Computer-Aided Civil and Infrastructure Engineering **20** (2005) 280–293

Searching for Better Negotiation Agreement Based on Genetic Algorithm

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Abstract: *Negotiation is commonly required in the procurement of construction materials to reach the final contractual agreement. In current practice, contractors negotiate with suppliers according to negotiators' experiences instead of extensive exploration of negotiable options and negotiators' preferences. Consequently, negotiators often reach suboptimal agreements, and leave money on the table. This research intends to help negotiators explore negotiable options by developing a computer system, named* C-Negotiator*, using the genetic algorithm. This article also describes experiments conducted to determine how much money was left on the table on typical realistic construction procurements. The result shows that* C-Negotiator*'s negotiation improved the joint payoff of the contractor and supplier from 1.5% to 9.8% compared with conventional human negotiation. The improvement may increase for more complex negotiation problems with more options and complicated preferences or for inexperienced negotiators.*

1 INTRODUCTION

Negotiation is commonly required in the procurement of construction materials to reach the final contractual agreement. For a construction procurement item (e.g., reinforcing steel, formwork, and waterproofing), a general contractor typically solicits several price quotations from suppliers, considers the suppliers' performance (e.g., quality of work and timely delivery), evaluates those quotations, and narrows down a few prospective suppliers. Subsequent processes often involves formal or informal negotiations between the general contractor and the prospective suppliers to finalize the price and other contractual terms (e.g., payment by 30-day check or 60-day check, and payment calculated monthly or at completion).

Nevertheless, a general contractor needs to limit the number of prospective suppliers to negotiate with and the number of negotiation meetings because of the time and man hours involved. As a result, the negotiation agreement is usually reached depending on experience instead of extensive exploration of negotiable options and preferences of negotiating parties. As concluded by Raiffa (Raiffa, 1982), even in simple negotiations, people often reach suboptimal agreements, thereby "leaving money on the table." Although many factors lead negotiators to miss out on gains, falsely assuming fixed pies and the framing of the situation often causes parties to miss reaching mutually beneficial agreements. The challenge of negotiation arises, in part, from the fact that each side has private information about their own utility function, but is ignorant of the other's values and strategies (Oliver, 1996).

This research proposes a framework where two subsystems representing the negotiating contractor and supplier negotiate with each other through another coordinator subsystem. The genetic algorithm is used to help the system search the negotiation space and present the best mutually beneficial agreement. The result of the proposed *C-Negotiator*'s negotiation conducted on three procurement items (i.e., premixed concrete, rebar, and rebar assembly) of two construction projects of office–plant building complexes is compared with that of conventional human negotiation to determine how much money has been left on the table in typical construction procurement negotiations.

2 RELATED WORK

Negotiation is a process for resolving conflicts between two or more parties (Anson and Jelassi, 1990). Ali

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(1998) investigated the factors that suppliers might consider when submitting a bid to a general contractor, including prompt payment habit, reputation for shopping after contract award, experience in building similar projects, efforts in planning and supervision, financial capacity, reputation for finishing projects on time, other work opportunity, and chance to get the job of the contractor, past experience with the contractor, clarity of work's specifications, terms of general contract, construction schedule, and construction methods used. Many of these factors (e.g., reputation for shopping after contract award and experience in building similar projects of the contractor), despite being important for preparing the bid proposal, are unlikely to appear as an issue in the negotiation process.

Raiffa (1982) defined the negotiation as a four-stage process, including preparation, gambit opening, concession, and end play. Mumpower (1991) found that each negotiating party perceived the negotiable issues differently, and the perception of an issue might be represented by a function of judgment of utility, including weight, function forms, and organization of joint utility structure.

Bazerman (1994) divided the negotiation into two categories according to negotiators' attitudes: distribution (claiming the pie) and integration (enlarging the pie of available resources). The distribution type of negotiation is a zero-sum game, that is, one party's gain results in the other's loss. The strategy for such a negotiation is to predict the bottom line of the other and present such an offer to maximize one's own benefit. Such a negotiation usually results in a lower satisfaction level. On the other hand, the integration type promotes negotiators' cooperation. Because each negotiator has different preferences over each negotiable issue and option, the strategy is not to win on all issues, but to realize what issues the negotiators care about most and make tradeoffs. Such negotiation usually results in 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 et al., 1991) that stresses model visualization capabilities, NEGOPLAN (Kersten and Szpakowicz, 1990) that generates if-then production rules, and GBML (Matwin et al., 1991) that discovers rules for better negotiations.

Snadholm and Lesser (1995) found that cooperative negotiators often exist and perform tasks inside an enterprise such as production planning and meeting scheduling. A competitive negotiator will not give in unless it can receive comparable compensation during negotiation because it cares only for its own benefit and is least concerned with joint benefit. However, such a competitive style prevents disclosure of individual preferences and often results in individual loss of benefit. Many electronic commerce (EC) web sites such as OnSale (2003), eBay's Auction Web (2003), Kasbah (2003), and Auction Bot (2001) also offer software agents that help on-line negotiation on price. For example, Kasbah adopts the distribution type of negotiation 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, and greedy), and initialization parameters (e.g., asking price, acceptable price, and deadline). T@T (2003), in addition to price, allows both buyers and sellers to customize their agents and negotiate on warranty, delivery time and method, service plan, return policy, and free bonus.

Most research on automated negotiation is concerned only with standardized products that can be described in detail, thereby ensuring comparability of offers and requests (Schoop et al., 2003). Several researchers have addressed the difference between the supply chain management in the construction industry and that in other industries. Vrijhoel and Koskela (2000) characterized the construction supply chain as a typical make-to-order supply chain, with every project producing a new product. The construction "factory" is set up around a single product, in contrast to most other manufacturing systems where multiple products are produced and distributed to many different customers.

The procurement negotiation in the construction industry involves some issues that are not addressed in the automated negotiation research. For example, typical construction procurement may require a supplier to deliver products to different sites at multiple times depending on the progress of the project. For large procurements, payments may also be made multiple times depending upon the progress of the project.

This research assumes an integration type of negotiation; that is, enlarging the pie of available resources. The proposed system consists of three subsystems, namely, *Contractor*, *Supplier*, and *Coordinator*. *Contractor* and *Supplier* have their own preferences, and their negotiation with each other is a collaborative effort. However, to be realistic, neither *Contractor* nor *Supplier* is aware of the preferences of the other, and communicate with each other through the intermediate *Coordinator* subsystem.

3 NEGOTIABLE ISSUES AND OPTIONS

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 according to these options. The proposed price may be continuously lowered during the negotiations. The supplier may also request to modify terms or to include new issues to offset price decreases. The negotiation ends when both parties agree on the options and price.

Dzeng et al. (2004) have conducted a survey to identify key negotiable 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%), among 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 according to the 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 in which 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.

Among the issues identified, only the first and second categories are considered negotiable in this research. Issues of the third and fourth categories are not considered because they mainly arise in a negotiation out of capacity leeway of a contractor and are wholly determined by the contractor. For example, a contractor only offers an opportunity for extended procurement to a supplier when there is still extended procurement that has not been tendered. It is uncommon for a supplier to make a contractor squeeze out new procurement during the negotiation. As a result, these issues are treated as nonnegotiable issues and are determined solely by a contractor.

The nonnegotiable issues, although they cannot be counteroffered by a supplier, may affect a supplier's quoted price. Because these issues involve uncertainty, they are represented by estimated expected monetary values in this research.

4 PAYOFFS OF 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. Payoff of an option with respect to a negotiator represents the negotiator's preference (or utility) over the option. This study uses the weighted payoff function to measure the goodness of a negotiation agreement.

Suppose n negotiable issues exist, where an offer x can be represented using an array $[x_1, x_2, \ldots, x_n]$, 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:

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

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

According to this concept, simplified, generalized contractor and supplier payoff functions used in this study are discussed below for the aforementioned two categories of negotiable issues.

Figure 1 illustrates conceptually typical payoff functions of contractors and suppliers regarding *price* (category I issue). 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). Further decrease in price has little effect on payoff increase until the price reaches $D_{\min}$ (the lowest desired price). 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

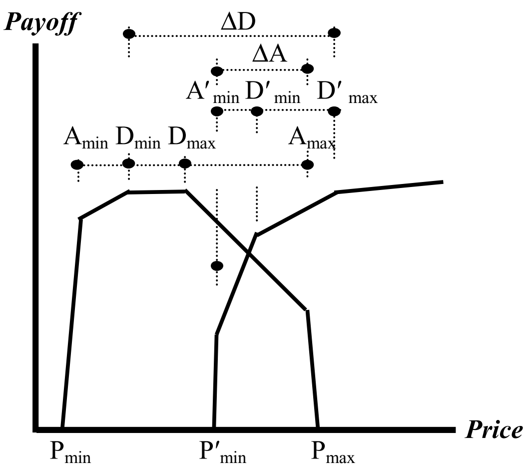


Fig. 1. Price negotiation space for contractor and suppliers.

credibility in terms of quality. 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. Initial contractor asking price in negotiations is within the desired price range, and depends on various conditions such as competition among prospective suppliers and familiarity with the negotiating supplier.

Figure 1 also 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 that of a contractor, a supplier's 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.

In Figure 1, $\Delta D = [D_{\min}, D'_{\max}]$ is the maximum possible difference between the initial asking price of the contractor and the initial offering price of the supplier, that is, space of starting points for the negotiation. $\Delta A = [A'_{\min}, A_{\max}]$ represents the space of agreement points in the negotiation.

Figure 2 illustrates a payoff function example of 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.

Negotiator payoff may positively correlate with issue options. For example, the contractor generally prefers longer *payment term*, to delay the payment as long as possible, and thus the contractor's payoff for "60-day check" is greater than that of "cash." Negotiators may also feel indifferent to some intermediate options. For example, some contractors may be indifferent to a payment term of "30-day check" or "45-day check." Similarly, a negotiator's payoff may also 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." Of course, some suppliers may also feel indifferent to the length of *payment term*.

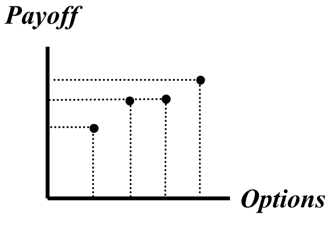


Fig. 2. Payoffs for options of category-II issues.

5 RESEARCH ASSUMPTIONS AND PROBLEM

This work developed a negotiation system, named Construction-Negotiators (*C-Negotiator*), using the following assumptions. A contractor has set up a virtual supply chain on the Internet where request-for-quotations (RFQ) can be announced for required procurement and prospective suppliers can respond to the requests by submitting their tenders. Both parties know the negotiation dimensions (i.e., negotiable issues such as price and delivery) and options available for each dimension.

Each negotiating party is rational in negotiation, and the objective is to maximize the payoffs. Nevertheless, research has indicated that consumer decisions may not always be rational. For example, a series of studies by Darke and Freedman (1995) demonstrated that shoppers gained satisfaction from bargain hunting even when the amount saved was insignificant or did not benefit them directly. Such nonfinancial factors are ignored in this research.

In the real world, a contractor's goal may be to maximize his surplus by balancing the amount of payoff saved from negotiating with prospective suppliers and the cost of continuing negotiation. In this research, the issue of negotiation cost is ignored because most negotiation is automatically conducted on the Internet and the cost is limited.

The preference of parties involved in the negotiation over each negotiable issue can be represented by the previously proposed generalized payoff functions. The dependency among options of different issues can be modeled by the exchange of payoffs over the issues. For example, a supplier is willing to discount the price by 10% (price issue) if the contractor pays by cash instead of a 60-day check (payment term issue). The rationale behind such behavior is that the supplier's payoff loss from the price issue can be offset by the gain from the payment term issue.

The research problem here is to assist a contractor and a supplier negotiating on the Internet to arrive at a jointly beneficial agreement, and to compare the agreement reached with that made conventionally by human negotiators.

6 *C-NEGOTIATOR* SYSTEM

The task of the proposed negotiation system involves subsystems playing the role of contractor, suppliers in a virtual supply chain. The s*ubsystems* negotiate and find the most beneficial agreement using genetic algorithms. 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 a low price, whereas the suppliers prefer a 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 counteroffer), but may be parallel for the contractor negotiating with multiple suppliers (i.e., simultaneously making offers to multiple suppliers). The *subsystems* negotiate by exchanging offers and counteroffers for the negotiable issues. Each negotiation session is free of time constraints.

Each negotiation session between a contractor and a supplier involves three subsystems, namely, *Contractor*, *Supplier*, and *Coordinator*. Human negotiators control *Contractor* and *Supplier* by setting payoff functions for each negotiable issue. The payoff function of *Contractor* differs from that of *Supplier*, and neither side knows the payoff functions of the others. However, *Coordinator* 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.

Contractor and *Supplier* interact by exchanging information via *Coordinator* in the form of offers and counteroffers. Offers made by each party are communicated via messages. Each subsystem incorporates the actions of other subsystems into its negotiation plan.

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 the following equation:

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

where $U_j(O_{ij})$ is individual payoff of option O_{ij} on issue j, W_j is weight on issue j, m is number of negotiable issues.

Because 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 the 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 (Equation (3)) (Buckles and 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.

$$g = \frac{\text{the highest fitness score} - \text{the average fitness score}}{\text{the average fitness score}} \tag{3}$$

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, and the threshold needs to be recalculated after operations. Figure 3 illustrates the crossover operation.

Figure 4 presents the flowchart of *C-Negotiator*, which shows the actions of three subsystems, including *Contractor*, *Coordinator*, and *Supplier*. Boxes with solid lines denote activities performed by the system, whereas boxes with dashed lines indicate those performed by humans.

The contractor must initiate *Contractor* 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

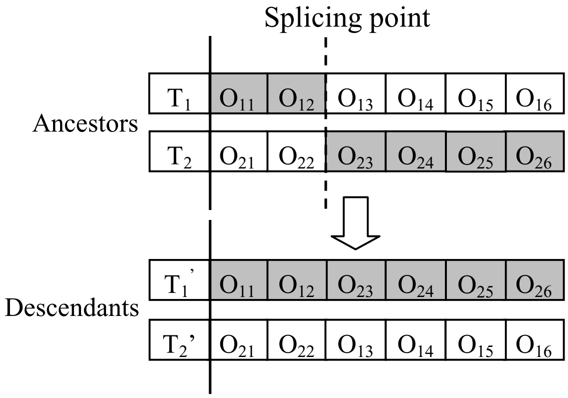


Fig. 3. Crossover operation.

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 functions for each negotiable issue.

C-Negotiator comprises two modes, namely, the traditional and automatic modes. In the traditional mode, *Contractor* generates and passes RFQ to *Supplier* according to 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 bookkeeping 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 maximizes the sum of contractor and supplier payoff. The following discussion refers to the automatic mode.

Contractor and *Supplier* have similar objectives, that is, to generate an offer that is acceptable to its own criteria and has payoff higher than the offer proposed by the counterpart through a continuously random selection process, and to develop the offer to find the best one through GA. Take *Contractor* as an example (Figure 4), 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 according to 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

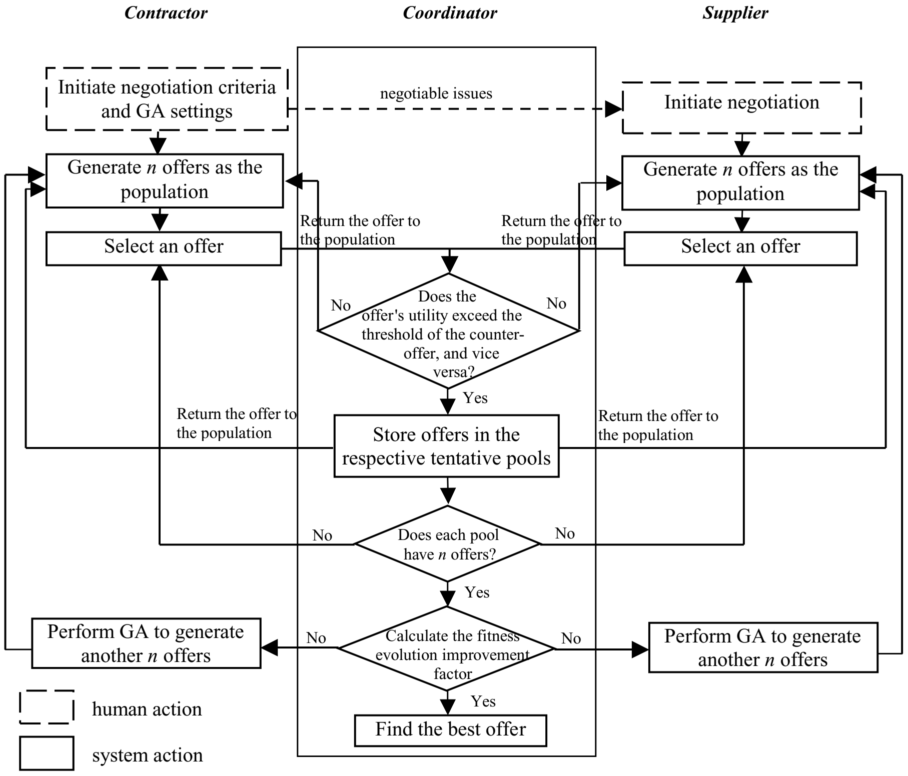


Fig. 4. *C-Negotiator* system flowchart.

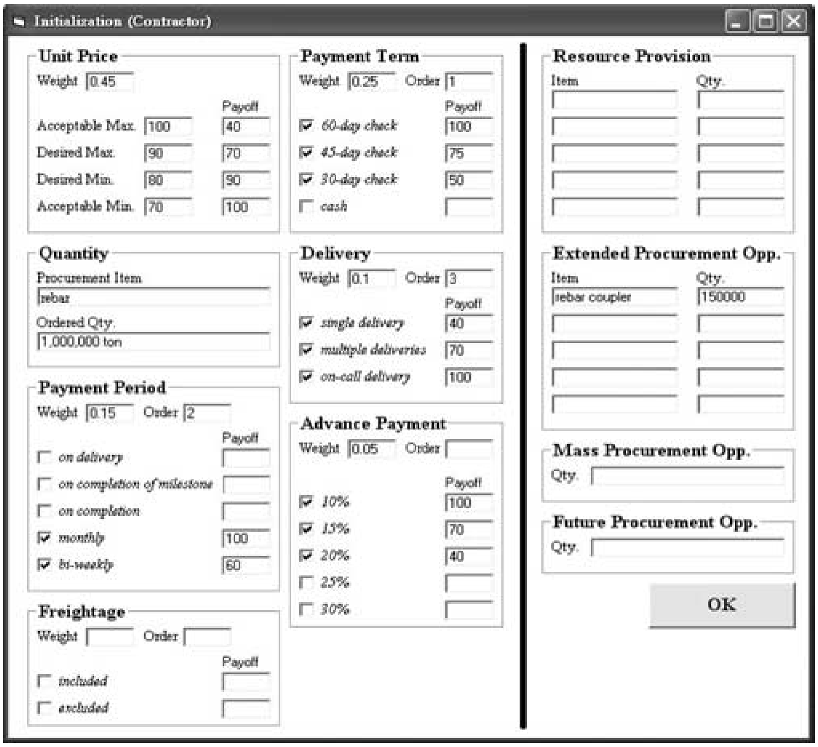
Supplier offer, and *Supplier* offer provides *Contractor* a payoff higher than the payoff of the *Contractor* offer, both offers are saved in their respective tentative pools. Otherwise, *Coordinator* passes the offer back to *Contractor* and *Supplier* and asks them to select another offer. This process 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 predetermined 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" takes *n* offers, crossover rate *c* and mutation rate *m* as the input, and generates a new population of offers using GA. 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. According to the roulette wheel method, selection for an individual i is stochastic and proportional to its fitness f_i (assumed to be a positive number). Each individual occupies a slice of pie, f_i out of a total size $\sum_{j=1}^{n} f_j$, where n is the population size. The probability of individual i being selected is $P(i) = f_i / \sum_{j=1}^{n} f_j$. A uniformly distributed random number is generated to determine which two slices of pie are selected.

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.

7 SYSTEM INTERFACE

C-Negotiator is implemented using Microsoft Visual Basic 6.0. The database for storing the contractor's and suppliers' information is implemented using Microsoft Access 2000. Figure 5 shows the contractor initiation dialog where the contractor can control negotiation



Initialization (Contractor)

Unit Price
Weight 0.45

		Payoff
Acceptable Max.	100	40
Desired Max.	90	70
Desired Min.	80	90
Acceptable Min.	70	100

Quantity
Procurement Item: rebar
Ordered Qty.: 1,000,000 ton

Payment Period
Weight 0.15 Order 2

	Payoff
☐ *on delivery*	
☐ *on completion of milestone*	
☐ *on completion*	
☑ *monthly*	100
☑ *bi-weekly*	60

Freightage
Weight Order

	Payoff
☐ *included*	
☐ *excluded*	

Payment Term
Weight 0.25 Order 1

	Payoff
☑ *60-day check*	100
☑ *45-day check*	75
☑ *30-day check*	50
☐ *cash*	

Delivery
Weight 0.1 Order 3

	Payoff
☑ *single delivery*	40
☑ *multiple deliveries*	70
☑ *on-call delivery*	100

Advance Payment
Weight 0.05 Order

	Payoff
☑ *10%*	100
☑ *15%*	70
☑ *20%*	40
☐ *25%*	
☐ *30%*	

Resource Provision

Item	Qty.

Extended Procurement Opp.

Item	Qty.
rebar coupler	150000

Mass Procurement Opp.
Qty.

Future Procurement Opp.
Qty.

Fig. 5. Contractor initiation dialog.

behavior of *Contractor* by selecting negotiable issues and allowable options, and determining payoff for each option.

8 EXPERIMENTS OF REAL CASES

This study conducted experiments to assess the *C-Negotiator*'s performance on the joint payoff sum of suggested negotiation agreements and to determine the amount of payoff left in traditional human-based negotiation. Three procurement items, namely, premixed concrete, rebar, and rebar assembly, of two construction 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, whereas 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 premixed concrete, rebar, and rebar assembly), and position and years of procurement experience of the participating professionals.

A virtual project was used to help participants familiarize themselves with the system before the experiments began. Performance measures for the experiments include individual payoffs and joint payoffs. Once the contractor and suppliers determined their payoff functions, the same set of functions was used to derive the individual and joint payoffs for outcomes of both human-based and *C-Negotiator*'s negotiations.

In each set of negotiations, both contractor and supplier input their own weights and values for each item being negotiated. The sum of all the weights of negotiable issues adds up to one. Both contractor and supplier also input the payoff for each allowable option representing their preference for the option. Payoff inputs are adjusted so that both parties have a similar sum total of option payoffs for each item while maintaining the original relative weighting. For example, the supplier's payoffs of 100, 70, and 30 (total payoff = 200) for three allowable options of an issue may be changed to 75, 52.5, and 37.5 if the contractor's corresponding payoffs are 60, 60, and 30 (total payoff = 150).

The population size chosen must be large enough to create sufficient diversity covering the possible solution space. A more complex problem requires a larger population size due to the larger possible combination of variables. However, a large population size also slows down the GA progress. Goldberg (1989) assumed constant convergence times in a serial GA, and derived population sizes that were relatively small for short chromosomes and increased exponentially with chromosome length. Goldberg et al. (1992) derived a population-sizing equation and tested it in GAs to optimize five real-valued functions. Reeves (1993) investigated the minimum practical population size in a GA and applied the requirement that every point in the search space be reachable by crossover alone. His proposed functions indicate population size as a function of chromosome length, alphabet size, and probability. These functions suggest that small populations suffice when chromosomes are binary, whereas coding over alphabets of higher cardinality requires larger populations.

We have tried the size of 10, 20, 30, 50, 100, and 200, and we found that the size greater than 30 resulted in a similar best agreement. Other parameters, such as crossover probability, mutation rate, and selection seem to effect the GA process less significantly when evaluated over a larger number of generations. The following presents the results with parameter values as suggested by DeJong

Table 1
Projects used in experiments

Project data	*Project A*	*Project B*
Total floor area	23,523 m^2	67,576 m^2
Total contract volume	US$7.77 million	US$22.79 million
Premixed concrete	US$1.18 million	US$2.82 million
Rebar	US$1.23 million	US$2.99 million
Rebar assembly	US$0.44 million	US$1.19 million
Participants' background		
Contractor	Deputy Section Manager (9 years' exp.)	Deputy Section Manager (9 years' exp.)
Premixed concrete supplier	Vice President (20 years' exp.)	Senior Manager (18 years' exp.)
Rebar supplier	Owner (18 years' exp.)	President (21 years' exp.)
Rebar assembly labor supplier	Owner (15 years' exp.)	Owner (16 years' exp.)

Table 2
Negotiation outcomes of the experiments

Item		*Negotiation outcomes*	*Experiment (project A)*			*Experiment (project B)*		
			Human	*C-Negotiator*	*Improvement*	*Human*	*C-Negotiator*	*Improvement*
Premixed concrete	Agreed options	Unit price	$57	$58		$47	$43	
		Payment term	60-day check	60-day check		60-day check	30-day check	
		Payment period	Monthly	Monthly		Monthly	On-delivery	
		Delivery	On-call	Multiple		On-call	On-call	
		Freightage	Included	Included		Included	Included	
	Payoffs	Contractor	71.964	68.000	−5.5%	90.727	90.273	−0.5%
		Supplier	73.994	79.531	+7.5%	63.600	67.500	+6.1%
		Joint	145.958	147.531	+1.1%	154.327	157.773	+2.2%
Rebar	Agreed options	Unit price	$293	$277		$272	$253	
		Payment term	60-day check	30-day check		60-day check	30-day check	
		Payment period	Monthly	Monthly		Monthly	Monthly	
		Delivery	Multiple	Multiple		Single	Multiple	
		Freightage	Included	Included		Included	Excluded	
	Payoffs	Contractor	85.268	92.545	+8.5%	86.250	86.394	+0.2%
		Supplier	68.603	72.500	+5.7%	64.357	79.000	+22.8%
		Joint	153.871	165.045	+7.3%	150.607	165.394	+9.8%
Rebar labor	Agreed options	Unit price	$103	$100		$108	$108	
		Payment term	Cash	30-day check		Cash	30-day check	
		Payment period	Monthly	Monthly		Monthly	On delivery	
		Delivery	Multiple	On-call		Multiple	On-call	
	Payoffs	Contractor	72.000	87.000	20.8%	73.000	85.500	17.1%
		Supplier	74.733	62.000	−17.0%	64.000	54.000	−15.6%
		Joint	146.733	149.000	1.5%	137.000	139.500	1.8%

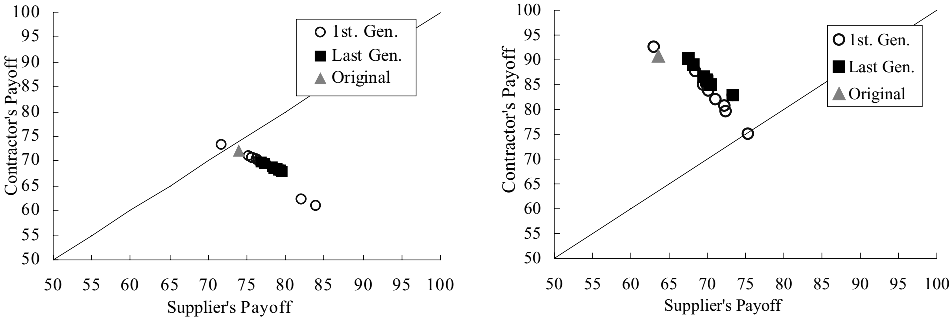
(1980), that is, population size = 50, crossover rate = 0.7, and mutation rate = 0.02. The threshold for the fitness improvement factor was set to be 5%.

Table 2 compares the negotiation outcomes of human-based negotiation (i.e., actual contract agreements) and *C-Negotiator*'s negotiation for three suppliers (i.e., premixed concrete, rebar, and rebar labor) of 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 in Columns Improvement the percentage increase in payoffs for *C-Negotiator*'s negotiation compared with human-based negotiation.

C-Negotiator's negotiation always reached an agreement with higher joint payoff (from 1.1% more to 9.8% more) than human-based negotiation. This difference occurred because the human negotiators tried to reach a mutually acceptable agreement according to experience, whereas the agents tried to maximize the joint payoff through extensive search. Thus, agents are more motivated in finding the best agreement.

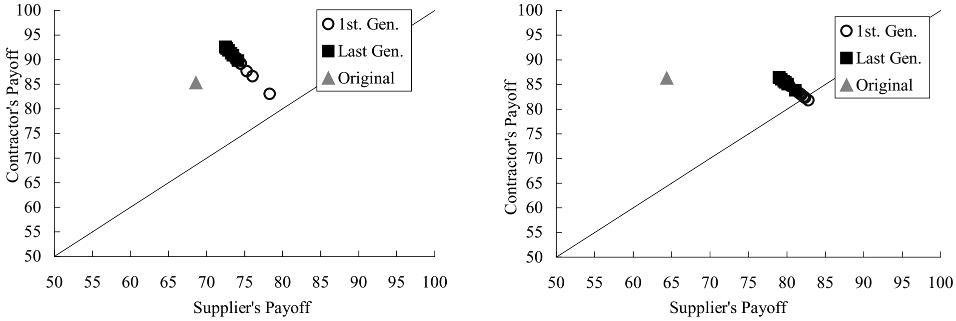
The improvement in joint payoff was smaller than expected. This phenomenon occurred because the number of negotiable issues and options were limited, and human negotiators could reach good agreement depending on years of experience. Nevertheless, the experiments also demonstrated that *C-Negotiator* 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 the rebar supplier for project B (Table 2).

C-Negotiator's negotiation does not always reach an agreement with higher contractor payoff or supplier payoff than human-based negotiation. Although *C-Negotiator*'s negotiation attempts to find the agreement with the highest joint payoff, it may also indirectly



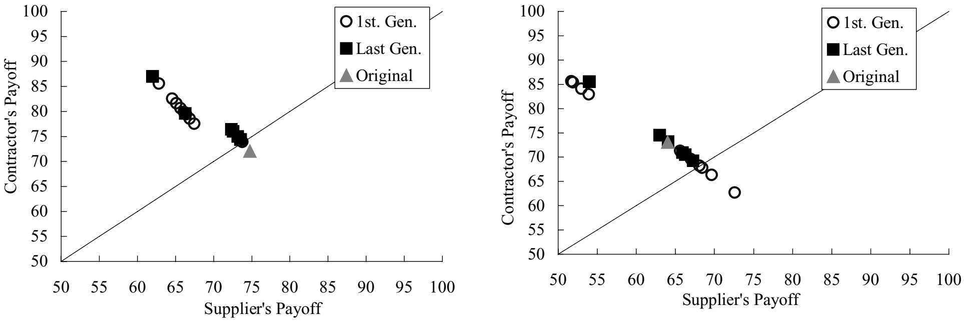
Pre-mixed concrete of Project A

Pre-mixed concrete of Project B



Rebar of Project A

Rebar of Project B



Rebar labor of Project A

Rebar labor of Project B

Fig. 6. Payoff of negotiation agreements for premixed concrete, rebar, and rebar labor of projects A and B.

redistribute the payoff between contractor and supplier. Therefore, one may not accept the agent-suggested best agreement if his/her payoff is lower than the payoff of human-based negotiation. The remedy to this problem presented here was to choose the agent-suggested 10 best offers, and present only those offers with individual payoffs equal to or higher than those of human-based negotiation. 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.

Figure 6 shows the payoff points of the original agreement (made by human-based negotiation), and the best 10 agreements of the first and the last generations of the GA search for each of the procurement items of the two projects. The figure compares the payoff distribution of original agreement and agent-suggested agreements, and the improvement direction of the GA through generations of evolution.

For the rebar of project A, and the premix concrete, rebar, and rebar labor of project B, the original payoff points are located above the 45° line, meaning that the actual agreement favored the contractor. In other words, these procurement items were of an unbalanced market (buyer's market), and the contractor had more negotiation power. For premix concrete and rebar labor of project A, the original payoff points are located below, but close to the 45° line, meaning that the contractor and the suppliers have approximately equal negotiation power in negotiating for these items. 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.

Although the best 10 agreements of the last GA generation have similar joint payoffs, they sometimes offered a diversified combination of contractor payoff and supplier payoff. Dispersed distribution of agreement points provides negotiators with flexible choices and allows negotiators to reflect a biased market condition.

Knowing the payoffs of their original agreement, human negotiators often only accepted a suggested agreement that has a payoff approximately equal to or greater than the original even though the suggested agreement offers a higher joint payoff. In this experiment, premixed concrete of project A is the only procurement item where negotiators cannot find an acceptable agreement from the best 10 agreements of the last GA generation. Negotiators need to adjust some terms from the chosen suggested solution to reach an agreement.

9 EXPERIMENTS OF SIMULATED SCENARIOS

In addition to comparing the payoffs of agreements found by *C-Negotiator* and human negotiators, this study also set up five simulated scenarios to investigate the impact of various negotiation settings on the evolution performance of *C-Negotiator* in converging solutions and knowing the best one to be found. Table 3 shows the input negotiation settings for the five scenarios, which were designed in the following way.

Scenario I:	Significant difference both in the weights of negotiable issues, and in the payoffs of options.
Scenario II:	Significant difference in the weights of negotiable issues, but minor difference in the payoffs of options.
Scenario III:	Minor difference in the weights of negotiable issues, but significant difference in the payoffs of options.
Scenario IV:	Minor difference both in the weights of negotiable issues and in the payoffs of options.
Scenario V:	Mixture of significant and minor differences in the weights of negotiable issues and in the payoffs of options.

Scenarios I and III represent negotiators with distinct preference difference over available options whereas II and IV represent negotiators with vague preference difference. Scenarios I and II represent a negotiation where key issues exist among negotiable issues, whereas III and IV represent a negotiation where negotiable issues are about equally important. Scenario V is a mixture of both.

Figure 7 shows the evolution performance of *C-Negotiator*. Each figure has two plotted lines, showing the best and average joint payoff of each generation during the evolution.

C-Negotiator can find the best negotiation agreement within 50 generations in most scenarios. The best joint payoff of each generation becomes stable at about the 20th up to 50th generation, and is equal to or close to the final best payoff, meaning the improvement after the 50th generation is limited.

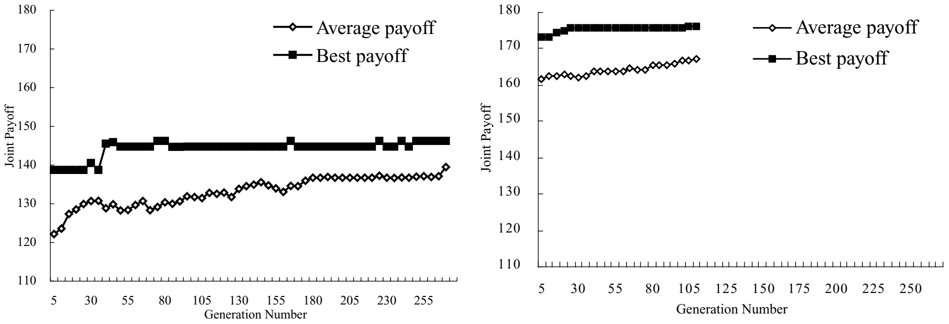
The limited improvement after the 20th generation can be attributed to the fact that GA is a parallel, multidimensional search instead of linear, single-dimensional search. Therefore, GA can achieve near-best solution within a few generations regardless of the assignment of issue weights or option payoffs.

Comparison between Scenarios I and II, or between III and IV shows that the payoff assignment of options affect the magnitude of the best joint payoff, and the weight assignment of issues does not. The average joint payoff of each generation always increases as the process evolves generation by generation. Nevertheless, the improvement rate of average joint payoff depends on the negotiation settings. Comparisons between scenarios I and III (a group with significant difference in the payoffs of options), and between II and IV (a group with minor difference in the payoffs of options) show that the improvement in average joint payoff is greater when there is a significant difference in the payoffs of options. Whether the difference in the weights of issues is significant has only limited impact on the improvement magnitude of average joint payoff. This is because the difference in the payoffs of options results in diversified populations, and thus lowers the average joint payoff of the initial generations and makes more room for subsequent improvement. In addition, *C-Negotiator* removes underperformed individuals fast, making the improvement rate seem higher. The weight assignment of issues affects the magnitude of the average joint payoffs, but does not create diversification of population because each individual shares the same set of weights. Thus, the impact of the assignment of weights on the improvement magnitude of average joint payoff is limited.

Scenario V shows a situation more like a negotiation in real life where a mixture of significant and minor differences exists among weights for issues and payoffs for options. The improvement rate is also not small because the difference in the payoffs for options is not minor.

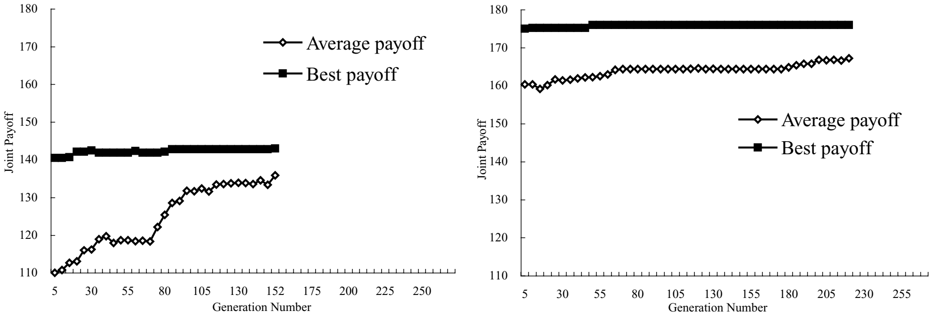
Table 3
Negotiation settings for five scenarios

	Scenario I				*Scenario II*				*Scenario III*				*Scenario IV*				*Scenario V*			
	Contractor		*Supplier*		*Contractor*		*Supplier*		*Contractor*		*Supplier*		*Contractor*		*Supplier*		*Contractor*		*Supplier*	
Issue and option	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*	*Value*	*Payoff*
Unit price	Weight = 0.45		Weight = 0.35		Weight = 0.45		Weight = 0.35				Weight = 0.3		Weight = 0.25		Weight = 0.3		Weight = 0.25		Weight = 0.3	
Acceptable max.	100	40	N/A	N/A	100	80	N/A	N/A			N/A	N/A	100	80	N/A	N/A	100	80	N/A	N/A
Desired max.	90	70	N/A	N/A	90	90	N/A	N/A			N/A	N/A	90	90	N/A	N/A	90	90	N/A	N/A
Desired min.	80	90	110	100	80	95	110	100			110	100	80	95	110	100	80	95	110	100
Acceptable min.	70	100	90	60	70	100	90	80			90	60	70	100	90	80	70	100	90	80
Payment period	Weight = 0.15		Weight = 0.15		Weight = 0.15		Weight = 0.15				Weight = 0.15		Weight = 0.15		Weight = 0.15		Weight = 0.15		Weight = 0.15	
At delivery	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A
At completion of milestone	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A
At completion	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A
Monthly	Y	100	Y	60	Y	100	Y	80			Y	60	Y	100	Y	80	Y	100	Y	80
Bi-weekly	Y	60	Y	100	Y	80	Y	100			Y	100	Y	80	Y	100	Y	80	Y	100
Payment term	Weight = 0.25		Weight = 0.25		Weight = 0.25		Weight = 0.25				Weight = 0.2		Weight = 0.25		Weight = 0.2		Weight = 0.25		Weight = 0.2	
60-day check	Y	100	Y	40	Y	100	Y	60			Y	40	Y	100	Y	60	Y	100	Y	60
45-day check	Y	75	Y	70	Y	85	Y	80			Y	70	Y	85	Y	80	Y	85	Y	80
30-day check	Y	50	Y	100	Y	70	Y	100			Y	100	Y	70	Y	100	Y	70	Y	100
Cash	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A
Delivery	Weight = 0.1		Weight = 0.05		Weight = 0.1		Weight = 0.05				Weight = 0.15		Weight = 0.15		Weight = 0.15		Weight = 0.15		Weight = 0.15	
One-time	Y	40	Y	100	Y	70	Y	100			Y	100	Y	70	Y	100	Y	70	Y	100
Multiple-time	Y	70	Y	70	Y	85	Y	90			Y	70	Y	85	Y	90	Y	85	Y	90
On-call	Y	100	Y	40	Y	100	Y	80			Y	40	Y	100	Y	80	Y	100	Y	80
Advance payment	Weight = 0.05		Weight = 0.2		Weight = 0.05		Weight = 0.2				Weight = 0.2		Weight = 0.2		Weight = 0.2		Weight = 0.2		Weight = 0.2	
10%	Y	100	Y	20	Y	100	Y	80			Y	20	Y	100	Y	80	Y	100	Y	80
15%	Y	70	Y	60	Y	85	Y	90			Y	60	Y	85	Y	90	Y	85	Y	90
20%	Y	40	Y	100	Y	70	Y	100			Y	100	Y	70	Y	100	Y	70	Y	100
25%	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A
30%	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A	N	N/A	N/A	N/A



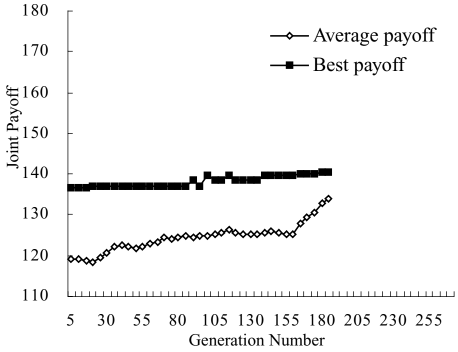
Scenario I

Scenario II



Scenario III

Scenario IV



Scenario V

Fig. 7. Comparison of evolution result of different scenarios.

10 CONCLUSIONS

This work has developed a computer system, named *C-Negotiator*, to help the negotiation between contractor and supplier by finding a better agreement using the genetic algorithm. The goodness of an agreement is measured according to its joint payoff, the sum of contractor payoff and supplier payoff regarding the agreement. The assignment of weight for each negotiable and payoff function for each option allows contractor and supplier to express their preference over the issues and options.

Experiments conducted in this study have demonstrated that *C-Negotiator* found agreements with from 1.1% to 9.8% higher joint payoff than actual agreements made by traditional human negotiation. The result indicated that human negotiators could reach near-optimum agreement according to years of negotiation experience without extensive search of the solution space. Although the increased payoff was not as great as expected, we believe that the improvement will become large for more complex negotiation problems (with more issues and options, or complicated preferences) or inexperienced negotiators. With *C-Negotiator*'s automatic negotiation, human negotiators may also be interested in exploring more issues and options that have been ignored in traditional human negotiation.

The application of the system is limited by its symmetric (unidirectional) optimization, whereas the procurement negotiation in construction is biased toward the contractor, and also by the users' comfort with their preferences and negotiations being monitored by the system. This problem can be tackled by presenting the best 10 agreements instead of only the best 1 to negotiators because the 10 best agreements offer similar joint payoffs, but quite diversified combination of contractor and supplier payoffs.

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. Because the construction procurement market is usually 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 to 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 need to adjust some terms to reflect their concerns.

Another anticipated application limitation did not occur in the experiments. Users who were familiar with *C-Negotiator* knew that the system-made suggestions according to 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-Negotiator* or other similar systems.

ACKNOWLEDGMENT

The authors would like to thank the National Science Council, Taiwan, for financially supporting this work under contract no. NSC-91-2211-E009-059.

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