Negotiation Mechanism for TAC SCM Component Market*

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ABSTRACT

This paper presents a new negotiation mechanism and a new supplier model for Trading Agent Competition Supply Chain Management(TAC SCM). Under the new negotiation mechanism, an agent is allowed to negotiate with component suppliers on price, delivery date and supply quantity while a supplier can autonomously vary its production capacity with market demands and allocate its products to buyers through auction. A mathematical analysis is given to ensure the new negotiation mechanism and supplier model effectively solve the existing problems while keeping most good features of the original TAC SCM game model.

Categories and Subject Descriptors

I.6.5 [**SIMULATION AND MODELING**]: Model Development

General Terms

Algorithms, Design, Experimentation

Keywords

negotiation, trading agent, multi-agent simulation and modelling

1. INTRODUCTION

Electronic commerce is one of the most important forces shaping business today. It presents a huge opportunity for creating economic value. Nevertheless doing business digitally brings with it significant risks. In circumstances where there are no tried and tested models, developing an e-business strategy involves forays into uncharted waters for most managers[15]. Trading Agent Competition(TAC) provides a set of Web-based multi-agent simulation environments for examining artificial e-market models and evaluating business strategies for electronic commerce[13, 17]. The TAC Supply Chain Management(TAC SCM) is one of two well-designed game scenarios with such a simulation environment. The game has been successfully run for two years from 2003[4]. The success of the game is embodied not only by its increasing popularity and a number of high quality research papers but more importantly by the initiation of research on several crucial issues in e-market modelling and trading agent design[2, 5, 9, 11, 12, 13, 14, **?**].

TAC SCM specifies a virtual three-level supply chain of personal computer(PC) manufacturing and marketing[1]. Participants in the game are invited to design autonomous agents, acting as PC manufacturers, capable of negotiating with component suppliers for PC parts procurement, managing daily assembly activities and competing with each other for customer orders. Besides the challenges to agent designers in developing cost-effective business strategies, the game has been also defying the game designers to provide functional market environments that ensure the techniques developed for the game to be applicable to the real business. The game specified two electronic marketplaces: *the component marketplace* where manufacturers acquire PC parts and *the product marketplace* where they sell their PC products to end customers. The product market operates with the standard multi-item auction mechanism, which was working very well in previous games. However, the component market exploited an artificial supply-dominant market mechanism under which the buyers have no determination on the market. With the TAC-03 SCM specification, the price of a component is determined by the following formula[2]:

$$p(d, d+i) = p_{base}(1 - 0.5\frac{C_{available}(d, d+i)}{iC_{nominal}}) \qquad (1)$$

where $p(d, d+i)$ is the price of the component under consideration on day d for delivery on day $d+i$; p_{base} is the pre-specified price of the component (base price); $C_{nominal}$ is the nominal production capacity of the product line that produces the component(constant); $C_{available}(d, d+i)$ is the total free capacity of the product line from day d to day $d+i$.

It is easy to see from the formula that the price of each component at the very beginning of a game is significantly lower than any following days because the full capacity of production is available at the beginning of a game. This feature encourages all agents order their components in the very beginning(referred to as "*day-0-procurement*"). Even worse, due to the acceptance of component orders is based

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on the nominal capacity of a product line regardless its actual production capacity, which varies day to day during a game, it happens very often that a supplier cannot commit its component contracts when actual production capacity is under the nominal capacity (no creditability on trade enforcement). The random arrival of components causes manufacturers to be unable to schedule their production and to fulfil their PC contracts. Most common business strategies in production scheduling, price forecasting and cost management are not applicable in agent design.

Another serious problem with the component market is that the supply of each component is independent of the market demand and market price but is determined by a random walking mechanism. This allows an agent to corner a whole market of a particular component(typically the cheapest component). A number of lottery effects have been seen especially in the final round of TAC-04 SCM games.

Many efforts to reduce the supply "lottery effects" have been put during the previous games. For instance, the price policy (Formula 1) was changed and a heavy storage cost was introduced in TAC-04 SCM specification in order to discourage day-0-procurement. However, the problems of the malfunctioning of component market still exist.

We argue that the problem of the TAC SCM component market is not the improper setting of the formulas for component price or production capacity but more deeply in its market mechanism. In fact, the current component market is not a market at all in economic sense. The supply of components follows the planned economy in which no market mechanism is applied. A supplier cannot adjust its production according to market demands. The supply of components deviates from their market price. The interaction between suppliers and agents is limited in information exchange. As a result, the behavior of the component market is far from the reality.

This paper introduces a new negotiation mechanism into the component market by allowing agents (component buyers) to negotiate with component suppliers on price, due date and quantity. Moreover, the autonomy is given to each supplier to decide its production capacity and selling price. A supplier is allowed to vary its production capacity according to the law of supply and to allocate its products to buyers according to *buyers offer price*, *due date* and *required quantity*. A mathematical analysis is given to show that the new market model can effectively solve the existing problems of the component market meanwhile keep the good features of the original proposal of the game, such as its simplicity and zero free inventory. A new TAC SCM server and AgentWare based on the existing system has been implemented[1].

2. NEGOTIATION PROTOCOL FOR COMPONENT MARKET

In the original TAC SCM specifications, the interaction between component suppliers and PC manufacturers is limited to three rounds: *agents send requests for quote(RFQ) to suppliers*, *suppliers make offers to agents RFQs* and *agents reply with orders for purchasing components*. An agent, acting as a manufacturer, is not allowed to bargain on price or due date with suppliers, either accept or refuse suppliers' offers. In our proposed component market model, we allow an agent to bargain with suppliers about price, delivery date and quantity. The interaction between agents and suppliers consists of the following four rounds:

- An agent sends RFQs to suppliers for querying the price and availability of a component whenever the agent wants to buy a component from a suppler;
- When a supplier receives an RFQ, the supplier can choose to either ignore the RFQ or send back an offer to the agent with its offer price, available date and available quantity;
- An agent can have three choices when it receives an offer from a supplier: reject the offer by doing nothing; accept the offer by sending back an order; or bargain with the supplier with price, delivery date, and/or quantity by replying with a counter offer;
- If a supplier receives an order, the supplier will sign the contract with no further negotiation. However a supplier can reject a counter offer according to its current reserve price and availability of the product. If a supplier accepts a counter offer, it will reply with a confirmation.

The protocol can be depicted by the following figure:

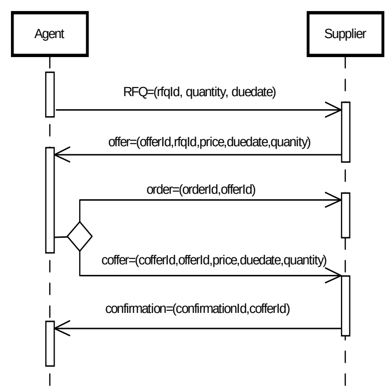

Figure 1: Negotiation Protocol between Agent and Supplier.

3. SUPPLIER MODEL

To demonstrate how negotiation strategies can be used under the proposed negotiation mechanism, we revamp the original supplier model so that a supplier can negotiate with component buyers on price, due date and supply quantity. The open model of supplier will help us to evaluate the business strategies developed for participating agents. To make the presentation simple, we will focus on the key features of the supplier model. The other features will remain the same as the TAC-04 SCM specification[3].

The major changes are the following:

- An adjustment has been introduced to the suppliers' decision on daily production to reflect the law of supply[10].

[1]The new server can be downloaded from `http://www.cit.uws.edu.au/ dongmo/newTACSCMServer/`. The system was built based on the SICS's TAC Supply Chain Management Simulator, which is copyrighted by SICS.

- Production scheduling is based on so-called *guaranteed production capacity* (see Section 3.3) rather than nominal capacity to ensure the fulfilment of all component contracts.
- Different price policies are applied to demonstrate the negotiation strategies of suppliers.

3.1 Assumptions

Most assumptions that made in TAC-03 and TAC-04 specifications will remain true under the new model. Some changes have been made to accommodate the new supplier model. We assume that:

1. At the beginning of a day, each supplier calculates its production capacity for each product line it owns.
2. All orders and counter offers received by a supplier on last day are then processed. Confirmations are sent to successful counter offerers immediately. The orders and accepted counter offers are scheduled for production. Production scheduling is based on the guaranteed production capacity.
3. Production of any products is strictly based on production schedule. End products are automatically transformed to inventory.
4. Orders are delivered to the manufacturers and charged exactly on their due dates. Only complete orders are shipped. No early payment or deposit is required.
5. At the end of the day, each supplier processes all the RFQs received from agents on this day and makes offers to manufacturers.

3.2 Daily production capacity

In the original TAC SCM game scenario, it is specified that each supplier has a dedicated product line with a nominal capacity C_0 (the expected or mean production) for each component type it supplies. The actual production capacity $C(d)$ of each component line varies day to day, which is determined by the following formula:

$$C(d) = max(C_{min}, C(d-1) + \sigma_1 C_0 + \sigma_2(C_0 - C(d-1))$$

where C_{min} is the minimal capacity the supplier of the component can commit. σ_1 is a random number, representing the unpredictable factor that affects the production of the product line. σ_2 is a constant which reverts the capacity back to nominal. The setting of the values are $C_{min} = 0$, $\sigma_1 = ramdom(-0.05, +0.05)$ and $\sigma_2 = 0.01$ in TAC-03 and TAC-04 specifications. As we have pointed before, this setting suffers several severe problems. On the one hand, there is no lower bound of production capacity for product lines. A supplier cannot fulfil its commitment to the accepted orders when the capacity is down to a low level because suppliers' scheduling is based on the nominal capacity. This causes many lottery effects in the previous TAC games. On the other hand, a supplier is unable to adjust its production when the demand of a product is increasing or decreasing. This incurred a problem that one agent could corner a component market and block other agents' procurement. To solve the problems, we introduce the following changes in the determination of supplier production capacity:

- Allow a supplier to have a non-zero minimal capacity.
- Allow a supplier to vary its production to reflect the law of supply[10].

With the ideas, each supplier's production capacity is determined by the following formula:
$C(d) =$

$$\max(C_{min}, C(d-1) + \sigma_1 C_0 + \sigma_2(C_0 - C(d-1)) + C_{adjust}) \quad (2)$$

where

$$C_{adjust} = \sigma_3 \frac{p_{average} - p_{expected}}{p_{base}} C_0$$

$p_{expected}$ is the supplier's expected price of the component; $p_{average}$ is its average selling price on last day (initially equals to expected price). $p_{expected}$ is currently set as $0.75 * p_{base}$ and $\sigma_3 = 0.1$.

For other parameters, we simply keep the original setting of TAC-04 except for C_{min}. In our current implementation of the supplier agent, C_{min} was set to a non-zero values, which was the half of the nominal capacity C_0. With the non-zero minimal production capacity, a supplier is able to guarantee its production without a breach of contract. This can be of great help to the supplier in the decision of accepting long term ordering and the reduction of the lottery effects.

We remark that those factors that affect supplier's production can be classified into two categories: *objective ones* and *subjective ones*. The random movement and reverting walk simulate the objective factors that a supplier cannot control whereas the capacity variation with selling price can be a full decision by the supplier itself.

3.3 Guaranteed production capacity(GPC)

As we have mentioned, a supplier uses the minimal production capacity of a product line for its long-term production scheduling. For short-term scheduling, a supplier can expect more production than the minimum because the actual production capacity on each day is normally much higher than the minimal capacity and the variation of capacity is limited as shown in the formula 2.

Suppose that the current production capacity of a product line is $C(d)$. The maximal reduction of the capacity that is out of the owner's control can only be:

- Reduction due to random variation: $-\sigma_1 C_0$;
- Reduction due to back reverting: $\sigma_2(C_0 - C(d))$.

where σ_1 represents the boundary of random variation(we overload the symbol just for simplicity).

Definition 1. *Let $C(d)$ be the production capacity of a component line on day d. For each $i \geq 0$, let*
$C_{GPC}(d, d+i) =$

$$\max(C_{min}, (1-\sigma_2)^i C(d) - (\sigma_1 - \sigma_2) C_0 \sum_{k=0}^{i-1} (1-\sigma_2)^k)$$

We call C_{GPC} the guaranteed minimal capacity (GPC) of the product line.

It is easy to show that if we ignore the part of the capacity adjustment C_{adjust} in Formula 2, then $C_{GPC}(d, d+i)$ will be always less than the actual production capacity $C(d+i)$.[2]

[2]In the implementation of the supplier model, a supplier always checks the current production schedule to find any possible over-commitment when it adjusts the production capacity for a product line.

Therefore a supplier can always guarantee its production with the quantity $C_{GPC}(d, d+i)$. According to the standard setting of σ_1 and σ_2,

$$C_{GPC}(d, d+i) = \max(C_{min}, 0.99^i C(d) - 20\sum_{k=0}^{i-1} 0.99^k)$$

For instance, if the current production capacity of a product line is 500 units, the C_{GPC} will not reach the minimum until 10 days later. If the current capacity is 800 units, the total accumulated extra capacity that the supplier can use for scheduling purpose is 5999 units, which is equivalent to 12 days nominal production capacity. This leaves a gap for agents to bargain about component price and due date.

3.4 Production scheduling

Before we describe the supplier's offering procedure, let's explain how a supplier schedules its production once a supply contract is signed.

Considering a product line of a component type, let $S(d, d+i)$ denote the production quantity scheduled on day d for day $d+i$. Initially we have

$S(0, d) = 0$.

Suppose that the day $d-1$'s scheduling has been done, which is:

$S(d-1, d-1+i)$ for any $i \geq 0$.

For each order or accepted counter offer for the component, we need to reschedule the product line so that the order can be produced on time. Similar to the original TAC SCM supplier model, a supplier always tries to defer the production of an order until the due date approaching in order to minimize inventory cost and productive capital. Thus a supplier will firstly try to fill an order (accepted counter offer) into the due date, if failed, then try the day before until all the free capacity between the current day and the due date is full. A significant difference between our scheduling mechanism and the original is that we use GPC for scheduling rather than the nominal capacity. This makes it possible for a supplier to guarantee the fulfilment of component contracts meanwhile maximize the use of its production capacity.

Let $\{(q_k, d_k) : k = 1, \cdots, m\}$ are all the orders received or the counter offers accepted by a supplier on day d for a component it produces. We calculate the schedule of day d recursively by putting these orders or counter offers into the existing schedule one by one: For each $i \geq 0$, let

$$S^0(d, d+i) = S(d-1, d+i)$$

Suppose that $S^{k-1}(d, d+i)$ is the result of scheduling after the first $k-1$ orders or accepted counter offers have been processed. Now we put the order(accepted counter offer) (q_k, d_k) into the schedule:

1. for any day d' after d ($d' > d_k$),
   $S^k(d, d') = S^{k-1}(d, d')$
2. for the days between d and d_k, we schedule the production backward from d_k to d recursively.
   Let $q^{d_k} = q_k$. For each $t = d_k, d_k - 1, \cdots, d$,
   (a) if $q^t \geq C_{GPC}(d, t) - S^{k-1}(d, t)$,
   $S^k(d, t) = C_{GPC}(d, t)$ and $q^{t-1} = q^t - C_{GPC}(d, t)$.
   (b) if $q^t < C_{GPC}(d, t) - S^{k-1}(d, t)$,
   $S^k(d, t) = q^t + S^{k-1}(d, t)$ and $q^{t-1} = 0$.

DEFINITION 2. *An order or an accepted counter offer* (q_k, d_k) *is scheduled if* $q^{d-1} = 0$.

We will prove in the next section that any order or counter offer accepted by a supplier can be scheduled to production by the supplier and is guaranteed to be produced and delivered on time under the new supplier model.

4. SUPPLIER PRICING POLICY

In this section we focus on suppliers pricing policies in offer-making and counter offer processing. We will see that a supplier uses different pricing policies in different stages of negotiation in order to maximize its bargaining power.

4.1 Making offers

On each day each supplier collects all RFQs it received on the previous day, calculate total amount of request quantity and make offers to selected RFQs.

Let $R = \{(rq_j, rdd_j) : j = 1, \cdots, n\}$ be all the RFQs a supplier received for a component, where rq_j represents the requested quantity and rdd_j the requested due date. Let $Q_{RFQ} = \sum_{j=1}^{n} rq_j$ be the total requested quantity. The procedure to process the RFQs is the following:

1. Calculates the *earliest completion date, ecd*, to produce the requested component:

   $$ecd = \min_u (Q_{RFQ} + \sum_{k=d+1}^{u} S(d, k) \leq (u-d-1)C_{min})$$

   Note that the checking for free capacity starts from $d+1$ because the actual orders won't arrive until the next day.

2. For each RFQ $r_j = (rq_j, rdd_j)$, calculate offering due date, *odd*, and offering price, op_j, as follows:

   $$odd_j = \begin{cases} rdd_j & \text{if } rdd_j >= ecd + 1; \\ ecd + 1 & \text{otherwise.} \end{cases}$$

   $op_j = p_{base}(1 - discount)$, where

   $$discount = \delta\left(1 - \frac{Q_{RFQ} + \sum_{k=d+1}^{odd_j - 1} S(d,k)}{(odd_j - d - 1)c_{min}}\right);$$

   p_{base} is the *base price* of the component;

   δ is the discount coefficient(standard value is 0.5).

In our implementation of the game server, some RFQs might be ignored if there is not enough production capacity available. The selection of RFQs are based on buyers' previous order ratios (reputation) and current requested quantities. An RFQ sent by an agent with higher reputation and requested for smaller quantity has higher priority to be processed. Once the total available minimal capacity of a product line for the whole game period has been used out, no further RFQs will be processed(a partial offer could be issued if a portion of request quantity can be met).

4.2 Counter offer processing

As we have described in the negotiation protocol, once an agent receives an offer of a component from a supplier, the agent can

- directly order the component if it accepts all the conditions in the offer, or

- reply with a counter offer for a better price and/or an earlier delivery date.

On the supply side, whenever a supplier received a valid order(referring to an offer that was sent by the supplier for the same component in last day), the supplier will simply accept the order and schedule its production immediately. For those counter offers, the process is slightly complicated. Firstly, the supplier will separate those counter offers in which the requested quantity is no more than offered quantity from the others, and then sort these two groups of counter offers respectively according to the following criteria:

- the higher offer price receives higher priority;
- if prices are the same, the earlier due date receives higher priority;
- if prices and due dates are the same, the larger request quantity receives higher priority;
- if prices, due dates and quantities are the same, the earlier arrived RFQ receives higher priority.

These two sorted lists are then put together with the first group in front. Let $coffer = \{(p_j, d_j, q_j) : j = 0, \cdots, m\}$ be the resulting list of all the counter offers. For each of the counter offer in the list, if the supplier decides to accept it, the supplier will schedule its production immediately; otherwise, move to the next one until all the counter offers have been processed. Suppose that the first $j-1$ counter offers have been processed and now consider the counter offer (p_j, d_j, q_j). Assume that the current production schedule is $S(d,k)$. Then the supplier *accepts* the counter offer if and only if it satisfies the following conditions:

1. $q_j <= \sum_{k=d}^{d_j-1}(C_{GPC}(d,k) - S(d,k))$
2. $p_j >= p_{base}(1 - discount)$, where

$$discount = \delta\left(1 - \frac{q_j + \sum_{k=d}^{d_j-1} S(d,k)}{\sum_{k=d}^{d_j-1} C_{GPC}(d,k)}\right)$$

We call $p_{reserve} = p_{base}(1 - discount)$ the supplier's *reserve price* of the component. Note that supplier's reserve prices are dynamic, which varies with the processing of component orders and counter offers. The following proposition shows that any accepted counter offer can be guaranteed to be produced and then be delivered on time.

PROPOSITION 1. *For any counter offer (p_j, d_j, q_j), if it is accepted, it can be scheduled for production.*

We remark that such a property might not be desirable because it does not allow a supplier breaches its contracts, which may happen in the real world. One possible solution is to introduce penalty into late delivery as it has existed in the product market. For the convenience of formal analysis of the supplier model, we will leave such an extension for future implementation.

5. PROPERTIES OF SUPPLIER MODEL

In this section, we presents some important properties of the proposed negotiation mechanism and supplier model to show that the existing problems can be efficiently solved.

5.1 Orders vs counter offers

As we have seen in the previous section, a supplier processes orders and counter offers separately. This makes it possible that any agent built on the original AgentWare is still workable under the new game server without any change. However, since orders are always processed before any counter offers, a question raises that if an agent orders a component by sending a counter offer with exactly the offer conditions, whether the counter offer can be accepted by the supplier as if an order were sent. The following theorem answers the question.

THEOREM 1. *Let $o = (op, odd, oq)$ be an offer a supplier sent to an agent on day d, where op,odd and oq are the offer price, offer due date and offer quantity, respectively. Let $co = (cop, codd, coq)$ be the respective counter offer that was received by the supplier on day $d+1$. If $cop = op$, $odd = codd$ and $oq = coq$, this counter offer will be accepted.*

Proof: Let Q_{RFQ} are the total quantity of all the accepted RFQs. According to the supplier's offering procedure, we have

$$Q_{RFQ} + \sum_{k=d+1}^{odd-1} S(d,k) \le (odd - d - 2)C_{min}$$

On the other hand, before the counter offer being processed, the exiting production schedule should satisfies:

$$\sum_{k=d+1}^{odd-1} S(d+1,k) \le Q_{RFQ} - oq + \sum_{k=d+1}^{odd-1} S(d,k)$$

Put these two inequations together, we have

$$\begin{aligned} oq &\le oq + (odd-d-2)C_{min} - (Q_{RFQ} + \sum_{k=d+1}^{odd-1} S(d,k)) \\ &\le (odd-d-2)C_{min} - (Q_{RFQ} - oq + \sum_{k=d+1}^{odd-1} S(d,k)) \\ &\le (odd-d-2)C_{min} - \sum_{k=d+1}^{odd-1} S(d+1,k) \\ &\le \sum_{k=d+1}^{odd-1} C_{GPC}(d+1,k) - \sum_{k=d+1}^{odd-1} S(d+1,k) \end{aligned}$$

Therefore the supplier can commit to the production of the counter offer. Note that there is one day delay between the offer date and the day the counter offer being processed. Now we calculate the reserve price of the supplier for the counter offer:

$$\begin{aligned} p_{reserve} &= p_{base}\left(1 - \delta\left(1 - \frac{oq + \sum_{k=d+1}^{odd-1} S(d+1,k)}{\sum_{k=d+1}^{odd-1} C_{GPC}(d+1,k)}\right)\right) \\ &\le p_{base}\left(1 - \delta\left(1 - \frac{Q_{RFQ} + \sum_{k=d+1}^{odd-1} S(d,k)}{\sum_{k=d+1}^{odd-1} C_{GPC}(d+1,k)}\right)\right) \\ &\le p_{base}\left(1 - \delta\left(1 - \frac{Q_{RFQ} + \sum_{k=d+1}^{odd-1} S(d,k)}{(odd-d-2)C_{min}}\right)\right) \end{aligned}$$

Therefore the counter offer can be accepted. ¶

According to the theorem it is equivalent for an agent to order a component by sending a direct order or replying with a counter offer with exactly offer conditions. This is not trivial because a counter offer can offer a price higher than the offer price. The theorem guarantees that such a counter offer won't disturb supplier's scheduling.

5.2 Large procurement

The following proposition shows that the new supplier model discourage large procurement.

PROPOSITION 2. *Let $r = (rq, rdd)$ be an RFQ an agent sent to a supplier for a component on a day d and $o = (op, odd, oq)$ be the supplier's offer w.r.t. the RFQ. If $rdd_i < odd_i$, then $op_i > p_{base}(1 - \frac{\delta}{odd-d-1})$.*

Proof: Let ecd be the earliest completion date for all the RFQs a supplier received for a component on day d. If $rdd_i < odd_i$, we have $odd_i = ecd + 1$. Let $\varepsilon = (ecd - d)C_{min} - Q_{RFQ} - \sum_{k=d+1}^{ecd} S(d,k)$. According to the definition of Earliest Completion Date, it follows that

$$0 \le \varepsilon < C_{min}$$

Then

$$\begin{aligned} op_i &= p_{base}(1 - \delta(1 - \frac{Q_{RFQ} + \sum_{k=d+1}^{ecd} S(d,k)}{(ecd-d)c_{min}})) \\ &= p_{base}(1 - \delta(1 - \frac{(ecd-d)c_{min} - \varepsilon}{(ecd-d)c_{min}})) \\ &= p_{base}(1 - \delta\frac{\varepsilon}{(ecd-d)c_{min}}) \\ &> p_{base}(1 - \frac{\delta}{ecd-d}) \\ &= p_{base}(1 - \frac{\delta}{odd-d-1}) \qquad ¶ \end{aligned}$$

According to the proposition, if an RFQ asks for more than 1000 for an early delivery, the discount it can expect will be less than 0.125 regardless other RFQs ($\delta = 0.5$). If each of six agents requests for 1000 units for a component on the same day, the discount each agent can expect will be about 0.02, which is nearly nothing.

5.3 Day 0 procurement

As we have seen above, the new supplier model discourages large procurement. Therefore it can mitigate significantly the problem of "Day-0-Procurement" and cornering market. However, the new model still keeps the feature of encouraging long term component procurement as TAC-04 supplier model. This is also applicable to day 0.

LEMMA 1. *Let $r_i = (rq_i, rdd_i)$ and $r_j = (rq_j, rdd_j)$ be two RFQs for the same component and sent to the same supplier on day 0. $o_i = (op_i, odd_i)$ and $o_j = (op_j, odd_j)$ are the offers for each of the RFQs, respectively. If $rdd_i \le rdd_j$, then $op_i \ge op_j$ and $odd_i \le odd_j$.*

Proof: Let ecd is the earliest completion date for all the RFQs the supplier received for the component on day 0. The offer due dates for r_i and r_j are then respectively:

$$odd_k = \begin{cases} rdd_k & \text{if } rdd_k >= ecd+1; \\ ecd+1 & \text{otherwise.} \end{cases} \quad k = i, j$$

Therefore if $rdd_i \le rdd_j$, then $odd_i \le odd_j$. For the offer prices, since we have $S(0, d) = 0$ for all d, we have

$op_k = p_{base}(1 - \delta(1 - \frac{Q_{RFQ}}{(odd_k - 1)c_{min}})), k = i, j$

Thus if $odd_i \le odd_j$, $op_i \ge op_j$. ¶

The lemma shows that if a long-term procurement made received higher discount than a short-term procurement if the procurements are made on day 0. However, this does not mean that the old *"day-0-procurement"* problem would come back again. Before we give the reason we remark that the decision of day-0-procurement for each agent is no long an optimization problem under the new supplier model but a game-theoretical problem because the discount an agent can get depends on the total quantity of RFQs rather than individual RFQs. Agents have to compete each other for day 0 procurement. The following theorem shows that agents have no incentive to join the competition of day 0 procurement under the new supplier model.

THEOREM 2. *Let n be the number of agents playing in a game. For each component from a supplier, if each agent orders a component on day 0 exactly in the market equilibrium quantity of the component and asks for the same due date, the discount each agent can get is $\frac{\delta}{n+1}$ and the associated market equilibrium quantity for each agent is $\frac{(dd-1)C_{min}}{n+1}$, where dd is the common due date.*

Proof: Let q_i be the total RFQed quantity from agent i. According to the proof of Lemma 1, the discount each agent can receive is then:

$$discount = \delta(1 - \frac{\sum_{k=1}^{n} q_k}{(dd-1)C_{min}})$$

Thus the benefit for ordering the component on day 0 for agent i will be:

$$B_i = p_{base} * q_i * discount$$

To maximize B_i, the first order condition for agent i is:

$$(dd-1)C_{min} - \sum_{k=1}^{n} q_k - q_i = 0, \; i = 1, \cdots, n$$

Solving the set of equations gives the Nash equilibrium quantity for each agent:

$$q_i^* = \frac{(dd-1)C_{min}}{n+1}$$

The discount each agent can gain is then:

$$discount^* = \frac{\delta}{n+1}$$

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Let $n = 6$ and $\delta = 0.5$. According to the theorem, if each agent order components on day 0 with the equilibrium quantity, the discount each agent can expect will be 0.07, which is much less than the average discount a supplier is giving (supplier's expecting discount is 0.25). Therefore no agent will have the incentive to involve in the severe competition of day 0 procurement. Since only half of production capacity is scheduled ahead, the other half of production capacity is left for short-term ordering. An agent can expect to acquire their component in a reasonable price during normal days. However, a small amount of day 0 procurement is still profitable for agents, which also benefits suppliers because a reasonable amount of long-term contacts are always welcome for suppliers.

5.4 Bargaining Range

Finally we consider the bargaining range of component purchasing from buyers perspectives. Since the new negotiation model for the component market is basically a special type of auction, the actual component price depends on the situation of market competition. Also an agent have no means to probe the exact value of suppliers reserve price because it dynamically changes. Nevertheless, there are still several ways for agents to guess suppliers reserve price which are helpful for an agent to make a good bargain.

Figure 2 shows the result of an experiment in which a dummy-agent-based agent competes with other five built-in dummy agents. The curves illustrates the suppliers's offer prices and reserve prices for CPU 2.0GHz on each day. It shows that the prices for day 0 are relatively less than its following days but higher than the average price. The offer prices are evenly distributed all the way in the game while the reserve prices start with high and evenly distribute later on, reflecting the effects of suppliers's self adjustment of production capacity. It is also observable that the less offer price is, the less an agent can bargain. This is more visible for day 0 procurement.

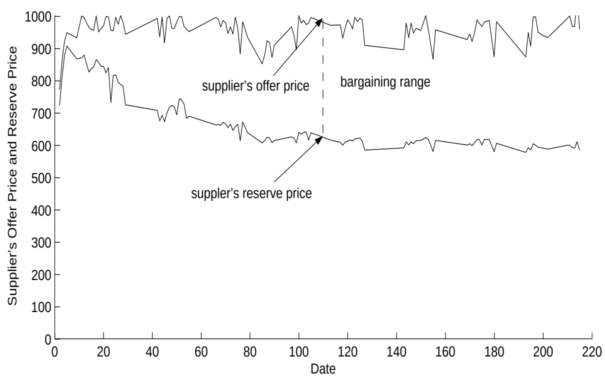

Figure 2: Agent's bargaining range for component price(Pintel CPU 2.0GHz).

Figure 3 illustrates the bargain range for due dates. It can be seen that the average bargaining range of due dates is about 4 to 5 days. However the actual bargaining range varies with the agents' bargaining strategies. Normally higher counter offer prices gain bigger bargaining range for due date.

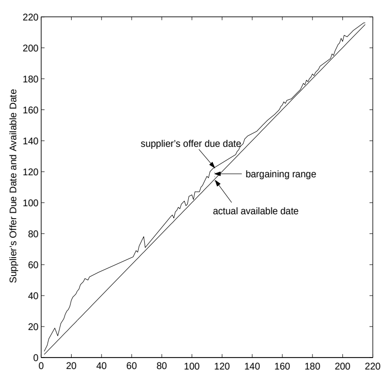

Figure 3: Agent's bargaining range for component due date(Pintel CPU 2.0GHz).

6. CONCLUSION AND RELATED WORK

In this paper, we presented a new negotiation mechanism for TAC SCM component market and a new supplier model to demonstrate how negotiation strategies can be applied in automated negotiation. With the proposed negotiation mechanism both sellers and buyers are able to operate the component market autonomously. The new supplier model simulates the operation of modern enterprise in more aspects than the original proposal:

- A supplier is seeking to maintain its credibility in the fulfilment of component contracts.
- A supplier is seeking to maximize its profits by utilizing market competition .
- A supplier is seeking to balance long-term business relationships and short-term market supply.
- A supplier is seeking to enhance its negotiation power.

With the new market model we have shown that most of the existing problems with the TAC SCM game, such as *day 0 procurement*, *lottery effects of component supply* and *coverage of a particular component market*, have been effectively solved.

Due to the serious problem of lottery effects in component market, intensive discussion has been made through the TAC forum in last two years. This provided a great resource of good ideas. Many suggestions have been integrated in the draft proposal of TAC-05 SCM specification, which was recently released on the TAC website for discussion[7]. Similar to our market model, the proposed specification introduced an auction-like mechanism into the component market by allowing agents to set a reserve price. The advantage of the approach is that the old three-round interaction model can be kept without any change. However, it leaves much uncertainty to agents for component price and availability. Another similarity between our proposal and the new specification is that both models reserve some capacity from long-term commitments. A linear reduction function is introduced to limit committed contracts. Nevertheless, no formal analysis has be done for either the original specifications or the new specification on component market.

The direct goal of this paper is to improve the realism of the TAC SCM simulation. As an extension of auction, the proposed negotiation mechanism may be used in other market situations. Although the formal analysis of market mechanisms is mostly domain dependent, this paper shows an example of how a formal analysis and a deliberate design of market mechanism could improve the efficiency of an e-marketplace. We believe that a well-designed negotiation mechanism and a well-tested market model will not only make the TAC games more interesting but more importantly will secure the emerged techniques for trading agent design and e-market development to be more applicable to the real e-business.

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