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A Framework for Agents Conducting E-Business in a Supply Chain

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ABSTRACT

This paper describes the development of an agent-based framework that supports the purchasing function in supply chain management. The framework has been applied in a case situation for planned order releasing from a manufacturer's materials requirement planning (MRP) system. The proposed framework incorporates a negotiation protocol that can effectively coordinate the negotiation process between a buyer agent and several supply agents, which may represent the manufacturer and its suppliers respectively. These agents negotiate according to their preferred strategies which aim to conclude a deal that achieves their own objectives. The implementation of the negotiation process involves considerations of the price of the materials required, past delivery performance, and the quality of materials supplied in the past. Simulation is used to explore the effectiveness of the proposed framework using an agent-based negotiation model, and the results indicate that the proposed framework can be used to improve the overall efficiency of the purchasing process. A case example is also presented to demonstrate the usefulness of the framework.

INTRODUCTION

To cope with ever-increasing global competition, manufacturing enterprises need to eventually prepare themselves for full participation in the various forms of e-business related to supply chain management. Gangopadhyay and Huang (2004) discussed the value of e-business in supply chain management and concluded that, with the advent of electronic commerce, enterprises can reduce production costs through better management of inventories, backorder reduction, and with more competitive sourcing. For example, Motorola (Metty et al., 2005) deployed an Internet-based sourcing platform in 2002, which they claimed helped the company save US$600 million on a US$16 billion turnover in commodity items. Organizations which are not quite ready to take advantage of electronic marketplaces or B2B applications are usually considered as being less competitive than those companies that have embraced e-business applications, see Cucchiella et al. (2002) and Gottschalk and Abrahamsen (2002). Recent research has shown that e-business applications are capable of supporting many business activities such as e-marketing (Madariaga, 2004), e-procurement (Lightfoot and Harris, 2003), and supply chain integration (Yang et al., 2005). In this paper, we focus on the purchasing function of a manufacturing enterprise, as the costs of materials and associated services can often account for 70% - 80% of the total product cost (Ghobadian at el., 1993).

At the consumer market level, both online shopping (Zhang and Prybutok, 2003) and internet auctions (Bracker and Smith, 2004) have achieved excellent penetration, but this has not yet happened at the enterprise level. Contemporary Enterprise Resources Planning (ERP) systems such as SAP, PeopleSoft and Oracle, incorporate enhanced features that cater for strategic sourcing of e-procurement functions (Al-Mashari, 2003; Hsu and Chen, 2004). For example, Supplier Relationship Management (SRM) from SAP provides a procurement platform for online supplier participation, while other approaches such as Ariba (www.ariba.com) and GlobalSources (www.globalsources.com) have focused mainly on enhancing e-marketplaces participation. Buyers can announce their Request-For-Quotation (RFQ) on these e-portals or e-marketplaces and then systematically assess the quotations they received. However, these systems are regarded as too expensive for most small to medium-sized enterprises (SME), see Mabert (2002). Some SME also regard such systems as ungainly and difficult to implement.

The agent-based framework proposed in this paper attempts to meet a need to establish an economical e-business application that can help to manage the purchasing function of a supply chain, especially for the SME. The main aim is to facilitate the purchasing functions between trading partners through electronic agent-based negotiation. The framework developed was implemented in a local manufacturing company to help with the supplier selection problems. This paper begins with a general discussion of the relevant research work on the purchasing functions in a supply chain and the applications of multi-agent system in negotiation, a detailed discussion of the proposed framework, including the modeling of the agents and the negotiation protocol, forms the middle section, and a case example together with results of the simulation comparing different negotiation strategies by the buyer agent are discussed toward the end of the paper.

LITERATURE REVIEW

In the traditional purchasing function, supplier selection is one of the main aims. Following on Dickson's (1966) 23 considerations for vendor selection, considerable research has been conducted on the supplier(s) selection problem. Weber and Current (1993) considered the three attributes of: price, delivery performance and quality performance, and used a multi-objective programming approach to analyze the tradeoffs involved. Their approach was further developed and "shaped" into a tool for buyers to negotiate with the vendors (Weber et al., 2000 and 1998; Weber & Desai, 1996). Das and Tyagi (1999) studied negotiations between manufacturers and wholesalers and proposed a sequential method for price discount negotiation when the manufacturers and wholesalers are cooperative and exchanged all the relevant information. One of the problems with all these approaches is that they assume vendor performance data is available and centralized, but, as outlined in a case study of manufacturing firms by Wong and Leung (2002), the buyer-side's and seller-side's data are in reality separated into their own business environments. They are also unlikely to share sensitive company information such as the pricing or the historical records of the suppliers. This in turn tends to make the traditional supplier selection approach difficult to implement in real life situations. A good review of the problems that can arise when selecting supplies can be found in Bhutta (2003).

The multiple agent approach revolves around the concept of a multi-agent system (MAS), and has been widely used to effect negotiations involving parties with conflicting interests. A decentralized multi-agent system is based on the concept that several distributed decision-makers (or agents) can cooperate and interact, and obtain globally optimal performances (Durfee, 1999). Negotiation is the fundamental and useful mechanism for managing agent interactions in reaching a mutually agreeable state (Bond & Gasser, 1988). In a supply chain context, manufacturers and suppliers are usually involved in various kinds of negotiation related to order fulfillment and resource allocation problems. An agent-based framework is usually necessary to coordinate the negotiations effectively, see Lee and Anderson (2001). To enable software agents to support automatic negotiations (Jennings et al., 2001), the negotiation process has to be formally specified. A negotiation protocol is the formal specification of the rules that govern interactions during negotiation. This protocol is required to be precise, so that it can cope with all the situations that may arise during negotiations. In addition to the negotiation protocol, Jennings et al. (2001) also suggested that each participating agent should have a negotiation strategy. The negotiation strategy determines the decision-making steps for each agent. In an example in freight transportation decision-making, Kraus (1997) shows that negotiations can lead to significantly different results if different strategies are employed; a customer agent may wish to pay more for better quality and delivery, while another may only want the item with the lowest price, regardless of the other factors. A critical review of online reverse auctions and negotiations can be found in Kuo et al., (2004), who also identified the important factors for successful implementation.

In the formulation of a bid, several criteria including the unit cost, the delivery performance and the quality of an item need to be considered. An expected value was computed by aggregating these three decision variables after multiplying each by their respective numerical weights, weights derived from the buyer's perspective. The bid calculation used in our framework is similar to those used in the models of Talluri (2002) and Weber (1996). General qualitative factors used in their models are ignored, and only inputs that are available to the buyer such as price, delivery and quality are considered. It is also assumed that the weights given to all these criteria (i.e., unit price, cost of late delivery and cost of rejected units) are the same and equal to one, resulting in the equation:

B_i = Bid price + Expected Cost of late Delivery + Expected Cost of rejected Unit.

In algebraic terms the equation becomes:

$$B_i = P_i + \alpha_i (c^{late} - p_i^{late}) + \beta_i (c^{reject} - p_i^{reject}) \quad (1)$$

where P_i represents the bidding unit price by the ith supplier, α_i represents the percentage of expected late delivered item by the ith supplier, c^{late} represents the late delivery cost for the bidding item, p_i^{late} represents the committed penalty for late delivery by the ith supplier, β_i represents the percentage of expected rejected unit by the ith supplier, c^{reject} represents the rejected unit cost for the bidding item, and p_i^{reject} represents the committed penalty for rejected unit by the ith supplier. B_i is the aggregate true cost to the buyer, made up of the unit price and the two penalty costs. The smaller the value B_i, the more attractive the individual bid becomes, as it implies lower price and/or lower risk for late delivery and rejection.

We believe that the agent technology and the negotiation approach can provide feasible and flexible solutions for SME's who are interested in developing their e-business. The primary objective of this paper is therefore to develop an agent-based negotiation framework that can support the enterprises with purchasing functions. Our system differs from the conventional e-business packages in that the software agents can engage several unconnected parties into the negotiation process. Participants can readily be added or removed as negotiations proceed, and they are allowed to use various types of negotiation strategies under different purchasing scenarios.

BACKGROUND

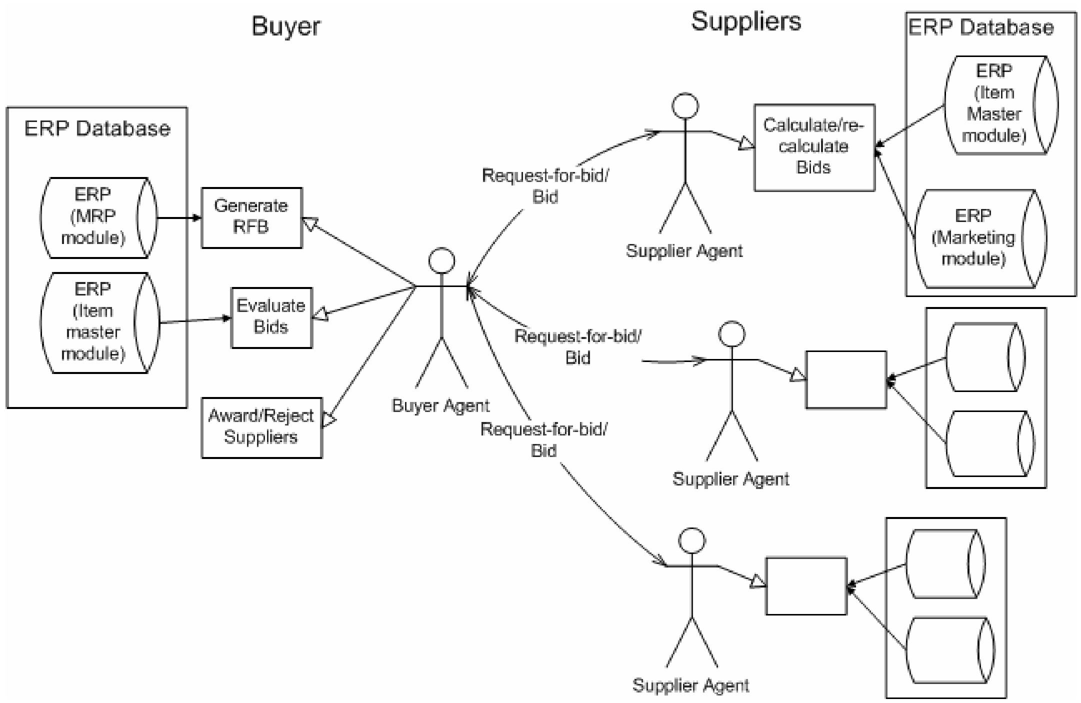
The agent-based framework proposed in this paper attempts to meet the practical needs of the SME engaged in OEM toys manufacturing as outlined by Wong and Leung (2002). The company used in this study receives orders mainly from U.S.A. and European customers, and then sources parts and sub-assemblies from selected suppliers in mainland China. The sales and marketing and the procurement and production cycles are all supported by an ERP system. The tailor-made ERP system acts as a centralized database that stores all transactions, e.g. sales orders, purchase orders, goods receipt notices, work orders, etc. However, the ERP system does not incorporate any supply chain functions for transaction-based operations that link up to the counterparts' systems, and which support decision-making processes such as supplier selection for planned order releasing (Halo & Szekely, 2005). In addition, the company uses its MRP module to plan manufacturing schedules and to place purchase orders.

At the time of this study, the supplier selection processes and the releasing orders were all performed manually, which at times was exhausting and burdening. The purchasing manager had to announce requests for quotations, collect quotations, and then negotiate with individual suppliers before confirming any deals. The manager usually had to negotiate with four to eight suppliers for each item to be purchased. As these suppliers were spread out worldwide, the negotiation processes was inefficient, costly and often prone to errors. It was obvious that some form of electronic negotiation for order releasing would, to a large extent, improve efficiency, reduce costs, and minimize the risk of human errors.

PROPOSED AGENT-BASED INTELLIGENT FRAMEWORK

The agent-based e-business framework for supply chain management proposed in this paper is designed with the main aim of supporting enterprises with their purchasing functions. It comprises two types of agents, buyer and supply, representing the buyers and sellers in the supply chain respectively. An autonomous negotiation process is established for the supplier selection problem and for the coordination of the agent-based negotiations. The negotiation protocol is an extension of the contract net protocol of Smith (1980). A schematic view of the proposed model is given in Figure 1. The buyer agent and the supply agents are linked with their respective ERP systems through their corresponding databases: the buyer agents use their ERP systems to generate and evaluate bids, while the supply agents calculate and make reply bids also using their own ERP systems.

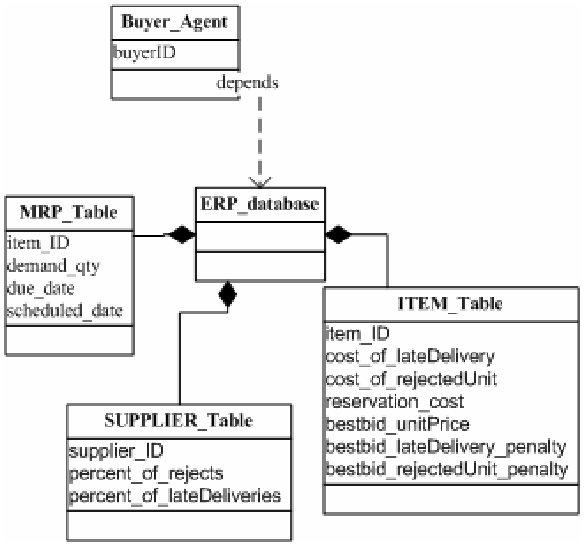
Figure 1. An agent-based framework.



Buyer agents

The responsibilities of the buyer agent include broadcasting the request for a bid to supply agents, evaluating bids, and communicating grant/reject information to the supply agents. The attributes and data required of a buyer agent are shown in Figure 2. Each buyer agent in the system is given a unique number (buyerID) to identify messages sent from that particular agent. Normally, the buyer agent can gather all the useful information for negotiation from his own ERP system, which contains a number of tables including the ITEM table, MRP table, SUPPLIER table, etc. To generate a request for bids, a buyer agent can search the MRP table to find which items (item_ID) and how many (demand_qty) need to be purchased and at what point in time (schedule_date). For evaluating bids and for granting offers or for indicating offer rejected, the buyer searches the ITEM table that stores the cost of late delivery and the cost of rejected units. Usually, the buyer will not buy the item if it is offered at price higher than a threshold price (Pruitt, 1981; Zeng & Sycara, 1998). An item's reservation (threshold) price may also be found in the ERP's ITEM table. Finally, the suppliers' Table provides a history of their performance on both delivery and product quality.

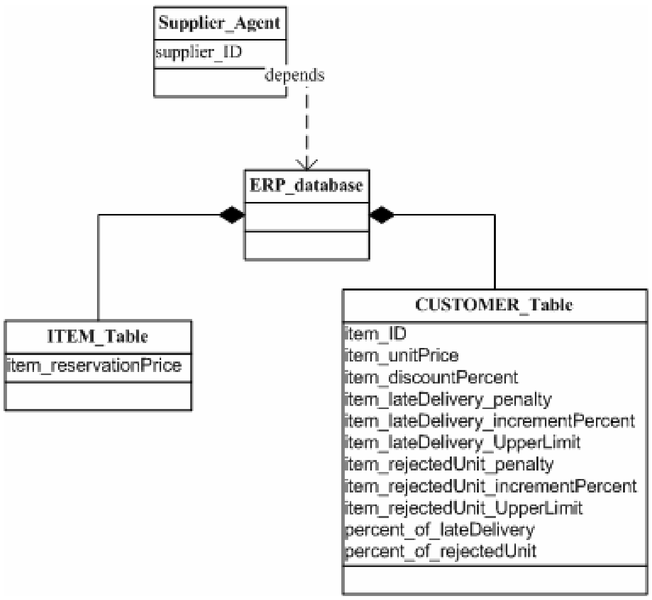
Figure 2. Attributes and data required by a buyer agent.



Supply agents

Similar to the buyer agent, each supply agent is uniquely identified in the system and is linked to the supplier's ERP system, see Figure 3 for the data used by a typical supply agent. The supply agent's reservation price (in the ITEM table) is the lowest price at which an item can be sold (Zeng & Sycara, 1998). The unit price (item_unitPrice) specifies an item's price, while the discount percentage is the discount normally given to a customer. Since late delivery and below quality can incur unexpected costs for the buyer, a penalty cost for late delivery (item_lateDelivery_penalty) and for below quality items (item_rejectedUnit_penalty) will be paid by the supplier when these situations occur. Such penalties will compensate the buyer and at the same time demonstrate a supplier's commitment to a deal. However, such penalties have an upper limit (item_lateDelivery_UpperLimit and item_rejectedUnit_UpperLimit) respectively. The past delivery and quality performance data is stored in the CUSTOMER table.

Figure 3. Attributes and data required by a supplier agent.



Negotiation Protocol

The construction of an effective negotiation protocol is essential to the model. For the implementation of the agent-based negotiation system, the Contract Net Protocol (CNP) has been commonly used (Smith, 1980). The original CNP specifies the communications and controls required in a distributed problem solver. It relates to how contract managers announce the tasks to the agents, how the potential bidders return bids to the managers, and how the managers award or reject the bidders.

CNP has in fact been applied extensively in real-world distributed tasks allocation problems, possibly because of its simplicity and intuitiveness. Enterprises or business units can easily be modeled as agents who participate directly in autonomous negotiations. In another contribution, Collins at el., (2000) developed a market architecture for e-commerce negotiation under CNP between the main two types of agents - customer and supplier. In a generalized market architecture, the roles used for customer and the supplier can be extended to other relationships: a customer may represent a manufacturer who wants to buy materials from vendors, or a project manager who wants to allocate jobs to sub-contractors, or even a job order which seeks the correct machines failures. In this paper the buyer agent represents a manager in the CNP, which is actually the buyer (manufacturer) and who sources materials for the manufacture of parts for assembly or for sale. The supply agents represent contractors in the CNP that provide materials to various buyers.

The negotiation protocol in the proposed framework allows multiple rounds of negotiations, enabling re-negotiation between the buyer agent and the supply agents, so that a temporary grant/reject can be repeatedly given to the bidders until some criteria such as time constraints and price are satisfied. The number of re-announcement depends on the buyer agent's preferences and his decision-making strategies. In this multi-round type negotiation, a buyer agent is responsible for the whole negotiation process, which includes: (re-)announcement of bid-request to multiple supply agents, bid evaluation, announcement of permanent/temporary grant/reject to the supply agents. In some cases the calculated bid will exceed the suppliers' predefined pricing limits, in which case agents will ask a human decision maker to modify the parameters as necessary. Figure 4 illustrates the negotiation protocol for the order-bidding process, beginning with the buyer selecting an item or with a planned order for bidding which is constrained by a time limit depending on the order's due date. The interaction, status, and actions of the agents are listed in Table 1.

Figure 4. Negotiation Protocol between the buyer agent and supply agents.

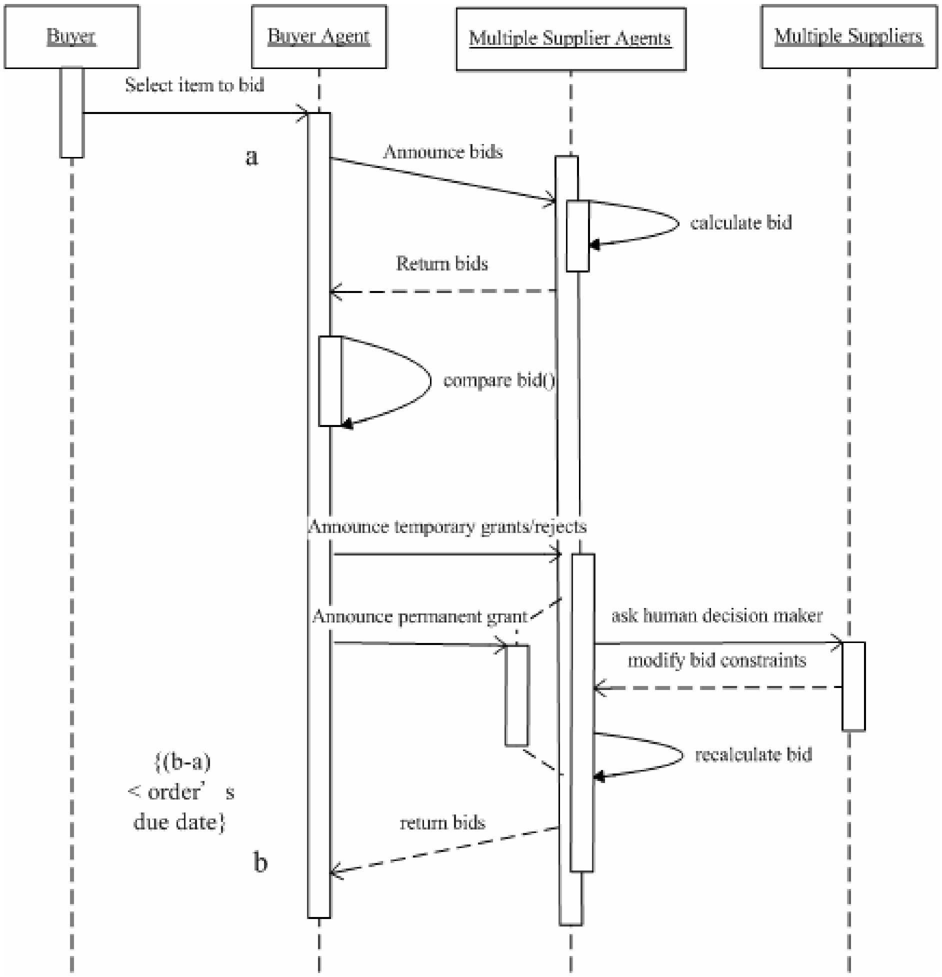


Table 1. Interaction between Buyer Agent and Supply Agent.

Buyer agent	**Supply agent**
1. Select order for bidding	(Waiting for RFB)
2. Announce Request-for-bid (RFB)	
(Waiting for bids returned)	1. Calculate and return bid
	(Waiting for bidding result)
3. Evaluate bids	
4. Re-announce RFB or give offer to the winning agent	2. Re-calculate and return bid

APPLICATION TO A CASE EXAMPLE

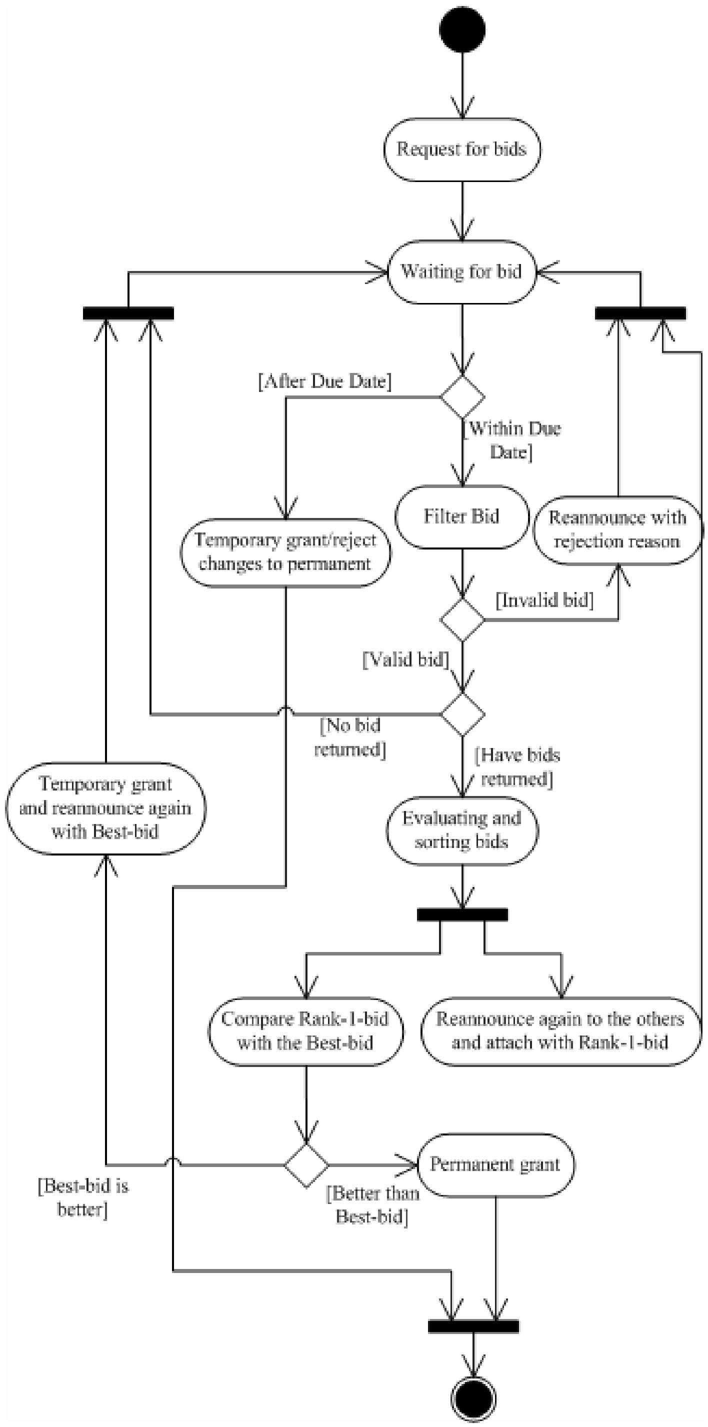
This case example applies the proposed framework in a supplier selection process involving an order-bidding scenario between the buyer (the case company) and its suppliers. The data used in the example was compiled from the company's records. It is assumed that the buyer agent, representing the company, and supply agents, representing the suppliers, are all connected via their ERP respective real-time systems. These systems store all the relevant data needed by the agents. Since the company in the case study has a large variety of items, each of them with different characteristics and purchasing requirements, the company can employ different negotiation tactics for different items. In order to demonstrate the adaptability and flexibility of the proposed framework, three different buyer agent strategies are used as follows.

Negotiation Strategies used by the company

a) Time-constrained outbid negotiation scheme. In principle, the primary objective of a buyer agent is to allocate the planned order to an appropriate supplier, one that offers the minimum item cost and the minimum risk of late delivery and rejects. The first negotiation scheme incorporated in the buyer agents is termed "Time-constrained Outbid Negotiation Scheme (TONS)". TONS is designed to safeguard the buyer's two basic objectives of the need to finish its tasks within a time limit and at the same time allowing negotiations to go on until an offer can surpasses previously recorded offers. Using the linkages to the ERP systems, the buyer agent first detects a need for releasing a planned order, and once it has clearly identified this task, it will issue a request for bids from the supply agents, and will wait until the order expires before the biding ends. The bids received are immediately filtered on the two criteria of whether the bidding price is greater than the item's reservation cost, and whether the committed delivery date is later than the required schedule date. The invalid bids will be re-announced to the particular suppliers (agents) together with the corresponding reasons. After the waiting time has expired, the collected (valid) bids are then evaluated and sorted.

In bid selection, the lowest bid value (B_i^{lowest}) will first be sorted and then compared with the value of a previous best bid (BestBid) for that particular item. If it is lower than the previous best bid, a permanent grant will be offered to that supplier and negotiations terminate; otherwise a temporary grant will be given and the company will request the particular supplier to re-generate the bid. A supplier with a temporary grant will also be given the value of the best bid, as the supplier is expected to re-generate a new bid which is lower. Other temporarily rejected bids will also be re-announced and returned to the supply agents who made them. These temporarily rejected suppliers will also know the value of the best bid (B_i^{lowest} , the temporarily granted bid) so that they still have chance to bid successfully in the next round. The negotiation process continues until the due date expires or there is a bid better than the reservation cost. Figure 5 illustrates the flow of the TONS negotiation scheme from the buyer or the company point of view.

Figure 5. TONS negotiation strategy for a buyer agent.



b) One-round Negotiation. Another strategy that can be employed by the company is termed the "One-round Negotiation (ON)." As the name implies, this strategy allows only one round of negotiation, no matter which supplier's bid is selected after the first round bids are evaluated. This strategy can be used when the items to be purchased have a short lead time or are required immediately. The ON strategy provides some alternative options for the buyer, even when operating under a very tight time constraint. Apart from reducing the number of negotiation rounds to one, the bid formation and bid evaluation are the same as those for TONS.

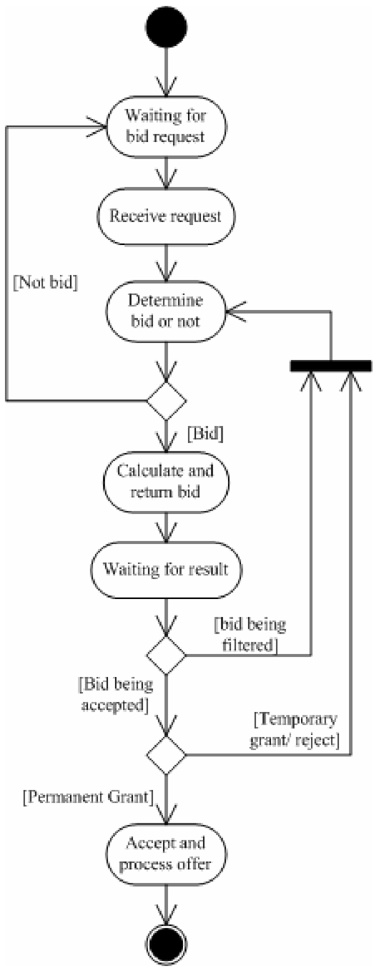
c) Until-Duedate Negotiation. The "Until-Duedate (UD)" strategy is for items that are less time-critical, but are still bounded by a purchase due date. Such items can include replenishment orders for safety stock. Such orders will still be constrained to individual purchase by dates, but are generally less time-critical than items for make-to-order. The buyer usually contacts several suppliers to get the best deal in price terms and delivery must be very close to the due date. In contrast to the TONS and ON strategies, the UD strategy allows negotiations to continue even if in the early stages there is an offer from one supplier which is clearly much better than the rest, as the company does not need to close the deal before the due date is reached.

Negotiation strategy used by the supply agents

This illustrative example is mainly used for bid (re-)construction when a supply agent receives a bid request and/or a temporary offer from the buyer. For an initial bid construction, the supply agent only has to reply with a bid specifying an item's price, and committed penalties for late delivery and for rejected (under quality) items, as required in equation (1). For a bid re-construction, which will involve re-negotiation, the supply agent will receive, after the initial bid is evaluated by the buyer, a temporary grant or a reject message. The temporary grant implies that the supplier's bid value is lower than that of the bids offered by the other suppliers, but still higher than the buyer's reservation price. A temporary reject implies the supplier's bid is not the best at the end of the last round of negotiations. If a temporary grant is given to a supply agent, the best bid figure will also be given for comparison. Temporarily rejected supply agents are also given the best bid for reference in future bidding, and thus both categories of suppliers are still eligible for bidding in the subsequent rounds. To enhance their chances of winning an order in subsequent rounds, the supply agents may reduce the original price and/or increase the penalties for late delivery and for under quality items, and the new bids will then be returned to the buyer for another round of evaluation and negotiation.

To improve expediency, a price reduction and/or an increase in penalty payments can be submitted at the same time. The price will decrease at a discounted percentage d in each round of price reduction, while the penalties for late delivery and under quality items will increase at percentage rates r^{late} and r^{reject} respectively. The lowest acceptable price for an item is set at P_{limit} , while the highest penalty costs of delivery and under quality must be below p_{limit}^{late} and p_{limit}^{reject} respectively. If any of the constraints are exceeded, or the new bid is still higher than the previous best, the supply agent concerned will be asked to abandon further submissions, see Figure 6 for an outline of the negotiation scheme for the supply agents.

Figure 6. Negotiation strategy for a supplier agent.



A case example

To better illustrate how the agent-based negotiation works, a case example is considered with the set of buyer's and suppliers' parameters given in Tables 2 and 3 respectively. As shown in Table 2, the buyer has selected an item for bidding and has placed a reservation price of $1329.03 (the buyer will not consider bids above the reservation cost). The penalty cost per unit for late delivery and the penalty cost for each unit rejected (under quality) are $258.15 and $208.53 respectively. The buyer's database also stores the previous best bid offered for the item, $800.51, and the highest late delivery and highest reject (under quality) unit penalties of $221.21 and $214.61 respectively. The supplier that has offered this best bid has a record of late delivery and rejected units percentages of 18.72% and 26.38% respectively. In accordance with equation 1, the weighted value of the best bid is calculated to be $805.82 [800.51+18.72% *(258.15-221.21) + 26.38% * (208.53-214.61)]. Table 3 summarizes the relevant data in the four suppliers' databases; it is further assumed that they are all interested in submitting bids for negotiation. Such data includes the item unit price, its discount percentage, and the reservation price. There are also late delivery penalties and rejected unit penalties specifying the compensatory costs for each late delivery and for each rejected item respectively. The increment percentages control each rising interval of the penalty costs up to the maximum penalty levels. The overall results when using TONS are shown in Figure 7 and the round by round results are given in Table 4.

Table 2. Buyer's Parameters.

Item to bid	ITEM102
Item reservation cost	$1,329.03
cost of late delivery	$258.15
cost of rejected unit	$208.53
Best Unit Price	$811.13
Best Late Delivery penalty	$221.21
Percent of Late Delivery	18.72%
Best Rejected Unit penalty	$214.61
Percent of Rejected Unit	26.38%

Table 3. Supplier's Parameters.

	S04	S06	S08	S10
Unit Price	$1,159.06	$1,104.70	$1,325.79	$1,031.20
Discount Percent	7.31%	5.77%	3.76%	8.13%
Reservation Price	1003.94	$935.69	$834.52	$882.77
Late Delivery penalty	$518.65	$195.16	$524.77	$311.39
Late Delivery Increment Percent	8.16%	6.77%	9.77%	7.51%
Late Delivery Upper Limit	$746.32	$254.59	$960.82	$479.97
Percent of Late Delivery	29.24%	13.91%	23.26%	1.66%
Rejected Unit penalty	$527.46	$166.51	$521.66	239.01
Rejected Unit Increment Percent	1.36%	2.54%	5.92%	2.22%
Rejected Unit Upper Limit	$712.32	$219.14	$684.82	$503.17
Percent of Rejected Unit	21.44%	11.87%	7.17%	7.52%

Figure 7. Examples of bid generated from the TONS negotiation strategy.

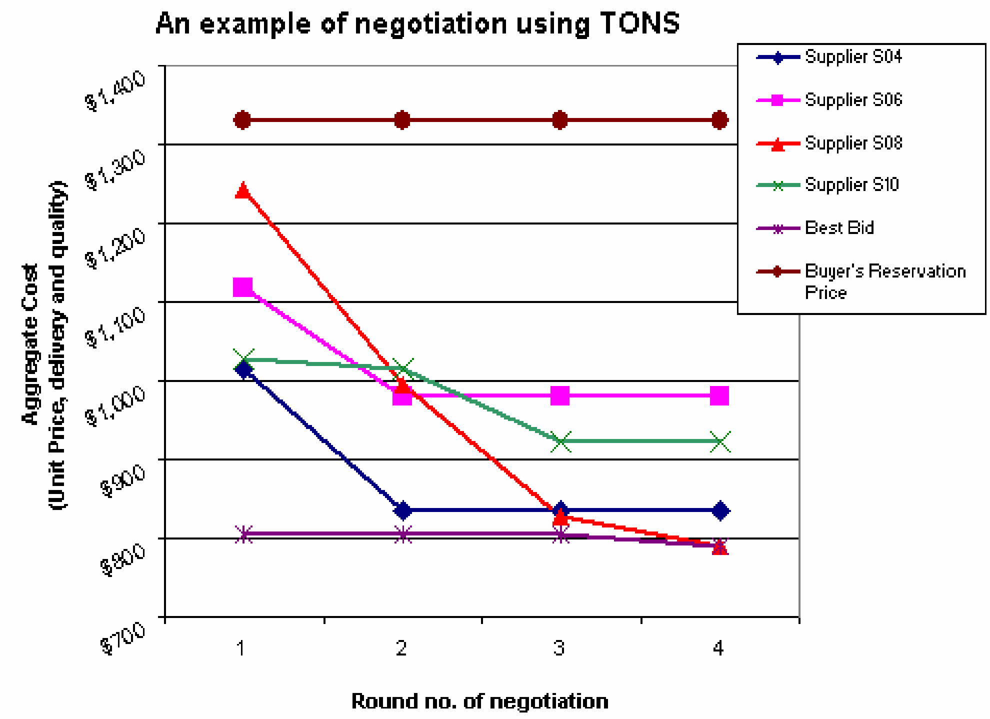


Table 4. Bids generated in the simulation run.

	Supplier	S04	S06	S08	S10	Best Bid
Round 1	Unit Price	1159.06	1104.70	1325.79	1031.20	
	Late Delivery Penalty	518.65	195.16	524.77	311.39	
	Rejected Unit Penalty	527.46	166.51	521.66	239.01	
	Aggregate Cost	**1014.51**	**1118.45**	**1241.32**	**1028.02**	**$805.82**
Round 2	Unit Price	1074.33	980.90	1181.79	1031.20	
	Late Delivery Penalty	709.81	253.62	918.06	447.25	
	Rejected Unit Penalty	709.99	213.98	656.60	396.04	
	Aggregate Cost	**834.75**	**980.88**	**996.17**	**1013.96**	**$805.82**
Round 3	Unit Price	1074.33	980.90	1013.83	870.34	
	Late Delivery Penalty	709.81	253.62	918.06	447.25	
	Rejected Unit Penalty	709.99	213.98	656.60	493.29	
	Aggregate Cost	**834.75**	**980.88**	**828.21**	**922.81**	**$805.82**
Round 4	Unit Price	1074.33	980.90	975.71	947.36	
	Late Delivery Penalty	709.81	253.62	918.06	447.25	
	Rejected Unit Penalty	709.99	213.98	656.60	493.29	
	Aggregate Cost	**834.75**	**980.88**	**790.09**	**922.81**	**$790.09**

The chart in Figure 7 shows that 4 suppliers (S04, S06, S08 and S10) made bids through their agents and that supplier S04's initial bid is evaluated at $1014.51 [1159.06 + 29.24% * (258.15 - 518.65) + 21.44% * (208.53 - 527.46)]. After the four bids are returned, the buyer will determine whether they are within the set limit of $805.82.

In Round 1, S04 has the best offer amongst the four suppliers, but its bid price ($1014.51) is above the limit ($805.82). Hence, S04 is temporarily granted the order and is allowed to re-bid, with the request that its next bid be lower than the limit of $805.82. The remaining suppliers will be temporarily rejected, with requests that their next bids should be less than the S04's bid of $1014.51. After the 2nd, 3rd and 4th rounds, S04's bid is valued at $834.75, which is still above the limit as its unit price and penalties have already reached their corresponding limits. S06 is also similar to S04, with its bid valued at $980.88, which is lower when compared to the previous best value of $1014.51. In the case of S06, the unit price has decreased at a discounted rate of 5.77% and the penalties have increased at rates of 6.77% and 2.54% respectively. S08 is the final winner (permanently granted) because its final bid in round 4, $790.09, is lower than the reservation value, $805.82. In fact, S08 was not the leader in every round of negotiations, with its bid of $996.17 ranking third in round 2. However, since S04 and S06 stopped top bidding after round 2, their first-ranking and second-ranking positions were taken up in round 3 by S08 ($828.21) and S04 ($834.75). Negotiation did not stop in round 3, because S08's offer was still above reservation figure, so S08 was requested to re-submit again, and it finally submitted the winning bit of $790.09.

SIMULATION AND RESULTS

Simulations were conducted to examine the effectiveness of the three strategies - TONS, ON and UD. The parameters of the simulation are summarized in Tables 5 and 6, and the schematic model is shown in Figure 8. In order to compare the performance of the three strategies, three indices were used:

The time to due date percentage, which measures the remaining time available after the negotiations stops.

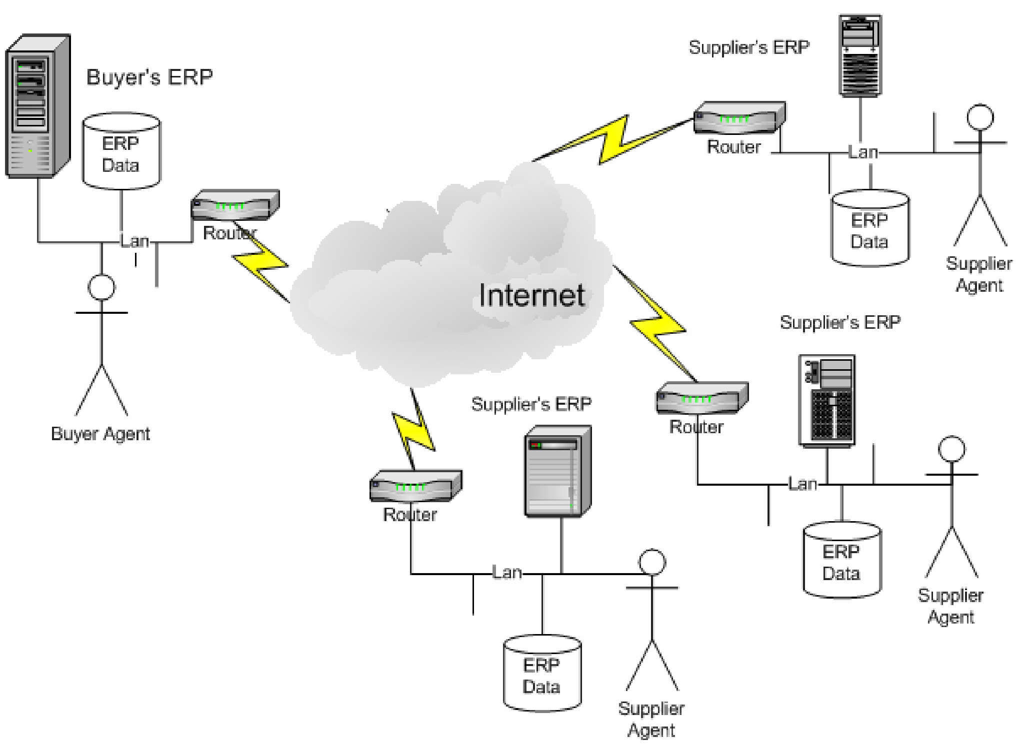
The outbid percentage measures, which measures percentage of bids better than the reservation.
The reduction in aggregate cost percentage, which measures the percentage decrease in aggregate cost between the average of the final offers and the average of the initial offers of all suppliers.

Table 5. Buyer-side Item data for the Buyer Agent

Released item	Randomly selected from the 200 items
Reservation price ($/unit)	Mean = 1000 Variance = 100
Cost of late delivery ($/unit)	Less than 50% of reservation price
Cost of rejected unit ($/unit)	Less than 50% of reservation price
Best-bid awardee	Randomly selected
Best-bid unit price ($/unit)	Mean = 500 Variance = 100
Best-bid late delivery penalty ($/unit)	Less than 50% of Best-bid unit price
Best-bid rejected unit penalty ($/unit)	Less than 50% of Best-bid unit price

Table 6. Supplier-side Item data for the Supplier Agent.	
Item No.	Randomly selected 120 items from the buyer database
Unit price ($/unit)	Mean = 1200 Variance = 100
Discount (%)	Below 10%
Reservation cost ($/unit)	Mean = 800 Variance = 100
Penalty of late delivery ($/unit)	Less than 50% of reservation cost
Increment percent of late delivery (%)	Below 10%
Upper Limit of late delivery ($/unit)	Less than 200% of penalty of late delivery
Past late Delivery percent (%)	Below 30%
Penalty of rejected unit ($/unit)	Less than 50% of reservation cost
Increment percent of rejected unit (%)	Below 10%
Upper Limit of rejected unit ($/unit)	Less than 200% of penalty of rejected unit
Past reject unit percent (%)	Below 30%

Figure 8. Web-based agent-based system.



100 items were used in each simulation, and results, see Table 7, suggest that a high outbid rate is always preferable. The results for 10 simulation trials show that TONS has a 67 % success rate for outbid, compared with 7% for ON and 90% for UD. When time constraint is a critical factor, TONS gives a reasonably high outbid rate when compared with the UD, as UD requires the negotiation process to go all the way to the due date. This is not surprising, since the buyer has more time to bargain, that a longer negotiation time will usually give a higher outbid rate. That is why the UD strategy will generally be the best. The TONS strategy results in an average aggregate

reduction of 39%, a generally satisfactory result. Table 7 shows that TONS can actually find the best supplier in the early stages of negotiations, since it has a 64.70% remaining time after the bid offer is accepted. For the UD strategy, the index is 0% because negotiations end on the due date.

Table 7. A comparison on the TONS, ON and UD Strategy.

	TONS	ON	UD
Time-to-duedate (%)	64.7	79	0
OutBid (%)	67	7	90
Reduction in Aggregate Cost (%)	39	12	68

Figures 9, 10, and 11 record particular simulation instances on using the three strategies. TONS can find an outbid offer on day 12, much earlier than the due date, day 17, see Figure 9; ON has only one round of bidding, see Figure 10; while UD is allowed to negotiate until the last day , see Figure 11.

Figure 9. Simulation result for TONS strategy.

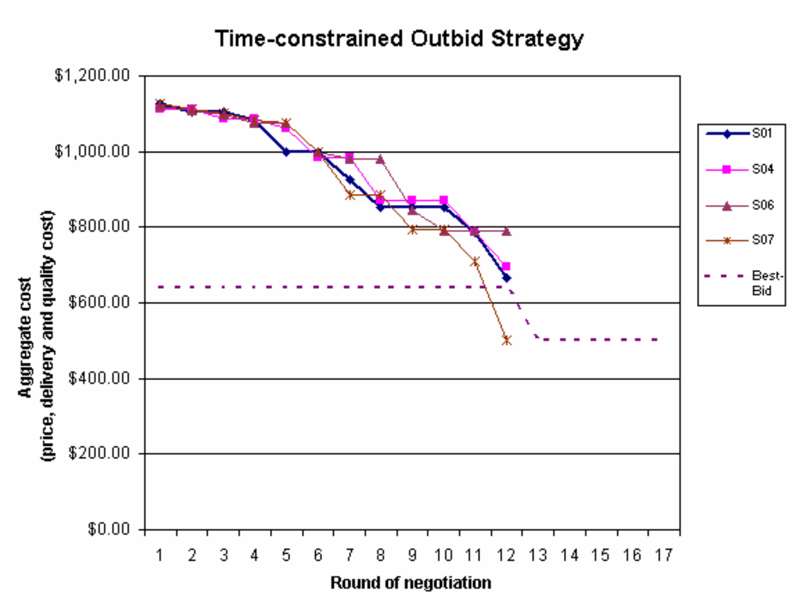


Figure 10. Simulation result for ON strategy.

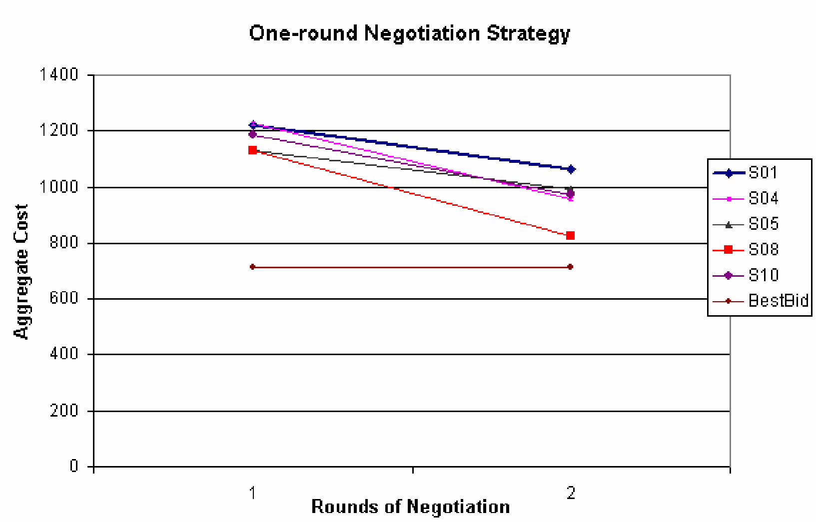
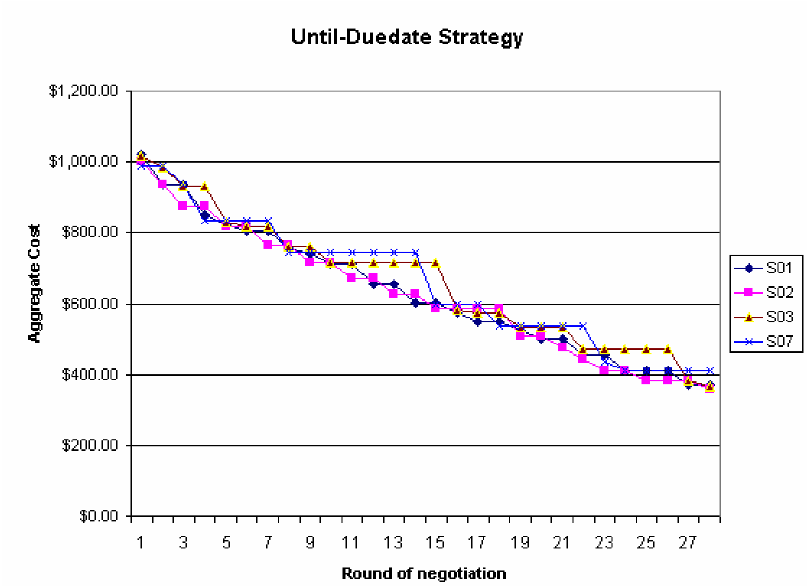


Figure 11. Simulation result for UD strategy.



CONCLUDING RESULTS

This paper presented an agent-based framework for some of the purchasing activities in supply chain management. The agent-based model comprises two types of agents, buyer agent and supply agents, representing the buyer and sellers in the supply chain respectively. The proposed negotiation protocol is an extension of Smith's (1980) Contract Net Protocol. To initiate the negotiation process, a buyer agent requests bids from the supply agents and then evaluates the returned bids, it then announces the results to supplies round by round until an offer is accepted on or by the due date. The bid selection method considers the three most important factors of price, acceptable quality and delivery time.

In conclusion, the authors believe that the framework presented and the concepts explored in this paper will be useful to both practitioners and researchers. With the globalization of supply activities and much shortened product lifecycles, conducting face to face negotiations with all possible worldwide suppliers is no longer effective, as this would be too costly and time consuming for the large majority of SME's. E-business activities in supply chain management will help companies cast a much wider, worldwide net for possible suppliers, and thereby help to reduce costs and improve quality in an environment of ever increasing competition.

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