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Intelligent agents for supporting construction procurement negotiation

Ren-Jye Dzeng*, Yu-Chun Lin

Department of Civil Engineering, National Chiao-Tung University, 1001 Ta-Hsieu Rd., Hsinchu 30050, Taiwan, ROC

Abstract

Negotiation is commonly required to reach a final contractual agreement in construction material procurement. However, even simple negotiations often result in suboptimal agreements, thus 'leaving money on the table.' An automated system that could evaluate bids, negotiate to finalize the bid, and value the individual characteristics of negotiating parties would be useful to both contractors and suppliers. This study examines common negotiable issues and options for construction material procurement, and presents an agent-based system, named C-Negotiators, that helps a contractor and suppliers to negotiate via the Internet. Genetic algorithm is used to find the most beneficial agreement for all parties, and web-based development is used to improve negotiation efficiency. Experiments also were conducted and demonstrated that C-Negotiators improved negotiation efficiency by saving negotiation time and cost, and improved negotiation effectiveness by suggesting a better agreement with higher joint payoff. Although the increase in payoff was smaller than expected, the improvement should increase for more complex negotiation problems involving more issues and options, or complicated preferences and for inexperienced negotiators. The application of the system is mainly limited by its symmetric optimization, while procurement negotiations in the construction industry are biased towards the contractor, and also by user comfort with their preferences and negotiations being monitored by the system.

Keywords: Genetic algorithm; Intelligent agent; Procurement negotiation; E-commerce application

1. Introduction

Most construction business processes rely heavily on traditional means of communication such as face-to-face meetings and the exchange of paper documents such as technical drawings, specifications, and site instructions. The construction industry has long recognized the need to increase the efficiency of these processes by exchanging large volumes of information quickly and cheaply (Deng, Li, Tam, Shen, & Love, 2001). As international competition continues to intensify, significant numbers of construction organizations are strategically investing heavily in information technology to gain competitive advantage (Betts, 1999). Various web-based collaboration platforms for project management and procurement have also been developed. One example is the PrimeContract developed by Primavera System Inc (Primavera System, 2003), which attempts to streamline intra-company and inter-company business processes, and supports project team communication, procurement, bid/auction, bid analysis, and contracting.

Construction material procurement is a key business where negotiation is commonly required to reach final contractual agreement. However, even simple negotiations often result in suboptimal agreements, thus 'leaving money on the table' (Raiffa, 1982). Based on Oliver (1996), while many factors lead negotiators to miss out on gains, falsely assuming fixed pies and the framing of the situation often cause parties to fail to reach mutually beneficial agreements. The challenge of negotiation arises partly from the fact that each side has private information about their own payoff function but is ignorant of the values and strategies of the other side. Exacerbating this situation is the negotiators' incentive to misrepresent their preferences.

For illustration, consider the following scenario: a general contractor has solicited several bid proposals from suppliers registered on a web-based construction procurement platform. Besides preferring a cheaper price, the contractor also prefers payment by usance check instead of cash to maintain cash flow level, and prefers delivery of materials in small consignments as required to avoid

* Corresponding author. Tel.: +886-35733529; fax: +886-35745074.
E-mail address: rjdzeng@mail.nctu.edu.tw (R.-J. Dzeng).

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overloading site storage space. Suppliers with no previous business with a contractor are likely to attempt to show their competitiveness by offering the contractor considerable flexibility during negotiations. For example, one supplier, as a new comer, may be willing to offer large price discounts if procurement can be extended to include other related materials, as well as one-week notice for delivery, and 60-day usance check if future procurement is possible. Currently, such routine business transactions often involve some form of negotiation between the parties. Usually neither side knows the preferences of the other: the prospective contractor does not know the costs of the supplier, and the supplier does not know how much the buyer values each negotiable issue.

The cost and time involved in negotiation mean that contractors must limit the number of prospective suppliers they negotiate with, and also the number of options included in negotiations. A cheap and efficient negotiation method would allow the exploration of more prospective suppliers and options. Clearly, an automated system that could evaluate bids, negotiate to finalize the bid, and value the characteristics of the negotiating parties would be useful to both contractors and suppliers.

Bazerman (1994) classified negotiations into two categories based on negotiator attitudes: distribution (claiming a share of the pie) and integration (enlarging the available pie). The distribution type of negotiation is a zero-sum game, i.e. a gain for one party is a loss for another. Such negotiations involve each party using the strategy of predicting the bottom line of the other and presenting an offer that maximizes their own benefit. Such negotiations generally result in low satisfaction level. On the other hand, the integration type of negotiations promotes cooperation among negotiators. Because each negotiator has different preferences regarding each negotiable issue and option, the strategy is not to attempt to win on all issues, but to identify those issues that the negotiators care about most and make tradeoffs accordingly. Such negotiations usually achieve a higher satisfaction level.

Decision support research has focused on the design and development of tools for aiding negotiators in various domains, such as Genie (Harris, Kraus, Wilkenfield, & Blake, 1991) that stresses model visualization capabilities, NEGOPLAN (Krovi, Graesser, & Pracht, 1999) that generates if-then production rules, and GBML (Matwin et al., 1991) that identifies rules for improving negotiations. Software agents are also applied to facilitate negotiation. Software agents are computer programs with a certain degree of autonomy, which are continuously active and interact with other systems on behalf of users (Bradshaw, 1997). Snadholm and Lesser (1995) found that cooperative agents often exist and perform enterprise tasks such as production planning and meeting scheduling. Competitive agents do not give in during negotiations except in exchange for compensation because they only care about their benefit and do not consider mutual benefit. However, this competitive style prevents the disclosure of individual preferences and often compromises individual benefit. Several electronic commerce web sites, such as Auction Bot (2001), eBay's Auction Web (2003), Kasbah, 2003, and OnSale (2003), also offer agents that help in on-line price negotiations. For example, Kasbah adopts distribution type of negotiations and allows users to define their own agents with buying strategies (i.e. anxious, cool-head, and frugal), selling strategies (i.e., anxious, cool-head, greedy, and initialization parameters (e.g. asking price, acceptable price, and deadline). T@T (2003), additionally to price, allows both buyer and sellers to customize their agents and negotiate on the issues of warranty, delivery time and method, service plan, return policy, and free bonus. No agents have been developed specifically for negotiating construction procurement between contractor and suppliers.

This study examines common negotiable issues and options for construction material procurement, and develops an agent-based system that helps a contractor and suppliers to negotiate via the Internet. Genetic algorithm is used to find the most beneficial agreement for both parties, and web-based development helps improve the negotiation efficiency. Experiments were also conducted to assess the effectiveness and efficiency of the system compared with human negotiation.

2. Practice of negotiation on construction procurement

The general contractor for a project needs to procure materials and equipment from suppliers to execute the project. The contractor also may need to subcontract part of the work to specialty traders because of considerations of technological specialties, resource availability, profit margin, and risk diversification. After identifying procurement items, tenders from suppliers are invited and evaluated. The evaluation may lead directly to a final decision awarding the contract to the supplier offering the best deal without further negotiation. This situation frequently occurs when space in negotiable issues is limited because negation takes time and man-hours. However, especially for a valuable or complex contract, the procurement of some items still requires further negotiation with several prospective suppliers. Negotiation on issues such as price, terms of payment, and delivery may give the contractor business leverage.

In practice, issues to be negotiated are determined at the beginning of negotiations, but new issues sometimes may arise during negotiations. The contractor proposes desired options for the negotiable issues, and the supplier proposes a price based on these options. The proposed price may be continuously lowered during the negotiations. The supplier may also request that terms be modified or include new issues to offset price decreases. The negotiation ends when both parties agree on the options and price.

3. Negotiable issues

A survey and follow-up interview (Dzeng, Ho, & Lin, 2003) were conducted to identify key issues that may arise during construction material procurement negotiations. Common options used for each issue, and the preferences of both contractors and suppliers regarding these options were also studied. The survey was sent out to 90 contractors in Taiwan in 2003, and received 55 responses (response rate = 61.11%), within which 50 responses were valid (usable response rate = 55.6%). Key issues identified included: *price*, *payment term*, *payment period*, *advance payment, resource provision*, *freightage*, *delivery*, and opportunities for *extended procurement*, *mass procurement*, and *future procurement*.

These issues may be classified into four categories based on range of options available. The first category is *price*, for which options lie on a continuous spectrum.

The second category includes issues for which a limited number of commonly used options exist. For example, options for *payment terms* include: 'cash', '30-day check', '45-day check', and '60-day check'; for *payment period* options include 'on delivery', 'on completion of milestones', 'on completion', 'monthly', and 'bi-weekly'; for *advance payment* options include '10', '15', '20', '25', and '30%'; for *freightage* options include 'included' and 'excluded', for *delivery* options include 'single delivery', 'multiple deliveries', and 'on-call delivery'.

The third category includes issues whose options are a list of items and quantities. For example, options for *resource provision* are a list of provided resources and quantities, and options for *extended procurement opportunities* are a list of additional procured items and their quantities.

The fourth category includes issues for which options are quantity related. For example, options for *mass procurement opportunity* are the maximum quantities procurable; and options for *future procurement opportunity* are possible future procurement quantities. The implied procured item for these issues is the item being negotiated on.

4. Modeling negotiation preferences

Negotiating strategies and the reaching of a satisfactory agreement are usually determined subjectively based on the experience and intuition of negotiators. Controlling the behaviors of artificial agents in such a humane way is difficult, and a systematic, quantitative model is necessary. This study uses the weighted payoff function (i.e. utility function) to represent the preferences of human negotiators regarding each option for each negotiable issue, and to model the aggression and concession in the negotiation.

Negotiation can be viewed as a process of seeking an agreement point in a multidimensional space. Each dimension corresponds to a negotiable issue, and can be discrete or real valued. Each issue may have several options. Each negotiating party values these options differently, and a multidimensional payoff function exists over the space of possible agreement points.

Suppose n negotiable issues exist, where an offer x can be represented using an array one-dimensional matrix $[x_1, x_2, \ldots, x_n]$, where x_i denotes the chosen option for issue i. The payoff of a negotiator for a particular offer x can be represented as follows.

$$U(x) = \sum_{i=1}^{n} W_i U_i(x_i) \quad (1)$$

$U(x)$: total payoff of a negotiator for the chosen set of options x;
$U_i(x_i)$: issue payoff of a negotiator for the chosen option x_i for issue i;
W_i : weight of issue i for calculating negotiator payoff.

Based on this concept, contractor and supplier payoff functions are discussed below for the above four issue categories.

4.1. Category I issues

Figs. 1 and 2 illustrate conceptually typical payoff functions of contractors and suppliers for category I issue, which is price. Fig. 1 describes the preference of a typical contractor regarding price. As buyers, contractors have an acceptable price range $[A_{\min}, A_{\max}]$, which they consider reasonable and are willing to accept. Additionally, contractors also have a desired price range $[D_{\min}, D_{\max}]$, which falls within the acceptable price range. Starting from $A_{\max}$ (the highest acceptable price), contractor's payoff increases with decreasing price. The payoff reaches the highest peak when the price reaches $D_{\max}$ (the highest desired price).

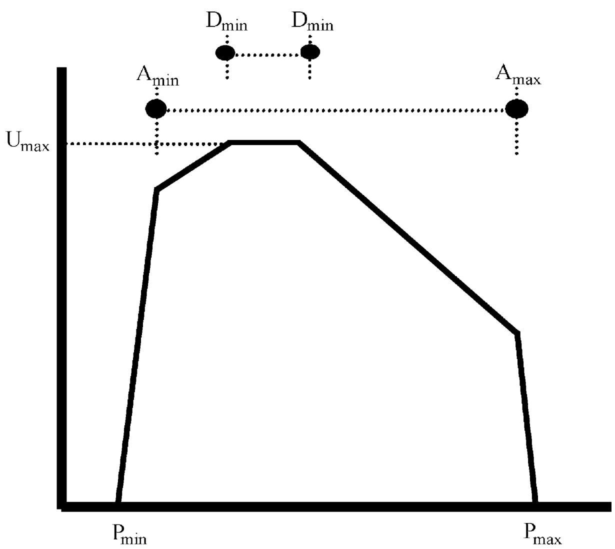

Fig. 1. Contractor's payoff function for price.

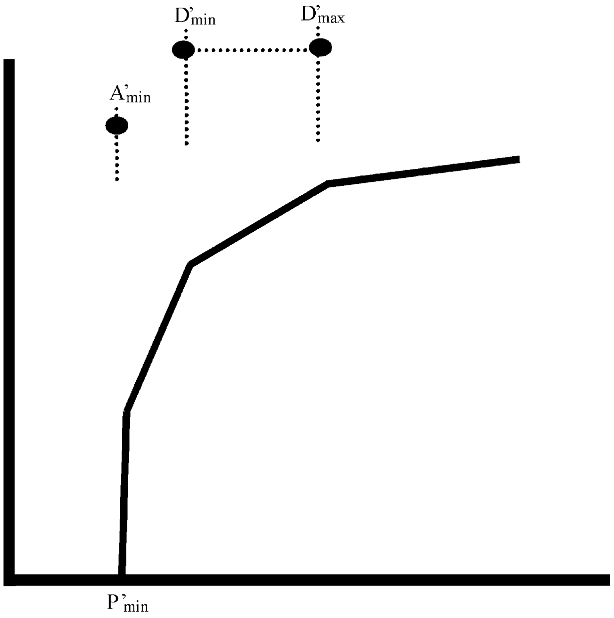

Fig. 2. Supplier's payoff function for price.

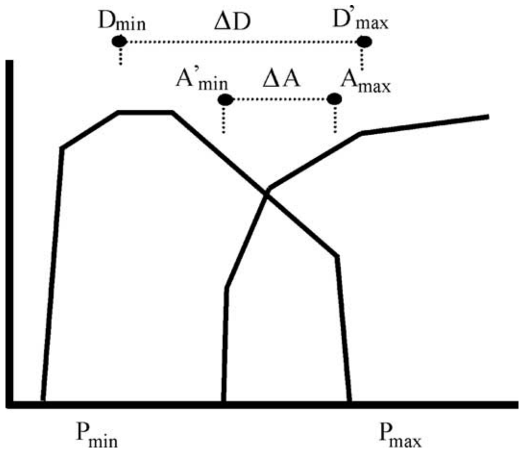

Fig. 3. Price negotiation space for contractor and suppliers.

Further decrease in price has little effect on payoff increase until the price reaches D_{min} (the lowest desired price). Initial contractor asking price in negotiations is within the desired prince range, and depends on various conditions such as competition among prospective suppliers and familiarity with the negotiating supplier. Price below D_{min} decreases the payoff rather than increasing it because the contractor starts to see the price as unreasonable and thus doubts supplier credibility. The payoff continuously decreases with price until the price reaches A_{min} (the lowest acceptable price), any price below which is considered unacceptable to the contractor.

Fig. 2 describes price preference of typical suppliers. Like a contractor, a supplier also has both an acceptable price range $[A'_{min}, A'_{max}]$ and a desired price range $[D'_{min}, D'_{max}]$. However, unlike a contractor, supplier payoff increases with increasing price. Excluding the possibility of fraud on the contractor's side, the supplier may have no apparent upper boundary for the price they are willing to accept ($A'_{max} = \infty$). Once again, the desired price range falls within the acceptable price range.

Fig. 3 shows both contractor and supplier payoff functions, where $\Delta D = [D_{min}, D'_{max}]$ is the maximum possible difference between the initial asking price of the contractor and the initial offering price of the supplier; i.e. space of starting points for the negotiation. $\Delta A = [A_{min}, A_{max}]$ represents the space of agreement points in the negotiation.

4.2. Category II issues

Fig. 4 illustrates five typical payoff functions for category II issues, including *options for mass procurement*, *payment term*, *payment period*, *advance payment*, *freightage*, and *delivery*. The options for each of these issues can be enumerated and their quantities are limited. Therefore, the respective payoff functions are discrete rather than continuous, as for category I.

Type I payoff function shows that negotiator payoff positively correlates with issue options. For example, the contractor generally prefers longer *payment term*, in order to delay the payment as long as possible, and thus contractor's payoff for '60-day check' is greater than that of 'cash'. Type II is a variation of type I and shows that the negotiator payoff tends to positively correlate with most issue options, but remains constant for some intermediate options. For example, some contractors may be indifferent between '30-day check' and '45-day check' for *payment term*. Type III shows that negotiator payoff tends to negatively correlate with issue options. For example, a supplier may prefer shorter *payment term*, and thus may have a smaller payoff for '60-day check' than for 'cash'. Similarly, type IV is a variation of type III. For example, some suppliers may feel indifferent between '30-day check' and '45-day check' for *payment term*. Type V shows that the negotiator is indifferent among issue options.

Generally, contractor payoff is of type I or II for issue *payment period* and *delivery*; of type III or IV for issue *payment term*, *advance payment*, and *freightage*; and of type V for issue *mass procurement opportunity*. On the other hand, supplier payoff is of type III or IV for issue *payment period*, *delivery*; and *mass procurement opportunity*; of type I or II for issue *payment term*, *advance payment*, and *freightage*; and of type V for issue.

Nevertheless, many factors may affect both contractor and supplier payoff. For example, *payment period* options include 'on delivery', 'on completion of milestones', 'on completion', 'monthly', and 'bi-weekly'. Normally, a contractor will have a payoff of type III for *payment period* (i.e. prefer 'on completion' to any other options) to delay the payment as long as possible, maintain high level of

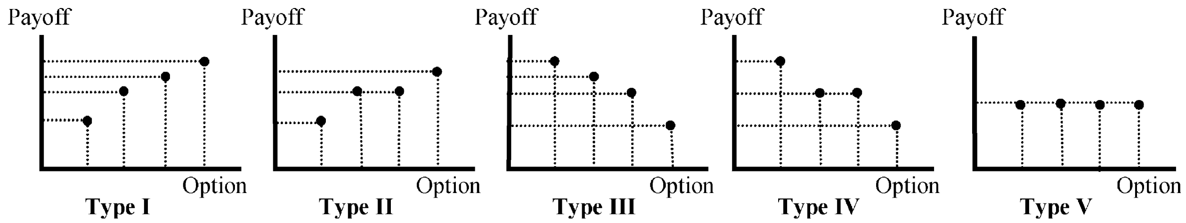

Fig. 4. Typical payoff functions for category II issues.

reserved cash, and guarantee quality of work received. However, the contractor payoff may be of type IV or V if the payment involved is small or the work duration is short. Similarly, a supplier may have a payoff of type I for *payment period* (i.e. prefer 'bi-weekly' to any other options) to receive payment as early as possible and so maintain higher cash reserves and also reduce the risk of completing the job without receiving payment. When the payment involved is small or the work duration is short, a type II payoff may be typical. Under such a condition, if the application of payment involves lengthy and complicated paper work, a supplier may even choose 'on completion' rather than 'bi-weekly' (type III or IV).

4.3. Category III and IV issues

Category III issues, such as *resource provision* and *procurement extension*, require two inputs: a list of items and their quantities. Meanwhile, category IV issues, such as *mass procurement opportunity* and *future procurement opportunity*, although requiring only quantity as an input, can be treated in the same way as category III because the implied procured item for these issues is that being negotiated on.

This study uses estimated value as the unified measurement unit for *procurement extension* and *resource provision*, and expected value as the unit for *mass procurement opportunity* and *future procurement opportunity*, where the unit is a monetary value in both cases. These issues have no individual payoff functions because the options of these issues generally are offered by the contractor as presumptions, and cannot be changed by a supplier. Nevertheless, the monetary value of these issues may significantly influence supplier payoff for issues such as *price*. The influence is bigger than for a contractor because the options offered by the contractor normally use the capacity leeway of that contractor rather than squeezing capacity (i.e. offering additional procurement that was originally planned or additional resource capacity that is not used), but represent an opportunity for a supplier to gain extra contract value or achieve cost savings.

5. Modeling negotiation process for agents

Krovi et al. (1999) proposed that the negotiation process might be captured by the interaction of three types of environments, namely: task, agent, and communications environments. Such environments of the proposed process model are described below.

5.1. Task environment

The task involves artificial agents playing the roles of contractor and suppliers in a virtual supply chain. The buyer is the contractor, and the sellers are the suppliers providing materials to the contractor. All parties try to maximize individual payoff through negotiation. Moreover, all parties have conflicts of interest regarding one or more issues. For example, the contractor prefers low price while the suppliers prefer high price. Notably, different suppliers may prioritize the negotiable issues differently.

The negotiation process is sequential for individual suppliers (i.e. making an offer and then waiting for a counter-offer), but may be parallel for the contractor negotiating with multiple suppliers (i.e. simultaneously making offers to multiple suppliers). Agents negotiate by exchanging offers and counter-offers for the negotiable issues. Each negotiation session is free of time constraints.

5.2. Agent environment

Each negotiation session between a contractor and a supplier involves three artificial agents, namely the contractor agent, supplier agent, and coordinator agent. Human negotiators control the contractor and supplier agents by setting payoff functions for each negotiable issue. The payoff function of the contractor agent differs from that of the supplier agent, and neither side knows the payoff functions of the others. However, the coordinator agent knows the payoff functions of both sides, and tries to identify an agreement point that meets the satisfaction levels and maximizes the joint payoff of both sides.

5.3. Communication environment

The contractor and supplier agents interact by exchanging information via the coordinator agent in the form of offers and counter-offers. Offers made by each party are communicated via messages. Each agent incorporates the actions of other agents into its negotiation plan. Messages and actions of the three agents are detailed in a subsequent section.

6. Genetic algorithm representation

Oliver (1996) automated negotiations on electronic commerce in consumer products using genetic algorithm (GA), and found that the negotiation results equaled, and sometimes outperformed, those achieved by humans. Matwin et al. (1991) suggested that GA is suitable for problems with four characteristics. The first characteristic is that the problem can be described as a sequence of moves. Second, the sequence may converge towards a final state when all states are comparable regarding their contribution to a certain goal. Third, moves that contribute to the achievement of a given result can be identified. Finally, credit for good results can be attributed to contributing moves.

Negotiation involves a sequence of offers and counter-offers. The sequence leads to either a final agreement point or a failure state. Each intermediate offer results in a payoff for the contractor and supplier, and is traced. The goal is to maximize the payoff sum, and the payoff of each offer can be calculated after determining the payoff for each negotiable option. Besides the present negotiation problem fitting the above characteristics, GA is also a heuristic search procedure that relies on very little domain knowledge. Because no research has been conducted on the negotiation strategies adopted in construction procurement, this study chose GA as a search algorithm for finding the most beneficial agreement point.

Each negotiation offer is represented as a gene, so that GA can apply genetic operators such as mutation and crossover to create a population of offers and evolve those offers to find the most beneficial one(s). Gene cell representation comprises two parts: the first cell is a threshold for accepting an offer, and the remaining cells represent the options associated with each negotiable issue. Offer i, a string of cells, can be represented by array $[T_i, O_{ij}]$, where T_i denotes the threshold for offer i, and O_{ij} represents a list of options for each negotiable issue j of offer i. Threshold T_i equals the payoff of offer O_{ij} to the offer maker.

The payoff of an offer i to a negotiator, representing negotiator satisfaction level with a particular offer, is defined as the weighted average of the payoff for each individual issue, as shown in formula (2).

$$U(i) = \sum_{j=1}^{m} W_j U_j(O_{ij}) \qquad (2)$$

$U_j(O_{ij})$: individual payoff of option O_{ij} on issue j;
W_j : weight on issue j;
m : number of negotiable issues

Since the objective here is to find the offer that is most beneficial to both negotiating parties, joint payoff (the sum of the contractor's payoff and the supplier's payoff on an offer) is defined as the objective function. Because negotiating party attempts to maximize their individual payoff, the GA fitness function of the contractor or supplier is the individual payoff function. Additionally, a fitness improvement factor g (formula (3)) (Buckles & Petry, 1992) is used to determine whether the evolution has reached convergence. The evolution stops if the improvement factor of an evolved population is below the user-defined threshold.

$$g = (\text{the highest fitness score} - \text{the average fitness score}) / (\textit{the average fitness score}) \qquad (3)$$

Genetic operators include reproduction, crossover, and mutation. The reproduction operator enables individuals to be duplicated for possible inclusion in the next generation. Crossover in biological terms describes the blending of chromosomes from the parents to produce new chromosomes in the offspring. Both crossover and mutation operations ignore the threshold cell.

Section 7 describes the proposed computation model for negotiation that involves three collaborative agents based on the gene representation, fitness functions, and genetic operators described above.

7. Computational model

Fig. 5 presents the flowchart of the proposed computational model. The model involves three agents, namely contractor, coordinator, and supplier agents. Boxes with solid lines denote activities performed by agents, while boxes with dashed lines indicate those performed by humans. To avoid confusion below, italic fonts refer to agents, while normal fonts refer to humans.

The contractor must initiate the agent with a set of negotiation criteria (i.e. negotiable issues and their allowable options, weights and payoff functions) and GA settings (i.e. population size n, crossover rate c, mutation rate m, and threshold for fitness improvement factor g). Information on the negotiation criteria and GA settings is passed to *Coordinator*, but not to *Supplier*, except for the negotiable issues and allowable options, which are passed further to *Supplier*. The supplier must respond to this message by determining acceptable options, weight, and payoff function for each negotiable issue.

The proposed model comprises two modes, namely the traditional and automatic modes. In the traditional mode, *Contractor* generates and passes request-for-quotations (RFQ) to *Supplier* based on the variety of combinations of allowable options determined by the contractor. *Supplier* presents each message to the supplier, and the supplier provides an appropriate price quotation for each RFQ. The whole process merely provides book-keeping and payoff calculation functions, and does not involve any intelligent decision-making. In the automatic mode, *Coordinator* coordinates *Contractor* and *Supplier* to reach an offer that

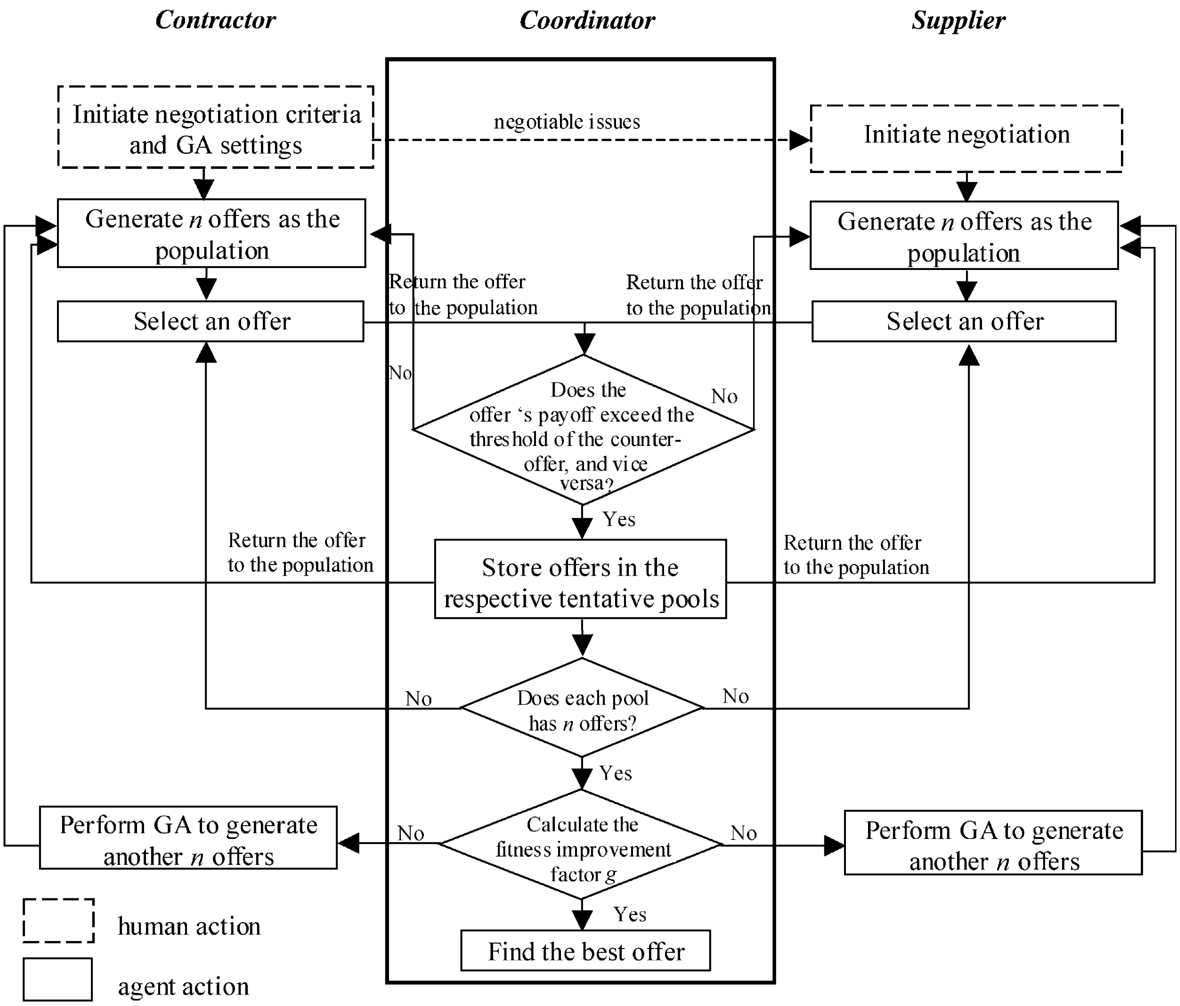

Fig. 5. Computation model for negotiation agents.

maximizes the sum of contractor and supplier payoff. The following discussion refers to the automatic mode.

Contractor and *Supplier* have similar objectives; i.e. to generate an offer that is acceptable to its own criteria and has payoff higher than the offer proposed by the counter part through a continuously random selection process, and evolve the offer to find the best one through GA. Using *Contractor* as an example (Fig. 5), the first step is to generate n offers as its population. Each offer includes an option for each negotiable issue and a threshold T, which equals the corresponding payoff of the option based on the payoff function of the contractor. The threshold represents the satisfaction level of the contractor with the offer. The second step involves randomly selecting an offer from the population and submitting it to *Coordinator*, who at this time also receives an offer from *Supplier*. If the offer of *Contractor* provides *Supplier* with a payoff higher than that from the *Supplier* offer, and *Supplier* offer provides *Contractor* a payoff higher than the payoff of the *Contractor* offer, both offers are saved in their respective tentative pools. Otherwise, *Coordinator* passes the offer back to *Contractor* and *Supplier* and asks them to select another offer. This process continues until *Coordinator* has n *Contractor* offers and n *Supplier* offers. The total of $2n$ offers are used to calculate the fitness evolution improvement factor g. If g is smaller than the pre-determined threshold, the search has reached a convergence, and *Coordinator* presents the offer with the highest sum of payoff of both contractor and supplier as the final result. Otherwise, *Coordinator* requests both *Contractor* and *Supplier* to generate another generation of offer populations. Through generations of evolution, when g is below the threshold, most offers in the population already have fitness scores approaching the best offer. Thus, further evolution achieves insignificant improvement, and so evolution can stop.

The activity ‘Perform GA to generate another n offers’ is a typical GA evolution process. The fitness is first calculated for each offer. Second, the tournament selection method is used to select offers for reproduction. In the tournament selection, a number of individuals are picked using roulette wheel selection, and the best of these are chosen for reproduction. When the corresponding two offers are selected, the next step is to apply user-defined parameters to determine if their offspring should be generated through reproduction, crossover, or mutation. The fitness scores are calculated for the two newly generated descendants, and only that descendent with the higher score is kept. This process continues for n times and produces a new population of n offers.

8. System implementation

The interface and reasoning engine of the proposed system, named C-Negotiators, are developed using Microsoft Visual Basic 6.0. Meanwhile, the database for storing the contractor and supplier information was implemented using Microsoft Access 2000. The interface enables the contractor to choose negotiable issues and allowable options, and define their preferences (payoff) regarding each option (shown in Fig. 6), and GA parameters. It also allows the suppliers to define their preferences regarding each of the allowable options set by the contractor. The engine includes GA engine, three types of intelligent agents, namely *Contractor*, *Coordinator*, and *Supplier*, and message communication between agents.

9. Case study

This study conducted experiments to assess the performance of C-Negotiators on the joint payoff sum of suggested negotiation agreements, and achieving benefits in saving negotiation time and costs. First, three procurement items, namely pre-mixed concrete, rebar, and rebar assembly, of two projects A and B were selected for the experiments. Both projects involved an office-plant complex. Project A has five stories plus one underground story, while Project B has five stories plus two underground stories. Table 1 compares the two projects in terms of total floor area, total contract volume (with specific subcontract volume for pre-mixed concrete, rebar, and rebar assembly), and position and years of procurement experience of the participating professionals.

Three experiments were conducted to assess the performance of C-Negotiators. Experiment I, termed traditional negotiation, represented a human negotiation process, the negotiation outcome of which was the actual agreement obtained from existing procurement contracts. C-Negotiator was not involved in this experiment. Experiment II, termed traditional Internet negotiation, represented a replayed human negotiation process conducted via the Internet without the involvement of artificial agents. C-Negotiator provided only the interface and book-keeping functionality in this experiment. Experiment III, termed agent-based negotiation, represented the negotiation process conducted via the Internet with full agent involvement. In this experiment, agents applied GA and negotiated via the Internet, and suggested final agreements. The parameter values used for GA were based on the suggestions proposed by DeJong, 1980), and included population size = 50,

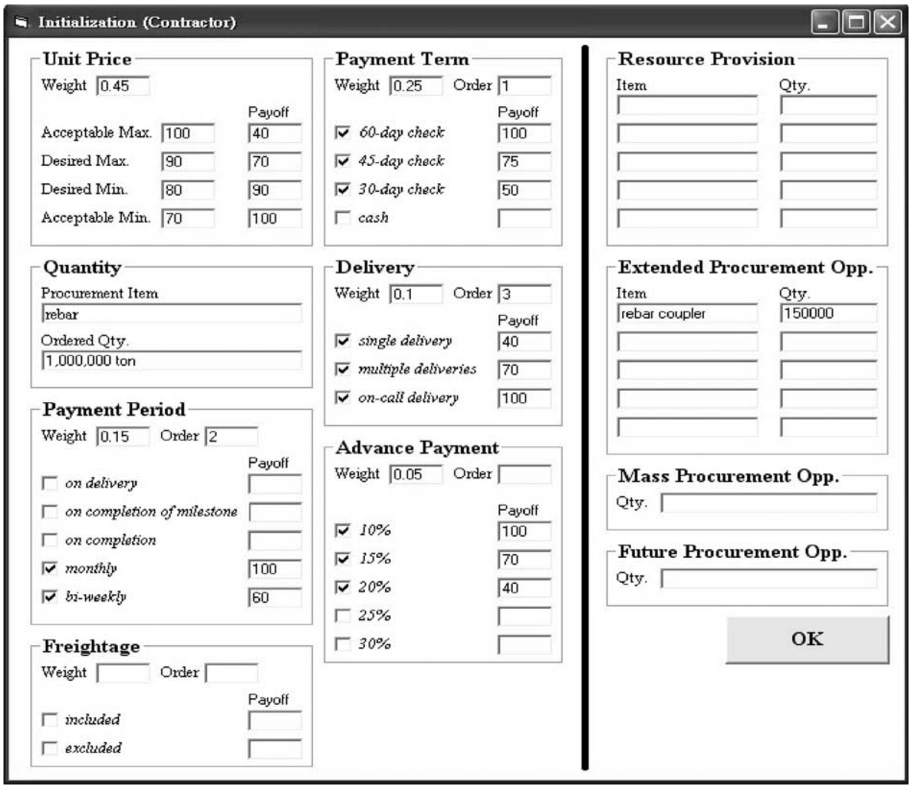

Fig. 6. Initiation dialog for contractor.

Table 1
Projects used in experiments

Project data	Project A	Project B
Total floor area	23523 M^2	67576 M^2
Total contract volume	$US 7.77 millions	$US 22.79 millions
Pre-mixed concrete	$US 1.18 millions	$US 2.82 millions
Rebar	$US 1.23 millions	$US 2.99 millions
Rebar assembly	$US 0.44 millions	$US 1.19 millions
Participants' background		
Contractor	Deputy Section Manager (9 yr)	Deputy Section Manager (9 yr)
Pre-mixed concrete supplier	Vice President (20 yr)	Senior Manager (18 yr)
Rebar supplier	Owner (18 yr)	President (21 yr)
Rebar assembly labor supplier	Owner (15 yr)	Owner (16 yr)

crossover rate = 0.7, and mutation rate = 0.02. The threshold for the fitness improvement factor was set to 5%. A virtual project was also used to help participants familiarize themselves with the system before the experiments began.

9.1. Performance measures

Performance measures for the experiments include individual payoffs, joint payoffs, negotiation costs, and negotiation time. Once the contractor and suppliers determined their payoff functions, the same set of functions was used to derive the individual and joint payoffs for all three sets of negotiation outcomes.

Negotiation costs include man-hour, communications, and travel costs. The costs incurred during the pre-negotiation (e.g. searching for business opportunities, historic data collection, cost estimation, and document preparation) and post-negotiation phases (e.g. contract preparation and reproduction, and delivery of goods) were assumed to be identical for all experiments and thus were ignored. The following formulas were used to calculate man-hours, communications and travel costs, where C represents cost, Q is quantity, T denotes time, and R represents rate.

$$C_{\text{man-hr}} = [Q_{\text{meeting}} * Q_{\text{negotiator}} * (T_{\text{meeting}} + T_{\text{travel}}) + T_{\text{communication}} + T_{\text{system}}] * R_{\text{man-hr}} \quad (4)$$

$$C_{\text{communication}} = T_{\text{communication}} * R_{\text{communication}} \quad (5)$$

$$C_{\text{travel}} = C_{\text{travel}} * Q_{\text{meeting}} * Q_{\text{participants}} \quad (6)$$

Negotiation time included communication time ($T_{\text{communication}}$) and negotiation meeting time (T_{meeting}). For Experiments II and III, the time further included time for initiating negotiable issues and options, and payoff functions, and time for system execution. Participant contemplation time during the negotiation phase was counted as part of the initiation time. Time spent playing with the virtual project during the pre-experiment phase, and that spent on Q and A conversation between participants and experimenters was ignored.

9.2. Experimental results and discussions

Table 2 lists the contractor negotiation outcomes for Experiments I, II, and III, with three suppliers (i.e. pre-mixed concrete, re-bar, and re-bar labor) for both projects. Each set of outcomes includes the agreed unit price and options for the negotiable issues, as well as individual and joint payoffs. The table also lists the percentage increase in joint payoff (shown by percentage numbers under each joint payoff) for Experiments II and III compared to Experiment I.

Table 3 lists the estimated values for the variables used in the formulas (4–6) and the calculated negotiation cost and time for the contractor and suppliers. The percentage cost and time savings for Experiments II and III in comparison with Experiment I are also listed.

The traditional Internet negotiation did not always produce an agreement with higher joint payoffs than the corresponding result in the traditional negotiation. Examples are Experiment II (Project A) for pre-mixed concrete (144.242 vs. 145.958) and rebar labor (145.200 vs. 146.733) as shown in Table 2. This is because C-Negotiator for the traditional Internet negotiation merely provides message communication and book-keeping services, and does not provide any guide on negotiation. However, as shown in Table 3, traditional Internet or agent-based negotiation always require less cost (from 83.8% less to 94.5% less) and time (from 95.3% less to 98% less) than traditional negotiation because communication via the Internet significantly reduces the costs and time required for travel and meetings.

Agent-based negotiation always reached an agreement with higher joint payoff (from 1.5% more to 9.8% more) than the other two methods as shown in Table 2. This difference occurred because the human negotiators tried to reach a mutually acceptable agreement based on experience, while the agents tried to maximize the joint payoff through extensive search. Thus, agents are motivated in finding the best agreement. The agent-based negotiation was also less costly (from 84% less to 94.5% less) than the traditional negotiation, but was not always less costly than the traditional Internet negotiation. The agent-based negotiation

Table 2
Negotiation outcomes of the experiments

Item	Negotiation outcomes		Experiment (Project A)			Experiment (Project B)		
			I	II	III	I	II	III
Pre-mixed concrete	Agreed options	Unit price	$57	$56	$58	$47	$46	$43
		Payment term	60-day check	45-day check	60-day check	60-day check	45-day check	30-day check
		Payment period	Monthly	On-delivery	Monthly	Monthly	Monthly	On-delivery
		Delivery	On-call	Multiple	Multiple	On-call	On-call	On-call
		Freightage	Included	Included	Included	Included	Included	Included
	Payoffs	Contractor	71.964	62.273	68.000	90.727	86.909	90.273
		Supplier	73.994	81.969	79.531	63.600	68.400	67.500
		Joint	145.958	144.242	147.531	154.327	155.309	157.773
		Improved (%)		−1.2	+2.2		+0.6	+2.2
Re-bar	Agreed options	Unit price	$293	$286	$277	$272	$263	$253
		Payment term	60-day check	45-day check	30-day check	60-day check	45-day check	30-day check
		Payment period	Monthly	Monthly	Monthly	Monthly	Monthly	Monthly
		Delivery	Multiple	Multiple	Multiple	Single	Multiple	Multiple
		Freightage	Included	Included	Included	Included	Included	Excluded
	Payoffs	Contractor	85.268	88.415	92.545	86.250	88.077	86.394
		Supplier	68.603	70.846	72.500	64.357	71.286	79.000
		Joint	153.871	159.261	165.045	150.607	159.363	165.394
		Improved (%)		+3.5	+7.3		+5.8	+9.8
Re-bar labor	Agreed options	Unit price	$103	$110	$100	$108	$113	$108
		Payment term	Cash	30-day check	30-day check	Cash	30-day check	30-day check
		Payment period	Monthly	Monthly	Monthly	Monthly	Monthly	On delivery
		Delivery	Multiple	On-call	On-call	Multiple	On-call	On-call
	Payoffs	Contractor	72.000	78.000	87.000	73.000	82.000	85.500
		Supplier	74.733	67.200	62.000	64.000	54.667	54.000
		Joint	146.733	145.200	149.000	137.000	136.667	139.500
		Improved (%)		−1.0	+1.5		−0.2	+1.8

also required less time (from 95.3% less to 98% less) than the other two methods as shown in Table 3.

The improvement in joint payoff was smaller than expected. This phenomenon occurred because the number of negotiable issues and options were limited, and human negotiators could reach good agreement based on years of experience. Nevertheless, the experiments also demonstrated that C-Negotiators occasionally might help negotiators 'leave less money on the table', achieving improvements of as much as 9.8% of payoff, as in the negotiation with re-bar supplier for Project B (Table 2).

Fig. 7 illustrates the payoff points for negotiating pre-mixed concrete for Project A, which include the original agreement points (from actual contracts), and the best ten agreements of the first and last GA generations from agent-based negotiation. The distribution of points in Fig. 7 was typical, and resembled the negotiation outcomes of most procured items and projects in the experiments. The original point was above the 45° line, meaning the actual agreement favored the contractor. In other words, the tested procurement items were of an unbalanced market (buyer's market), and the contractor had more negotiation power. The ten best agreements of the first GA generation might include points close to the original, points better than the original, and occasionally points approaching the best of the last generation. GA found a better point through generations of evolution. However, the small number of negotiable issues and options limited the improvement. Thus, rather than saying that GA improves the optimum through evolution, GA can be said to improve the population average through evolution.

Fig. 8 displays a special set of negotiation payoff points. The set resembled the typical one (e.g. Fig. 7) in that the average joint payoff of the first GA generation was higher than the payoff of the actual agreement, and was below the payoff of the last GA generation. However, unlike the typical one, the agreement points of Fig. 8 were distributed around the area below the 45° line, indicating that the supplier had strong negotiating power. A follow-up investigation indicated that this result occurred because the supplier was an owner-designated supplier and the contractor thus had less bargaining power.

10. Application limitation

Some limitations to the application of C-Negotiators exist. First, although the experiments demonstrated that the GA-suggested best agreement point produced higher joint payoff than the original agreement made by human, the improvement was smaller than expected, ranging from 1.5% (re-bar labor of Project A) to 9.8% (re-bar of Project B). One reason for the small improvement was that the number of negotiable issues and options of interest to negotiators for the tested procurement items was small, and the human

Table 3
Estimated cost and time for the experiments

Estimated data and result			Experiment (Project A)			Experiment (Project B)		
			I	II	III	I	II	III
Variables	Contractor	$R_{man\text{-}hr}$	$9.38	$9.38	$9.38	$9.38	$9.38	$9.38
		$Q_{negotiator}$	3	1	1	3	1	1
		$Q_{meeting}$	3	1	1	4	1	1
		Q_{offer}	4	7	N/A	4	7	N/A
	Supplier (concrete)	$R_{man\text{-}hr}$	$11.46	$11.46	$11.46	$12.50	$12.50	$12.50
		$Q_{negotiator}$	2	1	1	3	1	1
		$Q_{meeting}$	2	1	1	3	1	1
		Q_{offer}	4	5	N/A	4	6	N/A
	Supplier (rebar)	R_{man-hr}	$13.02	$13.02	$13.02	$13.89	$13.89	$13.89
		$Q_{negotiator}$	3	1	1	3	1	1
		$Q_{meeting}$	3	1	1	4	1	1
		Q_{offer}	3	5	N/A	3	6	N/A
	Supplier (labor)	$R_{man\text{-}hr}$	$14.58	$14.58	$14.58	$14.58	$14.58	$14.58
		$Q_{negotiator}$	3	1	1	2	1	1
		$Q_{meeting}$	3	1	1	3	1	1
		Q_{offer}	3	4	N/A	3	5	N/A
Cost (US$)		Contractor	$692	$66	$66	$861	$66	$66
		Improved (%)		+90.5	+90.5		+92.3	+92.3
		Supplier (concrete)	$470	$76	$75	$1038	$76	$79
		Improved (%)		+83.8	+84.0		+92.7	+92.4
		Supplier (rebar)	$1,100	$81	$81	$1499	$83	$83
		Improved (%)		+92.6	+92.6		+94.5	+94.5
		Supplier (labor)	$1,189	$85	$81	$793	$84	$83
		Improved (%)		+92.9	+93.2		+89.4	+89.5
Time (min)		Contractor	1620	40	33	1620	40	33
		Improved (%)		+97.5	+98.0		+97.5	+98.0
		Supplier (concrete)	1200	52	46	1200	48	56
		Improved (%)		+95.7%	+96.2%		+96.0%	+95.3%
		Supplier (rebar)	1620	56	47	1620	55	57
		Improved (%)		+96.5%	+97.1%		+96.6%	+96.5%
		Supplier (labor)	1620	55	38	1200	46	45
		Improved (%)		96.6	+97.7		96.2	96.3

negotiators could reach near-optimum agreement based on years of negotiation experience. However, the improvement should increase with increasing number of negotiable issues or options.

Also note that the GA-suggested best agreement point was always closer to 45° than the original because the GA sought to optimize the joint payoff rather than the individual payoff of the contractors or suppliers. Since the construction

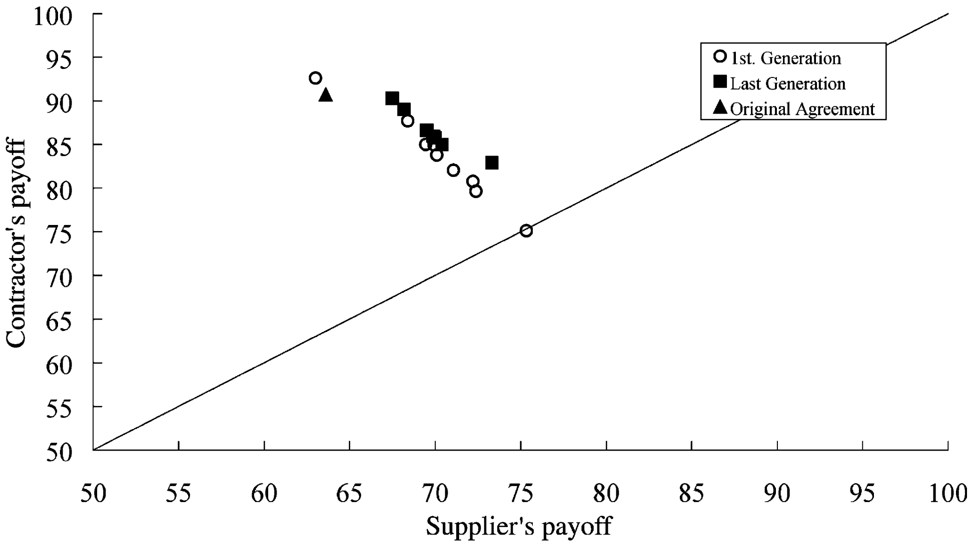

Fig. 7. Typical negotiation points (for pre-mixed concrete of project B).

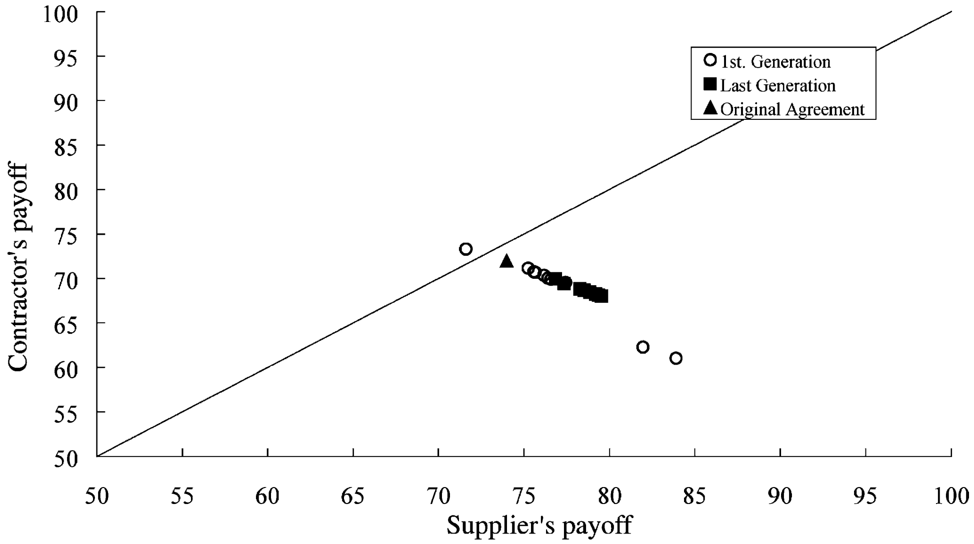

Fig. 8. Special negotiation points (for pre-mixed concrete of project A).

procurement market is a buyer's market, the contractor might not accept the GA-suggested best offer if the contractor payoff for the offer was below that of the original offer. The remedy to this problem presented here was to choose the GA-suggested 10 best offers, and present only those offers with a contractor payoff equal to or higher than that of the original. Negotiators found acceptable agreements from the presented ones in most cases. When none of the presented agreements was acceptable, the negotiators might adjust some terms to reflect their concerns.

Another anticipated application limitation did not occur in the experiments. Users who were familiar with C-Negotiators and knew that the system made suggestions based on the payoff functions might attempt to manipulate the system by misrepresenting their preferences. Understanding that the system suggestion is merely a suggestion that helps reach agreement and does not necessarily become the agreement may discourage such manipulation behavior. Furthermore, some conservative users may be uncomfortable with the system knowing their preferences and observing their offers. Such distrust may discourage users from using C-Negotiators or other similar systems.

Nevertheless, C-Negotiators is multidimensional instead of single dimensional, unlike the difficulty encountered in practice when applying game-theoretic models of bargaining. Moreover, C-Negotiators does not require common knowledge of negotiating parties. For example, a negotiating agent in C-Negotiators does not directly require any explicit knowledge of its counter-part agent such as payoff functions.

11. Conclusion

Effective intelligent agents not only allow a contractor and suppliers to negotiate more efficiently through efficient exchange, but also offer a better agreement that benefits both parties more than one they could have reached. This work examines the negotiable issues and options for construction procurement. Contractor and supplier preferences regarding the options also were compared. An agent-based system, C-Negotiators, also was developed to help the negotiation between contractor and supplier using the genetic algorithm. Experiments were also conducted and demonstrated that C-Negotiators improved negotiation efficiency by reducing negotiation time and cost, and improved effectiveness by suggesting a better agreement with higher joint payoff. Although the increased payoff was smaller than expected, we believe that the improvement will increase for more complex negotiation problems involving more issues and options, or complicated preferences and for inexperienced negotiators. System application is limited mainly by its symmetric (uni-directional) optimization, while the procurement negotiation in construction is biased towards the contractor, and also by level of user comfort with system monitoring of their preferences and negotiations.

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