Fig. 2. There is a nested structure in the
hierarchical structure, where the second and third layer games
are nested inside the first layer game. The first layer game starts
and then the second and third layer games are triggered if neces-
sary. But the first layer game can be finished only if the second
and third layer games have been finished. In other words, the
first layer game is based on the results of the second and third
layer games. The details of the protocol are discussed in the
following sections.

3.1 Determination of Coalitions

In the second layer game (see the area marked by dotted line
in Fig. 2), MSAs negotiate with each other to find partners to
establish a coalition when the orders of MAs are profitable but
out of their abilities. Matrix $E = [e_{ij}]$ is used to evaluate the
order of MA $i$ for MSA $j$, where $e_{ij}$ equals to 1 means the order
of MA $i$ is in ability of MSA $j$, and $e_{ij}$ equals to 0 means the
order of MA $i$ is out of ability of MSA $j$. The second layer
game is triggered to find coalitions when $e_{ij}=0$. The coalition
formation and determination mechanisms have been discussed
in details in [9],[10].

3.2 Determination of Final Quotation

In the third layer game (see the area marked by dot-dashed
line in Fig. 2), MA negotiates with MSA (coalition) to de-
termine the final quotation. MA firstly announces its quotation,
and then MSA (coalition) reacts by playing the best move based
on the quotation of MA. Both MA and MSA (coalition) want
to maximize their profits by choosing their preferential quota-
tion. MA aims to determine the quotation as lower as possible
to maximize its profit, while MSA (coalition) wants to get the
quotation the higher, the better. Thus, there exists a conflict of
interests of the two sides. The key point is to find a balance
between the profits of MA and MSA (coalition). The inter-
action between MA and MSA (coalition) can be seen as MA-
Stackelberg game, where MA is the leader and has more deci-
sion power. The objective of the leader is to design its move to
maximize its profit after considering all rational moves the fol-
lower may devise. Therefore, the problem is transformed into
finding the Stackelberg equilibrium of MA-Stackelberg game.

3.2.1 Determination of the final equilibrium

Therefore, the determination of the agreement on the quota-
tion of the product and so to maximize the total profits of MA
and MSA (coalition) can be transferred into finding the equi-
librium of MA-Stackelberg game. Thus, the problem can be
solved by tackling following problem:

$$\max \pi^M_i + \pi^S_j + (1 - e_{ij})\pi^C_{ij}$$  (2)

s.t. $w^F_{ij} = e_{ij}w^M_{ij}[k] + (1 - e_{ij})w^M_{ij}[k]$  (3)

$Q^F_{ij} = e_{ij}Q^M_{ij}[k] + (1 - e_{ij})Q^M_{ij}[k]$  (4)

$LT^F_{ij} = e_{ij}LT^M_{ij}[k] + (1 - e_{ij})LT^M_{ij}[k]$  (5)

$\pi^M_i + \pi^S_j \geq e_{ij}\pi^M_{ij}[k], k < TN - 1$  (6)

$\pi^M_i + \pi^S_j > 0, k = TN - 1$  (7)

$(1 - e_{ij})\pi^C_{ij}[k] \geq (1 - e_{ij})\pi^C_{ij}[k], k < TN - 1$  (8)

$(1 - e_{ij})\pi^C_{ij}[k] > 0, k = TN - 1$  (9)

$w^F_{ij} \geq e_{ij}PSI_j + (1 - e_{ij})PCI_j$  (10)

$e_{ij}AC_{ij}[k] + (1 - e_{ij})AC_{ij}[k] \geq Q^F_{ij}$  (11)

$e_{ij}LT^F_{ij} + (1 - e_{ij})LT^F_{ij} \geq e_{ij}\frac{Q^F_{ij}}{\gamma_j} + (1 - e_{ij})\frac{Q^F_{ij}}{AC_{ij}}$  (12)

$e_{ij}Q^F_{ij} + (1 - e_{ij})Q^F_{ij} \geq e_{ij}Q^min_f + (1 - e_{ij})Q^max_f$  (13)

$e_{ij}Q^F_{ij} + (1 - e_{ij})Q^F_{ij} \leq e_{ij}Q^max_f + (1 - e_{ij})Q^min_f$  (14)

where superscript $F$ means it’s the final decided quotation of
negotiation, when $e_{ij}=1$ means the negotiation is between MA
$i$ and MSA $j$, and when $e_{ij}=0$ means the negotiation is between
MA $i$ and coalition $s_{ij}$. Equation (3) - (5) define the final quo-
tation of the negotiation, eq. (6) - (10) ensure that the final quotation must be profitable, eq. (11) - eq. (12) indicate the order must be in ability of MSA \( j \) or coalition \( s \). Equation (12) and (13) indicate the minimum quantity should be met and the maximum quantity can offer by MSA \( j \) or coalition \( s \), respectively.

In order to solve eq. (2), we should know the profits of MA and MSA (coalition). Specially, the profit of MSA (coalition) takes the quotation of MA and that of takes its own quotation. We define the profits of MA and MSA (coalition) at \( k \) as follows:

\[
\pi_{ij}^M[k] = (p_{ij} - c_{ij}^M)D_{ij}[k] - cl_{ij}^M(LT_{ij}^M[k] - LT_{ij}^M[0]) + sgn(Q_{ij}^M[k] - D_{ij}[k])(Q_{ij}^M[k] - D_{ij}[k])sv_{ij} - sgn(D_{ij}[k] - Q_{ij}^M[k])(D_{ij}[k] - Q_{ij}^M[k])c_{st},
\]

\[
- w_{ij}^M[k]Q_{ij}^M[k] - \frac{c_{fi}[D_{ij}[k]]}{Q_{ij}^M[k]} - \frac{b_{ij}^M[Q_{ij}^M[k]]}{2}
\]

\[
\pi_{ij}^S[k] = \left( w_{ij}^S[k] - c_{ij}^S \right) Q_{ij}^S[k] + cl_{ij}^S(LT_{ij}^S[k] - LT_{ij}^S[0]) - c_{sj} - \frac{L_{ij}^S[k]}{2},
\]

\[
\pi_{ij}^C[k] = \sum_{k \in \bar{L}} \pi_{ij}^S(w_{ij}^S[k], QS_{ij}^S[k], LT_{ij}^S[k]),
\]

where \( sgn(x) \) equals to 1, if \( x \) is greater than 0, and otherwise it equals to 0. The first item of eq. (15) is the profit of sales, the second item is the increased or reduced profit by reducing or extending the lead time, the third item is the salvage values of the unsold parts, the fourth item is the shortage cost, the fifth item is the purchase cost, the sixth item is the fixed cost per order, and the last item is the holding cost. The first items of eq. (16) - (17) are the net profits, the second items are increased or reduced profits by extending or reducing the lead time, the third items are the setup costs per order and the last items are the holding costs.

Equation (18) - (19) are the sums of all the profits of its members, where \( Q_{ij}^S[k] \) is the order allocation when the total order equals to \( Q_{ij}^M[k] \).

3.2.2 Determination algorithm

As we know, there are three attributes involve in this research. We should know the quotation of MAs and MSAs (coalitions) in order to determine the final quotation. In this research, we negotiate three attributes simultaneously. The quotation must conclude the values of all the three attributes at each round of negotiation. The flowchart of multi-attribute negotiation to determine the final quotation is shown in Fig. 3.

The algorithm of the final quotation determination can be got as follows:

1. **Step 1:** MA \( i \) defines its initial quotation of the product it wants to buy as eq. (20) - (22) and then announces to MSA \( j \). If MSA \( j \) is in ability, goes to Step 2, if it is out of its ability, then goes to Step 3.

\[
w_{ij}^M[0] = PMI_i
\]

\[
Q_{ij}^M[0] = c_i - b_iPMI_i(1 + a_i^{max})
\]

2. **Step 2:** MSA \( j \) evaluates the quotation of MA \( i \), if it agrees, the negotiation ends, if it doesn’t agree, then makes a counter quote as eq. (23) - (25) based on the quotation of MA \( i \) and then feeds back the counter quote \( (w_{ij}^S[k], Q_{ij}^S[k], LT_{ij}^S[k]) \) to MA \( i \), and the negotiation enters into Step 4.

\[
w_{ij}^S[k] = w_{ij}^S[k] - 1 - (w_{ij}^S[k] - 1 - PS I_j)/TN - k
\]

\[
\delta_{ij}^S(LT_{ij}^M[k]) = \begin{cases} \delta_{ij}^S(LT_{ij}^M[0]) - \delta_{ij}(LT_{ij}^M[k]) & \text{if } LT_{ij}^M[k] \leq x_{ij}^L \leq LT_{ij}^M[0] \\ \theta_{ij}^S, & \text{if } LT_{ij}^M[k] \leq x_{ij}^L \leq LT_{ij}^M[0] \end{cases}
\]

\[
\delta_{ij}^S(Q_{ij}^M[k]) = \begin{cases} \delta_{ij}^S(Q_{ij}^M[0]) - \delta_{ij}(Q_{ij}^M[k]) & \text{if } Q_{ij}^M[k] \leq x_{ij}^Q \leq Q_{ij}^M[0] \\ \theta_{ij}^S, & \text{if } Q_{ij}^M[k] \leq x_{ij}^Q \leq Q_{ij}^M[0] \end{cases}
\]

\[
f_{ij}(w_{ij}^S[k]) = \begin{cases} \theta_{ij}^S, & \text{if } w_{ij}^S[k] \leq PS I_j \\ \theta_{ij}^S, & \text{if } PS I_j < w_{ij}^S[k] \leq PS A_j \\ \theta_{ij}^S, & \text{if } w_{ij}^S[k] \geq PS A_j \end{cases}
\]

\[
w_{ij}^S[0] = PS A_j
\]

\[
\theta_{ij}^S = Q_{ij}^S[0]
\]

\[
\theta_{ij}^S = c_{ij}/(w_{ij}^S[0] - c_{ij}^S)
\]

\[
\theta_{ij}^S - \delta_{ij}^S(Q_{ij}^M[k])/(PS I_j - PS A_j)
\]

\[
\theta_{ij}^S = \theta_{ij}^S + [(\theta_{ij}^S - \theta_{ij}^S)(PS I_j - PS A_j)]/PS I_j - PS A_j
\]

\[
PS A_j = (1 + \theta_{ij}^S)w_{ij}^S[0]/(PS I_j - PS A_j)
\]

Equation (25) is the function of lead time related to the quantity and is shown in Fig. 4 (d). Equation (26) - (27) are concession functions of wholesale price of MSA related to the quantity and lead time offered by MA. They are piece-wise function as shown in Fig. 4 (a) and (b). Figure 4 (a) means the higher quantity MA \( i \) buys, the higher discount of the price MSA \( j \) affords.
where:

\[ w_{ij}^C[k] = \frac{w_{ij}^C[k - 1] - (w_{ij}^C[k - 1] - PCI_{ij})}{TN - k} \]

\[ Q_{ij}^C[k] = f_{ij}(w_{ij}^C[k]) \]

\[ LT_{ij}^C[k] = \max_{f \in s_{ij}} (QS_{ij}[f]/y_f) \]  

where:

\[ f_{ij}(w_{ij}^C[k]) = \begin{cases} \theta_{ij}^{C_{\text{max}}} & \text{if } w_{ij}^C[k] \leq PCI_{ij} \\ \theta_{ij}^{C_{\text{min}}} & \text{if } PCI_{ij} < w_{ij}^C[k] < PCA_{ij} \\ \theta_{ij}^{C_{\text{min}}} & \text{if } w_{ij}^C[k] \geq PCA_{ij}. \end{cases} \]

\[ QS_{ij}[f] = A_{ij}[f]Q_{ij}[0]/AC_{ij}[f], f \in s_{ij} \]

\[ AC_{ij}[k] = \sum_{f \in s_{ij}} A_{ij}[f] = \sum_{f \in s_{ij}} LT_{ij}^C[k]y_f \]

\[ \theta_{ij}^{C_{\text{max}}} = Q_{ij}^C[0] \]

\[ \theta_{ij}^{C_{\text{min}}} = \sum_{f \in s_{ij}} c_{ij}y_f \]

\[ \delta_{ij}^Q = \theta_{ij}^{C_{\text{max}}} - \delta_{ij}^{C_{\text{min}}} \]

Equation (38) is a piece-wise function and has the same form as Fig. 4 (c). Equation (39) is acquired quantity of MSA \( j \) when it belongs to coalition \( s_{ij} \). Equation (41) is the maximum value of \( f_{ij}(w_{ij}^C[k]) \), which means the order must be in the ability of coalition \( s_{ij} \). Equation (42) is the minimum value of \( f_{ij}(w_{ij}^C[k]) \), which means the order must be profitable for coalition \( s_{ij} \). Equation (43) is mapping value related to \( w_{ij}^C[k] \). Equation (44) - (45) are the maximum and minimum wholesale prices of coalition \( s_{ij} \).

- **Step 4:** MA \( i \) evaluates the counter quote from MSA \( j \) or coalition \( s_{ij} \). If it agrees with the quotation, the negotiation ends; if it doesn’t agree, then it makes a counter quote based on the quotations of its own and the MSA’s at round \( k - 1 \) as follows and then reannounces the counter quote:

\[ w_{ij}^M[k] = w_{ij}^M[k - 1] + (PMA_i - w_{ij}^M[k - 1])/(TN - k) \]

\[ Q_{ij}^M[k] = D_{ij}[k] + \delta_{ij}^Q(w_{ij}^M[k]) \]

\[ LT_{ij}^M[k] = LT_{ij}^M[k - 1] + \alpha_{ij}^W(w_{ij}^M[k]) \]

\[ ps_{ij} = w_{ij}^M[k](1 + \alpha_{ij}^{\text{max}}) \]

\[ \delta_{ij}^M(Q_{ij}^M[k]) = \begin{cases} \theta_{ij}^{M_{\text{LT}}} & \text{if } LT_{ij}^M[k - 1] \leq x_{ij}^{LT} \\ \theta_{ij}^{M_{\text{LT}}} & \text{if } x_{ij}^{LT} < LT_{ij}^M[k - 1] < x_{ij}^{LT} \\ 0 & \text{if } LT_{ij}^M[k - 1] \geq x_{ij}^{LT}. \end{cases} \]

\[ \delta_{ij}^M(LT_{ij}^M[k]) = \begin{cases} \theta_{ij}^{M_{\text{LT}}} & \text{if } w_{ij}^M[k - 1] \leq x_{ij}^{LT} \\ \theta_{ij}^{M_{\text{LT}}} & \text{if } x_{ij}^{LT} < w_{ij}^M[k - 1] < x_{ij}^{LT} \\ 0 & \text{if } w_{ij}^M[k - 1] \geq x_{ij}^{LT}. \end{cases} \]

\[ \delta_{ij}^M(Q_{ij}^M[k]) = \begin{cases} \theta_{ij}^{M_{\text{LT}}} & \text{if } w_{ij}^M[k - 1] \leq x_{ij}^{LT} \\ \theta_{ij}^{M_{\text{LT}}} & \text{if } x_{ij}^{LT} < w_{ij}^M[k - 1] < x_{ij}^{LT} \\ 0 & \text{if } w_{ij}^M[k - 1] \geq x_{ij}^{LT}. \end{cases} \]

Equation (49) is selling price of MA \( i \) based on the quotation at round \( t \). \( \delta_{ij}^M(LT_{ij}^M[k - 1]) \), \( \delta_{ij}^M(Q_{ij}^M[k - 1]) \) and \( \delta_{ij}^M(LT_{ij}^M[k - 1]) \) are piece-wise functions as shown in Fig. 5 (a), (b) and (c), respectively. Figure 5 (a) means if MSA can offer shorter lead time, MA can increase more concession of the price. Figure 5 (b) means if MSA can offer lower price, MA buys more quantity of the product, and Fig. 5 (c) means if MSA can offer lower price, MA can extend longer lead time. All the threshold values \( x_c \) can be defined by MA according to its preferential quotation. The negotiation iterates until an agreement is reached. As we have mentioned above, negotiation ends only if an agreement is reached. Therefore, a rule should be proposed for MSAs (coalitions) to judge whether accept the quotation at \( k \) or not during the negotiation:

**Rule:** The quotation \( (w_{ij}^M[k], Q_{ij}^M[k], LT_{ij}^M[k]) \) of MA \( i \) at \( k \) is able to accept as the final quotation, if one of the following conditions are satisfied:

- when there are still many remain time for negotiation, the profit of MSA \( j \) (coalition \( s_{ij} \)) of taking this quotation is greater than or equals to \( \pi_{ij}^M[k] \); that of taking its own quotation \( (w_{ij}^C[k], Q_{ij}^C[k], LT_{ij}^C[k]) \) \( (w_{ij}^C[k], Q_{ij}^C[k], LT_{ij}^C[k]) \) at \( k \);
3.3 Determination of the Final Allocation Scheme

There are multi-MA and multi-MSA in SCN, and not only MSAs have competitors, but also MAs have contestators. All the MAs and MSAs have the rights to select trade partners to maximize their profits. All the MAs are prone to selecting the supplier with the lowest price to increase their profits and all the MSAs are prone to selecting the manufacturer with the highest price to increase their profits. Therefore, the main point is transformed into how to allocate the orders among MSAs. A two-person like Nash game was proposed in the previous work [10] to solve this problem. We generalize it to multi-attribute negotiation. All the MAs are considered as player 1 and all the MSAs are combined as player 2. Player 1 and player 2 make their strategies simultaneously. The strategy of player 1 in the first layer is the scheme to allocate the orders of its members to MSAs. The strategy of player 2 is the allocation of all the orders from MAs to its members. The agreement is reached only if the strategy of player 1 consists with the strategy of player 2. The final trade partnerships are determined as matrices $M$ and $N_{ij}$, where $M = \{m_{ij}\}$ is the allocation of the orders of MAs among MSAs and $N_{ij} = \{n_{ij}\}$ is the order allocation among the coalitions of MSA $j$ when the order of MA $i$ is out of ability of MSA $j$. There is only one matrix $M$ to record the final allocation of the orders of MAs to MSAs. The value of $m_{ij}$ equals to 1 means MA $i$ is allocated to MSA $j$ and $m_{ij}$ equals to 0 means MA $i$ is not allocated to MSA $j$. $N_{ij}$ exists only if $e_{ij}$ equals to 0 and $m_{ij}$ equals to 1. The value of $n_{ij}$ equals to 1 means the order is allocated to the $l$th coalition of MSA $j$ and $n_{ij}$ equals to 0 means the order is not allocated to the $l$th coalition of MSA $j$. Matrices $M$ and $N_{ij}$ can be got by solving following problem:

\[
\max \Pi_1 + \Pi_2
\]

s.t. \[\Pi_1 = \sum_{i=1}^{M} \sum_{j=1}^{N} m_{ij} \pi_{ij}^{a}(w_{ij}^{f}, Q_{ij}^{f}, LT_{ij}^{f}) \]  \[\Pi_2 = \sum_{i=1}^{M} \sum_{j=1}^{N} n_{ij} \pi_{ij}^{c}(w_{ij}^{f}, Q_{ij}^{f}, LT_{ij}^{f})\]

\[
+ \sum_{i=1}^{M} \sum_{j=1}^{N} (1 - e_{ij}) n_{ij} \pi_{ij}^{e}(w_{ij}^{f}, Q_{ij}^{f}, LT_{ij}^{f}) \]

The final trade partnerships are determined according to $M$ and $N$ after solving eq. (54) - (61), where eq. (55) - (56) are profits of player 1 and player 2, eq. (57) is used to ensure that all the allocated orders to MSA $j$ must be in its ability, eq. (58) is used to calculate the maximum ability at the longest lead time of all the accepted orders, and eq. (59) - (61) mean that each order must and only can be allocated to one MSA or coalition.

4. Numerical Example and Analysis

Numerical example is provided to illustrate the proposed protocol and verify the feasibility of the proposed protocol. The following data is taken just for an example and the settings of the parameters are not so important. That’s because users (MAs and MSAs) can change these parameters according to the indicated products and their own preferences, and the settings of the parameters have no effect on the feasibility of the protocol and the only effect is on the final acquired allocation scheme. Table 1 shows all the settings of the parameters of MAs and MSAs, and the concession function settings are shown as Table 2. For example, if $Q_{ij}^{f}$ (the first column and second line of Table 2) is less than $Q_{ij}^{f}$ (the first column and third line of Table 2), MSA gives a discount of 0.1 (the second column and third line of Table 2) of the wholesale price.

**Table 1** Data set for the numerical illustration.

<table>
<thead>
<tr>
<th>MSA (I=5)</th>
<th>MA (I=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_i \sim U(100,300)$</td>
<td>$h^{m}_{i} = 3$</td>
</tr>
<tr>
<td>$e_{ij} \sim U(200,300)$</td>
<td>$\alpha_{max} = 0.3$</td>
</tr>
<tr>
<td>$e_{ij} \sim U(7,8)$</td>
<td>$\alpha_{max} = 0.5$</td>
</tr>
<tr>
<td>$p_{ij}^{max} = 0.2$</td>
<td>$e_{ij}^{max} = 100$</td>
</tr>
<tr>
<td>$p_{ij}^{max} = 0.5$</td>
<td>$ct^{M}_{i} = 5$</td>
</tr>
<tr>
<td>$k_{ij} = 3$</td>
<td>$ps_{ij}[0] \sim U(13,14)$</td>
</tr>
<tr>
<td>$x_{ij}^{M} = 2$</td>
<td>$\alpha_{i} \sim U(1000,2000)$</td>
</tr>
<tr>
<td>$b_{i} \sim U(0,100)$</td>
<td>$b_{i} \sim U(0,100)$</td>
</tr>
</tbody>
</table>

Evaluation matrix can be get as: $E = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \end{bmatrix}$

and we can see all the orders are out of the abilities of MSA 2 and MSA 3. Thus, MSA 2 and MSA 3 should trigger the coalition formation mechanism to find coalitions.

4.1 Final Quotation of the Negotiation

Take the negotiation between MA 1 and coalition [21] as an example. The fluctuations of three attributes as $k$ goes by are shown in Fig. 6, we can get:
MSA  MA  

<table>
<thead>
<tr>
<th>$Q_{ij}^M$</th>
<th>$\delta_{ij}^M$</th>
<th>$w_i^M$</th>
<th>$\delta_{ij}^M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; Q_{ij}^M$</td>
<td>0.1</td>
<td>$P_M$</td>
<td>1000</td>
</tr>
<tr>
<td>$\geq Q_{ij}^M$</td>
<td>0</td>
<td>$PMI$ &amp; $&lt; w_i^M$</td>
<td>500</td>
</tr>
<tr>
<td>$\geq w_i^M$</td>
<td>0</td>
<td>$PMI$ &amp; $PMI$</td>
<td>0</td>
</tr>
</tbody>
</table>

**Remark:** MSAs (coalitions) failed to reach agreements with MAs because MAs decided their quantities based on the demand of market. The demand increases as the final wholesale price reduces. It may make MSAs (coalitions) finally cannot finish the order by themselves, which may be in their abilities at the first time.

**4.2 Final Allocation Scheme**

Then, the first layer game is used to find the optimal allocation scheme based on the results above. We can get the final allocation scheme by solving eq. (54) as follows:

$$M = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$N_{22} = [00100000000000000000000000]$$
\[ N_{32} = [00000000000000] \]
\[ N_{43} = [1000000000000] \]

That’s means that MA 1 is allocated to MSA 4, MA 2 is allocated to coalition [24] of MSA 2, MA 3 is allocated to coalition [214] of MSA 2, MA 4 is allocated to coalition [31], and MA 5 is allocated to MSA 5. It’s the optimal allocation scheme under the constraints of the three attributes, and the total profit under the above allocation scheme is 102956.86 by calculating eq. (54).

5. Conclusion
This paper discussed multi-attribute negotiation between multi-MA and multi-MSA of SCN, where there are MSAs cannot finish the order by themselves. Three attributes, which constraint each other, are negotiated simultaneously. The quotation of MA, at which the profit of MSA (coalition) of taking this quotation is greater than taking its own quotation, was determined as the final quotation when there are still a lot of time to negotiate. And the quotation of MA, at which the profit of MSA (coalition) of taking this quotation is greater than zero, was determined as the final quotation when negotiation deadline is reaching. A modified hierarchical-game based negotiation protocol was proposed based on the previous work. It was a changeable hierarchical game. It was a two-layer game when all the orders were in abilities of all the MSAs. However, it became to a three-layer game when there are some orders out of abilities of some MSAs. The second layer game was not existed all the time, it existed only if the order was out of ability of MSA and was used to find all the possible coalitions. Then, the third layer game was used to determine the final quotation of the negotiation. Finally, the first layer game tried to find the optimal allocation scheme to maximize the total profit of SCN based on the results of the second and the third layer games.

In this paper, there still exist some MSAs (coalitions) failed to reach agreements with MAs. One way to solve this problem is to adopt dynamic coalition formation mechanism, which makes MSAs (coalitions) dynamically add partners when the order suddenly become out of their abilities. Furthermore, it was assumed that there was only one product in this paper. However, in the real SCN, usually a lot of products are involved and it will become much more complicated. For future work, we will try to extend the results to more common situations.

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