Multi-Objective Negotiation Mechanism in Manufacturing Enterprise Supply Chain Based on Multi-Agent

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ABSTRACT

In the operation of manufacturing enterprise supply chain, there are lots of conflicts and differences between the node enterprises because of the different demands on the price, quality, cost, and other factors. These conflicts and differences can be effectively solved by negotiation. In this paper, the authors will abstract different entities in manufacturing enterprise supply chain as agents, and present a negotiation mode, and then discuss the negotiation tactics and procedures between the purchasing agent and supplier agent. Next, a practical example will be discussed and simulated for validating the negotiation model. Application of negotiation tactics and models will be helpful for resolving differences and conflicts, and improving negotiation efficiency. That will be used for optimizing the supply chain management, maximizing the benefits, and improving the operational efficiency of manufacturing enterprise supply chain.

KEYWORDS
Negotiation Mechanism, Negotiation Model and Tactics, Supply Chain Management

1. INTRODUCTION

IT technology has been widely used in enterprise management practice (Ensslin et al., 2019; Peng et al., 2020). As an inevitable development result of artificial intelligence, agent and multi-agent have attracted attention and concern in the academic research, and are widely used in various fields (Morrar et al., 2019; Yang et al., 2019). In the multi-agent system of supply chain, the node enterprise is independent, the goal of each node enterprise is to maximize profits, and different cooperation strategies and trading mode will be adopted by each node enterprise based on interests, operation mode and product features (Charles, 2002; Hsu et al., 2016; Nader & Ala, 2020). Therefore, each

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enterprise has different requirements on quality, product price, cost, quantity, delivery, service conditions, response time and other factors. All of these demands will develop a large number of conflicts between the manufacturing enterprise and cooperative partner. Negotiation is the frequently-used method for resolving the conflicts and is the main form of interaction between supply chain partners. Cooperative enterprise can realize bilateral or multi-joint tactics by means of negotiation in the manufacturing enterprise (Ji et al., 2017; Du, 2019; Chen et al., 2020). The application of multi-agent technology to manufacturing enterprise supply chain negotiation, will be helpful to realize the coordination and control between enterprises in manufacturing enterprise supply chain, to promote efficient, flexible and efficient cooperation among enterprises, improve negotiation efficiency and save negotiation time, to improve the operation efficiency of supply chain.

The authors mainly discuss the multi-objective multi-agent negotiation mechanism of manufacturing enterprise supply chain in this paper. At first, the main problems will be put forward after analyse relevant literature. And then, the negotiation model is built, and the negotiation process is analysed. Finally, an actual example is applied for validating the effect of the negotiation model and strategies.

2. LITERATURE REVIEW

The agent and multi-agent as well as the negotiation between them have been extensively researched. Soam and Franklin thought the agent is a system that perceives the environment and acts on the environment to achieve its plan (Franklin, 1996; Soam et al., 2017). Wooldridge considered the agent was a computer system designed to achieve the goal of pure packaged, can perform flexible behavior (Wooldridge, 1997). Shoham considered the agent was an entity with the mental state of beliefs, capabilities and commitments (Shoham, 1993). Lane believed the agent is a computing unit with control problem solving mechanism, which can be known as a solver, a module or an expert system (Lane et al., 1994). In solving complex problems, the ability of a sole agent is limited, so, lots of mutually independent agents can be formed a multi-agent system by coordinating their behavior. The different agent will coordinate their goals, accomplish some specific tasks or achieve some goals by collaboration, and share knowledge about solving problems and solving methods in the multi-agent system (Yang et al., 2018).

If the negotiation is conducted under complete information, the agent involving the negotiation will fully understand each other’s information. It is not difficult to reach the Nash equilibrium, communication and negotiation time between negotiating agents will be reduced greatly. In fact, more negotiations are non-cooperation based on incomplete information, such as multi-objective negotiation. Both parties are involved in the negotiation for multiple target negotiation, after several rounds negotiation maybe achieve the possible solutions. Durfee and Lesser think, negotiation is the process of exchanging information between the parties to form a plan. Conflict is the starting point of the negotiation, through a series of mutual concessions, and consensus in the end, the negotiation is a process of bilateral or multi-joint decision-making and mutual compromise (Durfee & Lesser, 1989). In the multi-agent negotiation process of manufacturing enterprise supply chain, each agent representing the enterprise is to communicate with each other through the network, and interact with each other until the goal is reached (Sikora & Shaw, 1997). Huang and Sycara focused on the study of justice, is to use the negotiation model, analyze and improve negotiation strategies, choose the right way to negotiate, arrange a reasonable agenda for the negotiations, and maximize the interests of both parties (Huang & Sycara, 2002). Neumann and Morgenstern divided the negotiations into sole objective and multi-objective. Sole objective negotiation refers to the two sides to negotiate a goal. The goal is to achieve a consensus on negotiating success. Multi-objective negotiation means that the two sides will interact with each other. All the goals can be reached when the agreement is reached. In the negotiation process, it does exist to negotiate with a number of negotiating objectives, such as the price, quality, delivery time, supply quotas, etc. (Neumann & Morgenstern, 1994). Faratin studied from the perspective of negotiation tactics, thought negotiation can be divided into resource-
dependent, time-dependent and dependent behaviour, the factors that affecting the negotiation process mainly includes resources, time and behaviour, and the deliberative bodies can produced a variety of negotiation strategies, the calculation function for negotiating the fuzzy value is given, and the validity of the calculation function is verified by empirical data (Faratin et al., 1998).

About the research of sole objective negotiation, Fatima et al. have studied negotiation between two parties on utility and price based on web. Based on multi-agent system, they built the negotiation model, and proposed the negotiation tactics of the two fair prices (Fatima et al., 2002; Fatima et al., 2004). Sierra et al. have proposed the calculating function of the fuzzy value, the validity of the calculating function has been verified by empirical data (Sierra et al., 1999). Valverde has mainly studied the computing method of fuzzy value in the negotiation (Valverde, 1985). Srinivas has presented a game model of buyer-seller; the model effectively evaluates other bids based on the ideal target set by the buyer (Srinivas, 2002). Joe has presented a new game model between buyer and seller, which maximizes the efficiency of the game according to the multiple goal set by the buyer. The model allows the buyer to evaluate and select the seller in the context of best practice (Joe, 2004). Wan and Far have developed an agent negotiation protocol that is conducive to solving group selection decision problems (Wan & Far, 2007). Wang and Tadisim have studied a case and presented a simulation system based on the theoretical model and actual cases (Wang & Tadisina, 2007). Li and Agent have described and created a multi-agent prototype system based on internet, and explored how to improve the process of marketing strategy through the multi-agent intelligent system supporting Internet (Li & Agent, 2007). Kwon et al. have implemented MACE-SCM, and developed a framework of multi-agent and case-based reasoning, that will helpful to promote collaboration and information sharing in the demand uncertainty and presence of high supply (Kwon et al., 2007). Gao et al. have focused on the multi-stage model of virtual enterprise cooperation and the self-learning negotiation model based on deviation distribution, the problem of task allocation and conflict resolution in a virtual enterprise is solved by the agent, and the validity of the model is proved by experiments (Gao et al., 2003; 2004). Carrascosa and Lin have studied the multi-agent negotiation mechanism for enhancing the existing methods, and then the performance of the integrated system has been evaluated through experiments of the order fulfillment process (Carrascosa et al., 2008; Lin et al., 2006). Suh and Wen have established the links between non-cooperative bargaining solutions based on multi-agent system (Suh & Wen, 2006).

About the research of multi-objective negotiation, Kraus et al. have proposed a general multi-agent negotiation framework model, which is a formal definition of negotiation tactics, negotiation goal and negotiation process, and the sociality and cooperation of multi-agent negotiation are discussed (Kraus et al., 1995). Park and Yang have proposed a multi-objective negotiation model under the e-commerce environment, and discussed the method for making the negotiation agent satisfied or optimal (Park & Yang, 2008). Huang et al. have presented a multi-agent negotiation method for multi-objective parallel machine scheduling in the electro-etching process (Huang et al., 2009). Huang and Liao have presented a 4-phase negotiation model for B2C e-commerce which includes information search, collection, negotiation and evaluation (Huang & Liao, 2012). Jiao et al. have developed a collaborative multi-contract negotiation system based on agent for supporting multiple echelon negotiation (Jiao et al., 2006). Li and Sheng have discussed the multi-agent model for uncertain information reasoning (Li & Sheng, 2011). Jorge et al. have discussed the problem of supply chain coordination planning based on negotiation mechanism and multi-agent system (Jorge et al., 2014). Wang and Chen have proposed the multi-agent multi-objective negotiation model, and put forward a general multi-agent negotiation protocol based on Q-study and Bayesian learning machine (Wang & Chen, 2014). Shi et al. have proposed a multi-agent negotiation model for multi-objective optimization. The model is applied in the evolutionary multi-objective optimization for realizing the distributed and parallel computation (Shi et al., 2006). Fei and Chen have proposed an intelligent negotiation model of integrated multi-agent, multi-object and multi-attribute. The simulated annealing iterative algorithm has been introduced in this model, and SA algorithm has been considered to dynamically adjust the correlation degree for obtaining the optimal negotiation solutions (Fei & Chen, 2007). Wu and Chen
have proposed a buyer collective procurement model applied in a multi-agent framework, and verified the effectiveness of the model by experiments (Wu et al., 2007; Chen et al., 2008). Lee et al. have proposed an interdisciplinary procurement system and searched for information with relevant parties to better coordinate the demand and supply sides (Lee et al., 2009).

As can be seen from the related literatures, negotiation change process of both parties has not been carefully quantified. Questions such as whether the risk preferences of both parties affect the negotiation process and different risk preferences affect the losses of both parties. Therefore, the goal of this paper is to quantify the effect. In this paper, the manufacturing enterprise supply chain multi-agent system will be took as the research object, and take the multi-agent negotiation mechanism as the core. The multi-agent multi-objective negotiation model of manufacturing enterprise supply chain will be constructed based on the related theory, the multi-objective negotiation mechanism between the core enterprise of manufacturing enterprise supply chain and suppliers will be discussed, and the actual calculation example is to verify the negotiation model. That will be helpful for clearly understanding and learning the multi-agent multi-objective negotiation essence, for improving the operational efficiency of manufacturing enterprise supply chain.

3. NEgotiation MODEL AND TACTICS

3.1 Negotiation Hypothesis

The negotiating parties need communicate for completing the negotiation at a specific time in the negotiation process. In order to solve the differences and conflicts, it is necessary to make some hypothesis.

1. Agent is rational and striving to maximize the own interests. And do not accept the solution which is less than the deserving benefits. If \((u_s, u_c)\) is the final negotiation results, there are \(u_s \geq c_s\) and \(u_c \geq c_c\). \(c_s\) and \(c_c\) is the conflict point of the two sides.

2. Agents have joint rational. If there is a negotiation result \(N_p\) which will enable every participant to gain the greater utility, negotiating participants do not choose another result \(N_Q\) as the final result of the consultation.

3. In the offer and counter-offer process, the bid of supplier agent is higher than the bid of manufacturing enterprise purchase agent. The supplier agent is \(U^s(X^i) \geq U^c(Y^{i-1})\) and the purchasing agent is \(U^c(Y^i) \leq U^s(X^{i-1})\), the price of the both parties will tend to an agreement. Here, \(U^s\) and \(U^c\) will represent the utility functions of the supplier and purchasing agent, \(X\) and \(Y\) will represent the offer combinations of the supplier and purchasing agent.

4. If there are two suppliers in the negotiation process, \(U^s_{S_1}(Y^i) > U^s_{S_2}(Y^i)\), the two suppliers will involve negotiation, the willingness of participating in negotiation is \(X^1 = (X^1_p, X^1_q) = (400, 100\%)\).

5. The negotiation process between the purchasing and supplier agent is the offer and counter-offer in manufacturing enterprise supply chain, the offer of purchasing agent is less than the supplier agent, but the eventual offer will tend to be consistent.

3.2 Negotiation Model and Strategies

The multi-objective negotiation of manufacturing enterprise supply chain multi-agent system is the negotiation between the core enterprise and supplier, which is between the purchasing and supplier agent. The main participants will negotiate about price, quality, delivery and supply quotas in the operation of manufacturing enterprise supply chain. At this time, the price is no longer the dominant position. The research significance of the delivery date is not important. The delivery date is ahead of time, and it
will increase the cost of inventory for the core enterprises, delivery delay will cause shortages, so that the interests of enterprises are damaged. Therefore, the delivery date as far as possible is just in time. In this paper, the negotiation of delivery time is not studied further. The suppliers and core enterprise among the manufacturing enterprises supply chain will share the benefits. From the long-term strategic partnership, supply quotas are generally fixed or change range is very small, so the supply quota is not the focus in the paper. And the price and quality negotiation will be conducted in-depth research on.

In the multi-objective negotiation process of manufacturing enterprise supply chain multi-agent system, there is a situation which an agent negotiates with a number of agents. For example, the purchasing agent of the core enterprise in manufacturing enterprise supply chain will negotiate with the supplier agent on price and quality about some parts or raw materials. The negotiation procedure is described in Figure 1.

1. The offer tactics of the purchasing agent and supplier agent

At time $t = t_i$, the offer combination of the purchasing agent is $X^i = (P^c_i, Q^c_i)$, $P^c_i$: represents price, $Q^c_i$: represents quality, $i = 1, 2, \ldots, n$.

The offer tactics of the purchasing agent are as following.

$$
P^c_i = P^c_{i-1} + a_c \times \frac{1}{\sqrt{T}} (P^c_{i-1} - P^c_{i-1})$$
$$Q^c_i = Q^c_{i-1} + a_c \times \frac{1}{\sqrt{T}} (Q^c_{i-1} - Q^c_{i-1})$$

(1)

In the formula, $a_c$: represents the degree of the risk appetite of the purchasing agent. That is, the higher for risk appetite of the purchasing agent is, the larger for $a_c$ is. When $i = 1$, the offer combination of the purchasing agent is $X^i = (P^c_1, Q^c_1)$.

Figure 1. Negotiation Process of One to Many of Manufacturing Enterprise based on Multi-Agent
At time $t = t_i$, the offer combination of the supplier agent is $Y^i = (P^i, Q^i)$, $P^i$: represents price, $Q^i$: represents quality, $i = 1, 2, ..., n$.

The offer tactics of the supplier agent are as following.

$$
\begin{align*}
P_i^s &= P_{i-1}^s + a_s \times \frac{1}{\sqrt{e}} (P_i^e - P_{i-1}^s) \\
Q_i^s &= Q_{i-1}^s + a_s \times \frac{1}{\sqrt{e}} (Q_i^e - Q_{i-1}^s)
\end{align*}
$$

(2)

In the formula, $a_s$: represents the degree of the risk appetite of the supplier agent. That is, the more for risk appetite of the supplier agent is, the bigger for $a_s$ is. When $i = 1$, the offer combination of the supplier agent is $Y^1 = (P^1, Q^1)$.

When $i = 1$, $X^1$ and $Y^1$ represent the initial offer of the purchasing and supplier agent respectively.

2. The unity of the purchasing agent and supplier agent

$U_p^c$ and $U_q^c$: respectively represents the utility function of price and quality in offer combination of the purchasing agent.

$U_p^s$ and $U_q^s$: respectively represents the utility function of price and quality in offer combination of the supplier agent.

The value ranges of $U^c$ and $U^e$ is $(0,1)$.

$W_s^p$ and $W_s^Q$: respectively represents the important degree of price and quality in the offer combination of supplier agent.

$W_c^p$ and $W_c^Q$: respectively represents the important degree of price and quality in the offer combination of purchasing agent. The relation of them is as following.

$$
\begin{align*}
W_c^p + W_c^Q &= 1 \\
W_s^p + W_s^Q &= 1
\end{align*}
$$

(3)

The utility function of the price and quality of the purchasing agent are as following.

$$
\begin{align*}
U^p_i &= \frac{P_i^e - P_i^c}{P_i^e - P_i^c} \\
U^Q_i &= \frac{Q_i^e - Q_i^c}{Q_i^e - Q_i^c} \\
U_i^c &= W_c^p U^p_i + W_c^Q U^Q_i
\end{align*}
$$

(4)
In the formula, $U^p_i$: represent the price utility function of the purchasing agent, $U^q_i$: represent the quality utility function of purchasing agent, $U^s_i$: represent the joint utility function of purchasing agent offer combination.

Similarly, the utility functions of supplier agent are as following.

$$
\begin{align*}
U^p_i &= \frac{P^e_i - P^p_i}{P^e_i - P^p_i} \\
U^q_i &= \frac{Q^e_i - Q^q_i}{Q^e_i - Q^q_i} \\
U^s_i &= W^p_i U^p_i + W^q_i U^q_i 
\end{align*}
$$

(5)

In the formula, $U^p_i$: represent the price utility function of the supplier agent, $U^q_i$: represent the quality utility function of the supplier agent, $U^s_i$: represent the joint utility function of the supplier agent offer combination.

The joint utility function of both sides is as following.

$$U_i = U^s_i \times U^s_i$$

(6)

3. The loss of the purchasing agent and supplier agent

The loss of purchasing agent in the negotiation progress is as following.

$$
\begin{align*}
L^p_i &= P^e_i - P^p_i \\
L^q_i &= Q^e_i - Q^q_i \\
L^{(p, q)}_i &= W^p_i L^p_i + W^q_i L^q_i 
\end{align*}
$$

(7)

In the formula, $L^p_i$: represents the price loss of the purchasing agent, $L^q_i$: represents the quality loss of the purchasing agent, $L^{(p, q)}_i$: represents the comprehensive loss of price and quality of the purchasing agent.

The loss of the supplier agent in the negotiation progress is as following.

$$
\begin{align*}
L^p_i &= P^e_i - P^p_i \\
L^q_i &= Q^e_i - Q^q_i \\
L^{(p, q)}_i &= W^p_i L^p_i + W^q_i L^q_i 
\end{align*}
$$

(8)
In the formula, \( L_i^p \): represents the price loss of the supplier agent, \( L_i^q \): represents the quality loss of the supplier agent, \( L_i^{p,q} \): represents the comprehensive loss of price and quality of the supplier agent.

4. The conditions of negotiation termination

Usually, if the price and utility comply with the requirements of both parties, the negotiation can be terminated. Sometimes, time can be used as a condition for the termination of a negotiation. Considering the resource constraints, fuzzy membership will be used as the condition for judging whether to accept the offer of the other party.

The fuzzy membership function of the purchasing agent is as following.

\[
\begin{align*}
V_s^e(F_s^e) &= e^{-\frac{E_s^e - E_s}{b}} \\
V_e^c(F_e^c) &= e^{-\frac{E_e^c - E_e}{b}} \\
F_s^e &= W_s^p P_s^e + W_s^q Q_s^e \\
F_e^c &= W_e^p P_e^c + W_e^q Q_e^c
\end{align*}
\]

In the formula, \( V_s^e \): represents the fuzzy membership of the purchasing agent, \( F_s^e \): represents the comprehensive calculation results of the offer combination of purchasing agent, \( F_e^c \): represents the comprehensive calculation results of the offer combination of supplier agent.

The fuzzy membership function of the supplier agent is as following.

\[
\begin{align*}
V_s^e(F_s^e) &= e^{-\frac{E_s^e - E_s}{b}} \\
V_e^c(F_e^c) &= e^{-\frac{E_e^c - E_e}{b}} \\
F_s^e &= W_s^p P_s^e + W_s^q Q_s^e \\
F_e^c &= W_e^p P_e^c + W_e^q Q_e^c
\end{align*}
\]

In the formula, \( V_s^e \): represents the fuzzy membership of the supplier agent.

5. The behavior of the purchasing agent and supplier agent

At the time \( t = t_i \), the behavior of the purchasing agent is as following.

\[
A^s(t_i, X_{c=t_i}) = \begin{cases} 
  \text{Quit} & t > T_{Max} \\
  \text{Accept} & N(Y^i) \geq N(X^i) \\
  \text{Offer} & N(Y^i) < N(X^i)
\end{cases}
\]

(11)
At the time \( t = t_i \), the behavior of the supplier agent is as following.

\[
A^i \left( t_i, Y^i_{s} \right) = \begin{cases} 
\text{Quit} & t > T^{Max} \\
\text{Accept} & G \left( X^i \right) \geq G \left( Y^i \right) \\
\text{Offer} \left( x^{i+1} \right) & G \left( X^i \right) < G \left( Y^i \right) 
\end{cases}
\] (12)

In the formula, \( T^{Max} \) represents the deadline that purchasing agent and supplier agent will complete negotiation and reach an agreement.

### 3.3 Negotiation Procedure

There does exist one purchasing agent and lots of supplier agent \( Y^1 = \left( Y^1_p, Y^1_q \right) = \left( 480, 95\% \right) \) that is suitable for negotiation in manufacturing enterprise supply chain in reality. The sort is set according to the given utility of supplier and meet \( U_s \left( n_1 \right) > U_s \left( n_2 \right) > \cdots > U_s \left( n_l \right) \), the negotiation procedures can be drawn as follows. The negotiation process is as showed in Figure 2.

Step 1: At time \( t = t_i \), the two sides begin to negotiate. The purchasing agent must meet \( U_c \left( Y^2 \right) \leq U_c \left( X^i \right) \), and the supplier agent must meet \( U_s \left( X^2 \right) \geq U_s \left( Y^1 \right) \), and the supplier that cannot satisfy the conditions will be eliminated. And then the purchasing agent will negotiate with the supplier agent \( \left( n_1, n_2, \cdots, n_l \right) \), if \( U_s \left( X^i \right) \leq U_s \left( Y^{i-1} \right) \), turn to step 5.

Step 2: Set up \( l_m \left( l_m < l \right) \) as the number of the supplier agent that can negotiate with the purchasing agent. At time \( t = t_i \), when both parties meet \( U_c \left( Y^i \right) \leq U_c \left( X^{i-1} \right) \) and \( U_s \left( X^i \right) \geq U_s \left( Y^{i-1} \right) \), the supplier with satisfying the conditions will gain the supply quantity that is decided by the supply quota coefficient. If \( M_D = \sum_{i-1}^{l_m} \beta \left( Y^i_D \right) \), then turn to step 4. In the formula, \( M_D \) is the all quantity that purchasing agent needs. \( Y^i_D \) is the supplying quantity of supplier agent \( l_i \) in the delivery time. \( \beta \) is the supply quota coefficient of supplier agent \( l_i \), in general, \( \beta \in \left[ 0.3, 0.7 \right] \). This can prevent some unforeseen circumstances, for example, suppliers cannot timely supply in some unforeseen circumstances. This can reduce the possibility of shortages. Different supplier has the different supply quota coefficient. For example, the supply quota coefficient of the supplier of the Philips Company is 0.3.

Step 3: If \( M_D = \sum_{i-1}^{l_m} \beta \left( Y^i_D \right) \), the purchasing agent will send the termination message to the supplier agent, and then turn to step 4. If all the negotiation tasks are completed, the negotiation process is automatically stopped, and turns to step 5. If the negotiation task is not accomplished, repeat step 2 and step 3.

Step 4: The purchasing agent will contract with the supplier agent, and will accept the task.

Step 5: Ending negotiation.

### 4. NEGOTIATION ILLUSTRATIONS

The difference risk appetite of the supplier agent and the purchasing agent will affect the negotiation. In the following illustration, the different risk appetite will be given to compare the negotiation results, which not only test the effectiveness of the negotiation model, but also understand the impact of risk appetite on the negotiation. The authors will select three values of 0.3, 0.5, and 0.7 to represent the
different degree of risk appetite, namely, risk aversion, risk neutrality and risk preference. In order to more clearly analyse the impact of different risk preference on the negotiation process, the risk appetite of the two parties is classified as showed in Table 1.

In the multi-agent negotiation process of manufacturing enterprise supply chain, the purchasing agent need negotiate with the supplier agent about price and quality for certain raw materials and spare parts. The degree of risk appetite can affect the negotiation times, utility and price. The following example is to discuss their changes.

The initial offer combination of the purchasing agent is \( X^1 = (300, 100\%) \), and the initial offer combination of the supplier agent is \( Y^1 = (500, 90\%) \). The conditions of negotiation termination is, that the difference between membership and acceptance is less than or equal to 0.01.
In the negotiation process, the participants will make an offer combination according to their respective offer tactics, the change of $a_c$ and $a_s$ will affect the negotiation process. There are three different situations will be discussed to clearly state the changes by means of computer simulation.

1. The case 1: Risk aversion ($a_s = 0.3, a_c = 0.3, 0.5, 0.7$)

In the negotiation process, the participants will make an offer combination according to their respective offer tactics, the change of $a_c$ and $a_s$ will affect the negotiation process.

In this case, the supplier agent is risk aversion ($a_s = 0.3$), the risk appetite of the purchasing agent is changing, $a_c = 0.3, 0.5, 0.7$ will be selected as a sample. They will negotiate according to the negotiation procedure, and the specific negotiation process is as showed in Table 2, Table 3 and Figure 3. The negotiation results are shown in the Table 2($a_s = 0.3, a_c = 0.3, 0.5, 0.7$), the negotiation process is shown in the Figure 2($a_s = 0.3, a_c = 0.3, 0.5, 0.7$), and the negotiation data are shown in Table 3($a_s = 0.3, a_c = 0.3$).

When $a_s = 0.3, a_c = 0.3$, that means the purchasing agent and supplier agent are risk aversion, the negotiation times is 9, the negotiated transaction price is 400.00, the negotiated transaction quality is 95.00%, the joint unity is 0.25. The loss of price and quality of the purchasing agent and supplier agent is the same, the loss of price is 100, and the loss of quality is 5.00%. The unity is the same, that is 0.5, and the joint unity is 0.25.

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<th>$a_c$</th>
<th>$i$</th>
<th>$P^*$</th>
<th>$Q^*$</th>
<th>$V_{C}^*$</th>
<th>$V_{S}^*$</th>
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<td>400</td>
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<td>0.776</td>
<td>0.782</td>
<td>100</td>
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<td></td>
<td>4</td>
<td>0.612</td>
<td>0.615</td>
<td>139.887</td>
<td>6.99%</td>
<td>69.979</td>
</tr>
</tbody>
</table>

Table 1. Classification of risk appetite

<table>
<thead>
<tr>
<th></th>
<th>Risk Aversion</th>
<th>Risk Neutrality</th>
<th>Risk Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_s$</td>
<td>$a_c$</td>
<td>$a_s$</td>
<td>$a_c$</td>
</tr>
<tr>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 2. Negotiation Results ($a_s = 0.3, a_c = 0.3, 0.5, 0.7$)
As we know, in this case, the risk preference of the supplier agent is risk aversion, and the risk appetite of the purchasing agent is changing. It can be viewed from the negotiation results, when the risk appetite of the purchasing agent $a_c$ is changing from 0.3 to 0.7, the final transaction price is changing from 400.00 to 439.887, and the final transaction quality is changing from 95.00% to 93.01%. The price loss of the supplier agent is changing from 100 to 60.113, the quality loss is changing from 5.00% to 3.01%., and the comprehensive loss of price and quality is changing from 50.025 to 30.071. The price loss of the purchasing agent is changing from 100 to 139.887, the quality loss is changing from 5.00% to 6.99%., and the comprehensive loss of price and quality is changing from 50.025 to 69.979. The unity of the purchasing agent is changing from 0.5 to 0.7, the unity of the supplier agent is changing from 0.5 to 0.3, and the joint unity is changing from 0.25 to 0.21.

It can be viewed when the supplier agent and purchasing agent and are risk aversion, they will make small concessions for each negotiation, which maybe lead to negotiating many times and reach the final agreement. When one party’s risk preference is getting bigger and bigger, this will be led to negotiating fewer times and reach the final agreement.

2. The case 2: Risk neutrality ($a_s = 0.5, a_c = 0.3, 0.5, 0.7$)

In this case, the supplier agent is risk neutrality ($a_s = 0.5$), the purchasing agent is changing, $a_c = 0.3, 0.5, 0.7$ will be selected as a sample. They will negotiate according to the negotiation procedure, and the specific negotiation process is as showed in Table 4, Table 5 and Figure 4. The negotiation results are shown in the Table 4($a_s = 0.5, a_c = 0.3, 0.5, 0.7$), the negotiation process is shown in the Figure 3($a_s = 0.5, a_c = 0.3, 0.5, 0.7$), and the negotiation data are shown in Table 5($a_s = 0.5, a_c = 0.3$).

When $a_s = 0.5, a_c = 0.3$, that means the supplier agent is risk neutrality, and the purchasing agent is risk aversion, the negotiation times is 7, the negotiated transaction price is 375.163, and the negotiated transaction quality is 96.24%. The price loss of the purchasing agent is 75.163, and the
price loss of the supplier agent is 124.837. The quality loss of the supplier agent is 6.24%, and the quality loss of the purchasing agent is 3.76%. The unity of the purchasing agent is 0.376, the unity of the supplier agent is 0.624, and the joint unity is 0.235.

As we know, in this case, the supplier agent is risk neutrality, and the risk appetite of the purchasing agent is changing. It can be viewed from the negotiation results, when the risk appetite of the purchasing agent $a_c$ is changing from 0.3 to 0.7, the final transaction price is changing from 375.163 to 416.663, the final transaction quality is changing from 96.24% to 94.17%. The price loss of the supplier agent is changing from 124.837 to 83.357, the quality loss is changing from 6.24% to 4.17%., and the comprehensive loss of price and quality is changing from 62.449 to 41.699. The price loss of the purchasing agent is changing from 75.163 to 116.643, the quality loss is changing from 3.76% to 5.83%., and the comprehensive loss of price and quality is changing from 37.600 to 58.351. The unity of the supplier agent is changing from 0.376 to 0.583, the unity of the purchasing agent is changing from 0.624 to 0.417, and the joint unity is changing from 0.235 to 0.243.

Table 3. Negotiation Data ($a_s = 0.3, a_c = 0.3$)

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P^s$</td>
<td>500</td>
<td>477.927</td>
<td>449.568</td>
<td>428.258</td>
<td>415.053</td>
<td>407.659</td>
<td>403.769</td>
<td>401.809</td>
<td>400.851</td>
<td>$P^s = 400$</td>
</tr>
<tr>
<td>$P^c$</td>
<td>300</td>
<td>322.073</td>
<td>350.432</td>
<td>371.742</td>
<td>384.947</td>
<td>392.341</td>
<td>396.231</td>
<td>398.191</td>
<td>399.149</td>
<td>$Q^c = 0.95$</td>
</tr>
<tr>
<td>$Q^s$</td>
<td>0%</td>
<td>91.10%</td>
<td>92.52%</td>
<td>93.59%</td>
<td>94.25%</td>
<td>94.62%</td>
<td>94.81%</td>
<td>94.91%</td>
<td>94.96%</td>
<td></td>
</tr>
<tr>
<td>$Q^c$</td>
<td>100%</td>
<td>98.90%</td>
<td>97.48%</td>
<td>96.41%</td>
<td>95.75%</td>
<td>95.38%</td>
<td>95.19%</td>
<td>95.09%</td>
<td>95.04%</td>
<td></td>
</tr>
<tr>
<td>$V^s$</td>
<td>0.368</td>
<td>0.454</td>
<td>0.572</td>
<td>0.663</td>
<td>0.718</td>
<td>0.749</td>
<td>0.764</td>
<td>0.772</td>
<td>0.776</td>
<td>0.776</td>
</tr>
<tr>
<td>$V^c$</td>
<td>1</td>
<td>0.988</td>
<td>0.938</td>
<td>0.879</td>
<td>0.835</td>
<td>0.808</td>
<td>0.794</td>
<td>0.786</td>
<td>0.782</td>
<td>0.782</td>
</tr>
<tr>
<td>$V^s$</td>
<td>0.368</td>
<td>0.454</td>
<td>0.572</td>
<td>0.663</td>
<td>0.718</td>
<td>0.749</td>
<td>0.764</td>
<td>0.772</td>
<td>0.776</td>
<td>0.776</td>
</tr>
<tr>
<td>$V^c$</td>
<td>1</td>
<td>0.988</td>
<td>0.938</td>
<td>0.879</td>
<td>0.835</td>
<td>0.808</td>
<td>0.794</td>
<td>0.786</td>
<td>0.782</td>
<td>0.782</td>
</tr>
<tr>
<td>$L^p$</td>
<td>0</td>
<td>22.073</td>
<td>50.432</td>
<td>71.742</td>
<td>84.947</td>
<td>92.341</td>
<td>96.231</td>
<td>98.191</td>
<td>99.149</td>
<td>100</td>
</tr>
<tr>
<td>$L^q$</td>
<td>0</td>
<td>22.073</td>
<td>50.432</td>
<td>71.742</td>
<td>84.947</td>
<td>92.341</td>
<td>96.231</td>
<td>98.191</td>
<td>99.149</td>
<td>100</td>
</tr>
<tr>
<td>$L^s$</td>
<td>0</td>
<td>1.10%</td>
<td>2.52%</td>
<td>3.59%</td>
<td>4.25%</td>
<td>4.62%</td>
<td>4.81%</td>
<td>4.91%</td>
<td>4.96%</td>
<td>5.00%</td>
</tr>
<tr>
<td>$L^c$</td>
<td>0</td>
<td>1.10%</td>
<td>2.52%</td>
<td>3.59%</td>
<td>4.25%</td>
<td>4.62%</td>
<td>4.81%</td>
<td>4.91%</td>
<td>4.96%</td>
<td>5.00%</td>
</tr>
<tr>
<td>$U^s$</td>
<td>1</td>
<td>0.791</td>
<td>0.559</td>
<td>0.411</td>
<td>0.331</td>
<td>0.29</td>
<td>0.269</td>
<td>0.259</td>
<td>0.254</td>
<td>0.25</td>
</tr>
<tr>
<td>$U^c$</td>
<td>1</td>
<td>0.89</td>
<td>0.748</td>
<td>0.641</td>
<td>0.575</td>
<td>0.538</td>
<td>0.519</td>
<td>0.509</td>
<td>0.504</td>
<td>0.5</td>
</tr>
<tr>
<td>$U^s$</td>
<td>1</td>
<td>0.89</td>
<td>0.748</td>
<td>0.641</td>
<td>0.575</td>
<td>0.538</td>
<td>0.519</td>
<td>0.509</td>
<td>0.504</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Table 4. Negotiation Results ($a_s = 0.5, a_c = 0.3, 0.5, 0.7$)

<table>
<thead>
<tr>
<th>$a_s$</th>
<th>$a_c$</th>
<th>$i$</th>
<th>$P^s$</th>
<th>$Q^s$</th>
<th>$V_{s}^c$</th>
<th>$V_{c}^s$</th>
<th>$L_i^P$</th>
<th>$L_i^Q$</th>
<th>$L_i^{P,Q}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.3</td>
<td>6</td>
<td>375.163</td>
<td>96.24%</td>
<td>0.675</td>
<td>0.680</td>
<td>124.837</td>
<td>6.24%</td>
<td>62.449</td>
</tr>
<tr>
<td>0.5</td>
<td>5</td>
<td>400</td>
<td>95.00%</td>
<td>0.778</td>
<td>0.780</td>
<td>100</td>
<td>5.00%</td>
<td>52.025</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>4</td>
<td>416.643</td>
<td>94.17%</td>
<td>0.840</td>
<td>0.841</td>
<td>83.357</td>
<td>4.17%</td>
<td>41.699</td>
<td></td>
</tr>
</tbody>
</table>

It can be viewed when the supplier agent is risk neutrality and purchasing agent is risk aversion, they will make bigger concessions for each negotiation, which maybe lead to negotiating less times and reach the final agreement. When one party’s risk preference is getting bigger and bigger, this will be led to negotiating fewer times and reach the final agreement. Compared with the case 1, the same indicators are less than the case 1.

3. The case 3: Risk preference ($a_s = 0.7, a_c = 0.3, 0.5, 0.7$)
In this case, the supplier agent is risk preference \( a_s = 0.7 \), the purchasing agent is changing, \( a_c = 0.3, 0.5, 0.7 \) will be selected as a sample. They will negotiate according to the negotiation procedure, and the specific negotiation process is as showed in Table 6, Table 7 and Figure 5. The negotiation results are shown in the Table 6\( (a_s = 0.5, a_c = 0.3) \), the negotiation process is shown in the Figure 5\( (a_s = 0.7, a_c = 0.3, 0.5, 0.7) \), and the negotiation data are shown in Table 7\( (a_s = 0.7, a_c = 0.3) \).

When \( a_s = 0.7, a_c = 0.3 \), that means the risk appetite of supplier agent is risk preference, and the risk appetite of purchasing agent is risk aversion, the negotiation times is 5, the negotiated transaction price is 360.113, and the negotiated transaction quality is 96.99%. The price loss of the supplier agent is 139.887, and the price loss of the purchasing agent is 60.113. The quality loss of the supplier agent is 6.99%, and the quality loss of the purchasing agent is 3.01%. The unity of the supplier agent is 0.301, and the unity of the purchasing agent is 0.699, and the joint unity is 0.21.

### Table 5. Negotiation Data \( (a_s = 0.5, a_c = 0.3) \)

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ps</td>
<td>500</td>
<td>463.212</td>
<td>420.409</td>
<td>394.38</td>
<td>382.305</td>
<td>377.52</td>
<td>375.814</td>
<td>( P^* = 375.163 )</td>
</tr>
<tr>
<td>Pc</td>
<td>300</td>
<td>322.073</td>
<td>347.754</td>
<td>363.372</td>
<td>370.617</td>
<td>373.488</td>
<td>374.512</td>
<td></td>
</tr>
<tr>
<td>Qs</td>
<td>90%</td>
<td>91.84%</td>
<td>93.98%</td>
<td>95.28%</td>
<td>95.88%</td>
<td>96.12%</td>
<td>96.21%</td>
<td>( Q^* = 96.24% )</td>
</tr>
<tr>
<td>Qc</td>
<td>100%</td>
<td>98.90%</td>
<td>97.61%</td>
<td>96.83%</td>
<td>96.47%</td>
<td>96.33%</td>
<td>96.27%</td>
<td></td>
</tr>
<tr>
<td>Vs</td>
<td>0.368</td>
<td>0.454</td>
<td>0.561</td>
<td>0.627</td>
<td>0.658</td>
<td>0.67</td>
<td>0.675</td>
<td>0.675</td>
</tr>
<tr>
<td>Vc</td>
<td>1</td>
<td>0.967</td>
<td>0.854</td>
<td>0.757</td>
<td>0.708</td>
<td>0.688</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td>Vs</td>
<td>0.368</td>
<td>0.514</td>
<td>0.696</td>
<td>0.801</td>
<td>0.844</td>
<td>0.861</td>
<td>0.866</td>
<td>0.866</td>
</tr>
<tr>
<td>Vc</td>
<td>1</td>
<td>0.988</td>
<td>0.945</td>
<td>0.905</td>
<td>0.883</td>
<td>0.874</td>
<td>0.871</td>
<td>0.871</td>
</tr>
<tr>
<td>Ls</td>
<td>0</td>
<td>36.788</td>
<td>79.591</td>
<td>105.62</td>
<td>117.695</td>
<td>122.48</td>
<td>124.186</td>
<td>124.837</td>
</tr>
<tr>
<td>Lc</td>
<td>0</td>
<td>22.073</td>
<td>47.754</td>
<td>63.372</td>
<td>70.617</td>
<td>73.488</td>
<td>74.512</td>
<td>75.163</td>
</tr>
<tr>
<td>Ls</td>
<td>0</td>
<td>1.84%</td>
<td>3.98%</td>
<td>5.28%</td>
<td>5.88%</td>
<td>6.12%</td>
<td>6.21%</td>
<td>6.24%</td>
</tr>
<tr>
<td>Lc</td>
<td>0</td>
<td>1.10%</td>
<td>2.39%</td>
<td>3.17%</td>
<td>3.53%</td>
<td>3.67%</td>
<td>3.73%</td>
<td>3.76%</td>
</tr>
<tr>
<td>U</td>
<td>1</td>
<td>0.726</td>
<td>0.458</td>
<td>0.322</td>
<td>0.266</td>
<td>0.245</td>
<td>0.238</td>
<td>0.235</td>
</tr>
<tr>
<td>Us</td>
<td>1</td>
<td>0.816</td>
<td>0.602</td>
<td>0.472</td>
<td>0.412</td>
<td>0.388</td>
<td>0.379</td>
<td>0.376</td>
</tr>
<tr>
<td>Uc</td>
<td>1</td>
<td>0.89</td>
<td>0.761</td>
<td>0.683</td>
<td>0.647</td>
<td>0.633</td>
<td>0.627</td>
<td>0.624</td>
</tr>
</tbody>
</table>
As we know, in this case, the supplier agent is risk preference, and the risk appetite of the purchasing agent is changing. It can be viewed from the negotiation results, when the risk appetite of the purchasing agent is changing from 0.3 to 0.7, the final transaction price is changing from 360.113 to 400.00, and the final transaction quality is changing from 96.99% to 95.00%. The price loss of the supplier agent is changing from 139.887 to 100, the quality loss is changing from 6.99% to 5.00%, and the comprehensive loss of price and quality is changing from 69.979 to 50.025. The price loss of the purchasing agent is changing from 60.113 to 100, the quality loss is changing from 3.01% to 5.00%, and the comprehensive loss of price and quality is changing from 30.072 to 50.025.

The unity of the supplier agent is changing from 0.301 to 0.5, the unity of the purchasing agent is changing from 0.699 to 0.5, and the joint unity is changing from 0.210 to 0.25.

It can be viewed when the supplier agent is risk preference and purchasing agent is risk aversion, they will make bigger concessions for each negotiation, it is easy for both sides to come to an agreement.

### Table 6. Negotiation Results ($a_s = 0.7, a_c = 0.3, 0.5, 0.7$)

<table>
<thead>
<tr>
<th>$a_s$</th>
<th>$a_c$</th>
<th>$i$</th>
<th>$P^*$</th>
<th>$Q^*$</th>
<th>$V_s^*$</th>
<th>$V_c^*$</th>
<th>$L^{p_s}$</th>
<th>$L^{q_s}$</th>
<th>$L^{(p_s,q_s)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.3</td>
<td>6</td>
<td>360.113</td>
<td>96.99%</td>
<td>0.612</td>
<td>0.615</td>
<td>139.887</td>
<td>6.99%</td>
<td>69.979</td>
</tr>
<tr>
<td>0.7</td>
<td>0.5</td>
<td>5</td>
<td>383.357</td>
<td>95.83%</td>
<td>0.711</td>
<td>0.712</td>
<td>116.643</td>
<td>5.83%</td>
<td>58.351</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>4</td>
<td>400.000</td>
<td>95.00%</td>
<td>0.779</td>
<td>0.779</td>
<td>100</td>
<td>5.00%</td>
<td>50.025</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$a_s$</th>
<th>$a_c$</th>
<th>$i$</th>
<th>$V_s^c$</th>
<th>$V_c^c$</th>
<th>$L^{p_c}$</th>
<th>$L^{q_c}$</th>
<th>$L^{(p_c,q_c)}$</th>
<th>$U$</th>
<th>$U^s$</th>
<th>$U^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.3</td>
<td>6</td>
<td>0.913</td>
<td>0.914</td>
<td>60.113</td>
<td>3.01%</td>
<td>30.072</td>
<td>0.210</td>
<td>0.301</td>
<td>0.699</td>
</tr>
<tr>
<td>0.7</td>
<td>0.5</td>
<td>5</td>
<td>0.840</td>
<td>0.841</td>
<td>83.357</td>
<td>4.17%</td>
<td>41.699</td>
<td>0.243</td>
<td>0.417</td>
<td>0.583</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>4</td>
<td>0.779</td>
<td>0.779</td>
<td>100</td>
<td>5.00%</td>
<td>50.025</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Figure 5. Negotiation process diagram ($a_s = 0.7, a_c = 0.3, 0.5, 0.7$)

As we know, in this case, the supplier agent is risk preference, and the risk appetite of the purchasing agent is changing. It can be viewed from the negotiation results, when the risk appetite of the purchasing agent $a_c$ is changing from 0.3 to 0.7, the final transaction price is changing from 360.113 to 400.00, and the final transaction quality is changing from 96.99% to 95.00%. The price loss of the supplier agent is changing from 139.887 to 100, the quality loss is changing from 6.99% to 5.00%, and the comprehensive loss of price and quality is changing from 69.979 to 50.025. The price loss of the purchasing agent is changing from 60.113 to 100, the quality loss is changing from 3.01% to 5.00%, and the comprehensive loss of price and quality is changing from 30.072 to 50.025. The unity of the supplier agent is changing from 0.301 to 0.5, the unity of the purchasing agent is changing from 0.699 to 0.5, and the joint unity is changing from 0.210 to 0.25.

It can be viewed when the supplier agent is risk preference and purchasing agent is risk aversion, they will make bigger concessions for each negotiation, it is easy for both sides to come to an agreement.
When one party’s risk appetite is getting bigger and bigger, this will be led to negotiating fewer times and reach the final agreement. Compared with the case 2, the same indicators are less than the case 2.

4. Analysis and discussion of results

The summary of the negotiation results is presented in table 8. From the table, how risk preference affects the negotiation process can be clearly observed.

Different from the existing research, how the different risk preferences of agents affect the negotiation process will be discussed.

1. The higher the risk appetite of the negotiators is, the fewer the negotiation times. The greater the difference in risk appetite between the negotiators, the smaller the negotiation utility, conversely, the more the negotiation utility tend to the ideal utility value of 0.25
2. The participant with a higher degree of risk appetite is in the more unfavorable position, that is, the higher the risk appetite of the negotiators, the greater the price loss, the greater the quality loss. This situation can be clearly seen in the negotiation of risk appetite combination (0.3, 0.7), (0.5, 0.7) and (0.7, 0.3). This means that the party with a higher risk appetite is at a disadvantage in the negotiation.

3. It can be drawn from Table 8, if the negotiating sides have a preference risk, the number of negotiations is the least and the utility is the largest. If neither side of negotiation has appetite for risk, both sides are very cautious, the change of price and quality is very small, so more consultations needed to reach an agreement. If one side has no appetite for risk, but the other has appetite for risk, so the utility of final offer combination is asymmetric, the utility of the side which does not have appetite for risk is much larger than the one has appetite for risk.

5. CONCLUSION

1. The multi-agent multi-objective negotiation is a complex problem. In this paper, the authors have discussed how the different risk preferences of agents affect the negotiation process. It has been found through research, (1) Different risk preferences will affect the number of successful negotiations. That is, the higher the risk appetite of the negotiators is, the fewer the negotiation times. (2) The participant with a higher degree of risk appetite is in the more unfavorable position, that is, the higher the risk appetite of the negotiators, the greater the price loss, the greater the quality loss. These findings will helpful for improving the efficiency of conflict resolution and resource allocation, and optimize the supply chain management, and achieve a win-win situation for the common interests of manufacturing enterprises.

2. There are two aspects will be mainly considered in the future research. First, the tripartite negotiation multi-party negotiation will be conducted based on the negotiation between the two parties. It does exist that the negotiation among three parties or multi-parties in the actual operation of supply chain. Second, with the development and application of Internet technology, personalized product supply chain of manufacturing enterprise has become the tendency. The negotiation between the personalized product supply chain multi-agent system and traditional manufacturing enterprise supply chain multi-agent system is not the same. And this problem is worth studying. It is our pleasure that will cooperate with researchers in this field to carry out research.
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