# COMPUTER-SUPPORTED COLLABORATIVE NEGOTIATION METHODOLOGY

By Feniosky Peña-Mora[1] and Chun-Yi Wang[2]

**ABSTRACT:** The development of large-scale civil engineering projects requires the collaboration of experts from different specialties. However, conflicts and disputes occur regularly during the entire life cycle of large-scale projects due to the complex structure of organization and the different types of expertise involved. If these disputes or conflicts cannot be resolved or addressed quickly and effectively, the collaborative mode of the participants can be affected, creating a hostile environment in which progress of the project will slow to a halt. Therefore, better methodologies are needed to improve the collaborative process and to create more effective, efficient, and sustainable solutions to conflicts. This paper presents a methodology for facilitating the negotiation of conflicts during the development of large-scale civil engineering projects. Two fundamental theories are used in this methodology: (1) game theory, which is the study of players' actions based on the premise that the decision of any player can affect the payoff of all players; and (2) negotiation theory, which is the study of the interactions between parties, designed to reconcile their differences and produce a settlement. The strong support given by these two theories to negotiators is highlighted in the following observations. First, people need to negotiate because of their conflicting interests. From the negotiator's point of view, expressing the interests of all participants is very important in conflict resolution and can be accomplished by following the principles outlined in negotiation theory. Once the interests have been expressed correctly, the influence of positions or of conflicting interests on the overall negotiation outcome is evaluated using game theory. Based on these two fundamental theories, this paper presents a collaborative negotiation methodology and a computer agent named CONVINCER, which incorporates that methodology to facilitate or mediate the negotiation of conflicts in large-scale civil engineering projects. Hypothetical case studies and resolution processes demonstrate the effectiveness of the CONVINCER agent in conflict resolution. Results of applying the methodology to different scenarios also show that the CONVINCER agent provides efficient, effective, and sustainable solutions, thus improving the conflict resolution paradigm in the A/E/C industry.

## MOTIVATION

The development of large-scale civil engineering projects requires the collaboration of individuals from different fields. The roles and positions each organization adopts are regulated by the contract they agreed upon prior to beginning the project. For example, architects from the design-bid-build contract organization play the role of the designer of the project and supervisor of the contractors. Their main goal is to protect their own and the owner's interests. In the design-build contract situation, the architects play the role of designers of the project and co-workers of the contractors. They are only interested in the benefits to the design-build team. Consequently, different contract types lead to varied positions and interests. These various attitudes are not confined to a specific group of participants but are universally prevalent. Participants therefore spend a great amount of resources, including time, in negotiation. Any faltering in the negotiation process leads to costly delays. On the other hand, if some information can be analyzed and directions can be provided to facilitate or mediate the negotiation process, conflicts can be resolved more efficiently and effectively.

It is necessary to develop a methodology for facilitating or mediating the negotiation process and reducing the tremendous amount of time and human resources invested in resolving conflicts. Many studies based on the game and negotiation theories exist. In the negotiation theory field, these methodologies break down the different types of conflicts to the detailed level of the components that have common properties in order to represent the qualitative aspects of the negotiation process (Susskind and Cruikshank 1987). In the game theory field, these methodologies build a set of functions to simulate the actions and attitudes of the participants in order to represent the quantitative aspects of the negotiation process. These previous studies serve as the foundation of a conflict resolution methodology in large-scale civil engineering systems (Peña-Mora et al. 1998). This study will add to the game and negotiation theories the specific characteristics that reflect the series of actions participants take during negotiations in the A/E/C industry. To outline these characteristics, introductions and explanations are given here in terms of the A/E/C industry.

*Cooperative-competitive environment.* Though numerous organizations are involved in a large-scale civil engineering project, participants have the common goal of successful project completion because it ensures a profit for all. If the project fails, some or all of them will bear a great loss because not only will they not profit from the project but they also will be liable for its failure. Consequently, they will cooperate with each other in order to finish the project on schedule and within budget. At the same time, they will also try to maximize their own profits without exceeding the profit boundary and thereby breaking the cooperative nature of the team. If some participants attempt to maximize their profits beyond the limit, it will be at the expense of others. This will severely strain the collaborative nature of the enterprise, a crucial element in the success of the project and profit sharing. Therefore, the collaborators operate within limits even while attempting to maximize profits. As a result, self-interest tempered by group interest guides the day-to-day operations in the A/E/C industry.

*Domain-dependent knowledge.* Large-scale civil engineering projects are complex and need different types of expertise. For example, architects have the educational background in comfort and aesthetics, while engineers have knowledge of the structural soundness and the feasibility of an engineering prod-

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uct. Based on the collaborative nature of the enterprise, they have to work together to finish a project. Problems arise when they have to communicate with each other about the project because the background and training they have can be very different. They view the project from their individual perspective and training. Thus the architect focuses on aesthetics; the engineer concentrates on feasibility. Consequently, none of the collaborators has a global view, which hampers finding a common meeting ground for the participants with domain-dependent knowledge.

*Strategy-influenced process.* Because of the collaborative-competitive nature of the game, participants in the A/E/C industry will try to maximize their gain from the project without breaking the collaboration. They take a course of action that will influence the outcome of the negotiations. This course of action is called the strategy. Because collaboration-competition exists every day throughout the project life cycle, strategies are employed frequently and have a strong influence on the outcomes of negotiations. The most common and easiest strategy used by participants is the use of domain-dependent knowledge. Participants can influence the outcomes of the issues related to their specialty by exaggerating to benefit without being caught because others are not really familiar with the issues. This domain-dependent barrier prevents participants from fully realizing the situation any other particular participant faces. Bringing in an expert on that area to inform teams that are not familiar with the issues can prevent the use of this strategy. However, the complexity of the problem increases as more people are involved in the negotiation and their preferences have to be considered. Therefore, given the collaborative-competitive nature and domain dependent barriers in the A/E/C industry, resorting to strategy is a common occurrence.

If it is possible to use a set of functions, say, preference or payoff functions, to represent the actions of participants in the A/E/C industry by incorporating the three characteristics described in the preceding paragraphs, then the negotiation process can be simulated and a set of settlements can be forecasted by analyzing the interactions of the preference or payoff functions of each negotiation participant. The methodology proposed in this paper is aimed at using such function sets to simulate the behavior of the participants, taking into account the special characteristics of the A/E/C industry as well as the basic negotiation behavior of the participants. After this simulation is performed, game theory is used as a tool to analyze the information given by the payoff functions and characteristics of the A/E/C industry and to propose a settlement. Detailed explanation and verification of this methodology is divided into the following sections. The next section explains the importance of the game and negotiation theories to the methodology and how to apply these two fundamental theories within the methodology. The section entitled Survey of Current Research on Computer-Supported Conflict Resolution discusses the classification and the positions of current studies in this area. The section entitled Methodology for Collaborative Conflict Resolution proposes the collaborative negotiation methodology. Implementation of Computer-Supported Collaborative Conflict Resolution provides a mechanism to encode

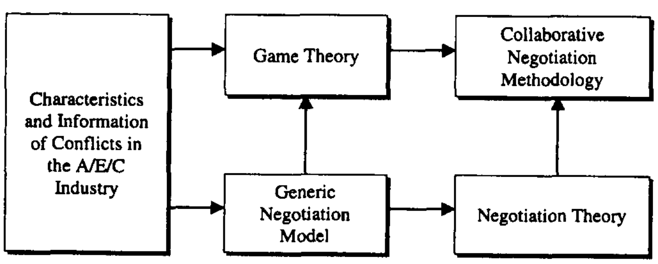



**FIG. 1. Current State of Research**

the methodology into computers and thus generate a computer-supported collaborative negotiation methodology. This section also verifies the methodology through a negotiation scenario. The final section assesses the contributions of the methodology to conflict resolution in the A/E/C industry and explains how it can serve as a theoretical foundation for negotiation.

## REQUIREMENT FOR GAME AND NEGOTIATION THEORIES FOR COMPUTER-SUPPORTED CONFLICT RESOLUTION METHODOLOGY

The collaborative-competitive nature, domain-dependent barrier, and strategy-influenced outcome of projects can be used as characteristics to model conflict structure in the A/E/C industry. Specific project information, such as project and participants' attributes, can also be used to define some of the conflict structure and applied as a foundation for a collaborative negotiation methodology. Fig. 1 shows the research in terms of the components of the collaborative negotiation methodology. In this research, different types of sample negotiations were studied in order to understand both characteristics and information embodied in common A/E/C projects. The information was then categorized into the different attributes belonging to a project and its participants, creating a generic negotiation model. Game theory, which is the study of human decisions based on the premise that each player's decision can affect the outcome for all participants, is customized and used in the methodology by incorporating characteristics of conflicts in the A/E/C industry. The decision analysis is performed using game theory to provide the quantitative aspects in the methodology; the negotiation process is supported by negotiation theory. The latter theory is the study of how to reconcile differences and reach consensus, to ensure the quality of a negotiation process. After these two theories are incorporated in the collaborative negotiation methodology, both qualitative and quantitative analyses of a negotiation can be performed. The following two sections analyze the two theories and discuss their applications to the collaborative negotiation methodology.

### Negotiation Theory

Negotiation theory is the study of the exchanges between parties designed to reconcile their differences and produce a settlement. As mentioned previously, negotiation theory aims at assisting in the negotiation process so that the qualitative characteristics of a negotiation are taken into consideration. The collaborative negotiation methodology applies negotiation theory to ensure maintenance of that quality. However, not all negotiation processes follow the same pattern. There are different forms of negotiation, such as fighting, facilitation, mediation, arbitration, and adjudication, which have different negotiation procedures. Furthermore, different participant organizations are considered and are represented by different parts of negotiation theory. Therefore, it is necessary to identify the correct form of negotiation to which the methodology can be applied.

The dispute resolution continuum (Susskind 1995, unpublished lecture notes) is examined to identify a suitable application area for the methodology (see Fig. 2). Several dispute resolution forms are proposed to address a negotiation within the dispute resolution continuum. This continuum indicates the correlation between different levels of the third party involvement and participants' power to control the settlement. Decreasing control by the participants and increasing involvement of the third party are shown from left to right in the continuum. The settlement is broken down into three distinct categories: unassisted, assisted, and adjudicated.

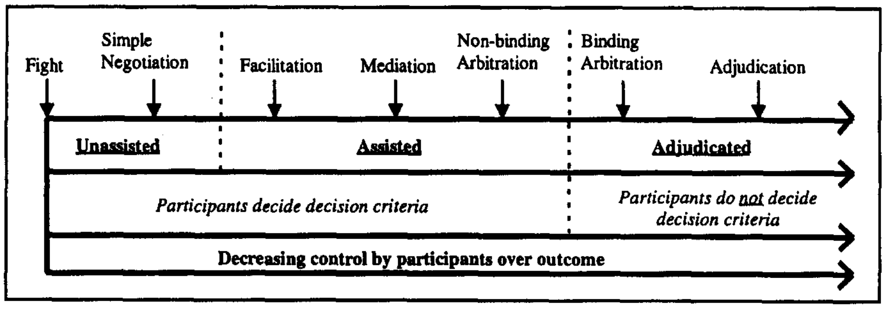



**FIG. 2. Dispute Resolution Continuum (Adapted from Susskind 1995, Unpublished Lecture Notes)**

Analyzing the dispute resolution continuum with respect to the collaborative negotiation methodology, the collaborative negotiation methodology is aimed at dealing with conflict situations in which the scope and complexity of the issues require that a third party mediate the process of achieving a solution. In the unassisted negotiation category of the continuum, participants try to understand the implications of the issue and resolve it by simple means (an aggressive encounter or persuasive manipulation). On the other extreme of adjudication, a third party hands down a verdict, and the participants lose the notion of consensus building and the natural ability to choose their own destiny. Therefore, the area of assisted negotiation is where the collaborative negotiation methodology is most appropriate. The methodology guides the process of negotiations, providing the facilitation area, and allows participants to focus on the collaborative process so that it does not degenerate into competition. It plays a mediation role to recommend a course of action and plays the role of non-binding arbitrator as it suggests the best outcome of possible alternatives.

In addition to the resolution categories, different attitudes and perspectives of participants, due to their different roles in the A/E/C industry, should be categorized to fit within the negotiation process. A generic negotiation model for the domain of large-scale engineering and construction has been generated (see Fig. 3). This model is a representation of the typical parties, structures, relationships, and attributes that compose a negotiation. It can assist researchers in understanding how the developed methodology fits within the subject environment when a methodology is encoded into a model and implemented with the other components.

The model consists of five basic elements: (1) the project; (2) the participants; (3) the negotiation process; (4) the collaborative negotiation methodology; and (5) the outcome. Each of these elements plays a role in a generic collaboration and negotiation problem within the domain of large-scale engineering and construction. The project data provide the background and environment of the conflict. The participants reveal different attitudes and interests in conflict situations due to their different parent organizations and their relationships to the issues. The negotiation process is the interactive exchange and elicitation of participants' preferences and iterative concessions to participants' positions. The negotiation methodology provides suggestions to participants on how they can collaborate to resolve the conflict. The outcome shows the final settlement determined by the project environment and the interactive process between participants following the methodology.

Additionally, the model describes many of the variables that the negotiation methodology needs to address in assisting the collaborators. After the complex negotiation form is broken down into the generic categories, the preferences and attitudes of different participants are determined (see the right side of Fig. 3). Note that the attitudes of the participants in Fig. 3 are not exhaustive and cross-reference can exist. Participants in different projects have different attitudes; the attitudes in Fig. 3 are examples. Another variable, payoff function forms, is introduced, based on the preferences identified by the generic negotiation model. These payoff functions are discussed in the section entitled Methodology for Collaborative Conflict Resolution, which describes the implementation of the methodology in detail.

## Game Theory

A game is a formal representation of a situation in which a number of individuals interact in a setting of strategic interdependence. Each individual's welfare depends not only on his or her own actions but also on the actions of the other individuals. Moreover, which actions are best for each participant may depend on what he or she expects the other players to do. In this definition, three basic elements are necessary to form a game: a number of individuals, individuals' actions, and individuals' welfare as a function of the actions that are taken. An individual, often referred to as a "player" in game theory, is a single participant in a game or is the corporate aggregate of participants who have the same preference over the outcomes. For example, the owner is one player in a game whether he owns a company or an individual enterprise, because he stands for a group of people who have the same interest. The actions of the individuals, often referred to as "moves" in game theory, are the movements or decisions the players make, subject to certain rules of the game, such as who moves, when, and how. The individual's welfare, often referred to as "payoff" in game theory, is the set of players' preferences for every possible result of their actions. If every result can be mapped onto a preference, then preference functions can be applied to show the relation between preference and outcome.

Negotiations have all three basic elements of games. For example, if the participants are treated as players in a game, and all possible settlements of the issues to be negotiated are treated as moves, then each player's "score" depends on how he or she interacts with others to gain more in the outcome. This describes a negotiation. Actually, all types of negotiations can be conceptualized as different kinds of games, using this same analogy (Brams 1990). The three major characteristics of the A/E/C domain that are the focus of this study—the collaborative-competitive nature, domain-dependent barrier, and strategy-influenced outcome of the project—are defined here with interpretations and strategic alignment in game theory.

*Cooperation-competition.* During the negotiation process in the A/E/C industry, every player targets his or her highest profit. Due to the fact that payoff is not at maximum for all players, participants have to use a set of strategies to realize maximum profit. Thus, a competitive environment is formed. However, the game is a non-zero sum because all players can get positive payoffs from the project if they cooperate with each other, so everyone can receive a reasonable profit instead

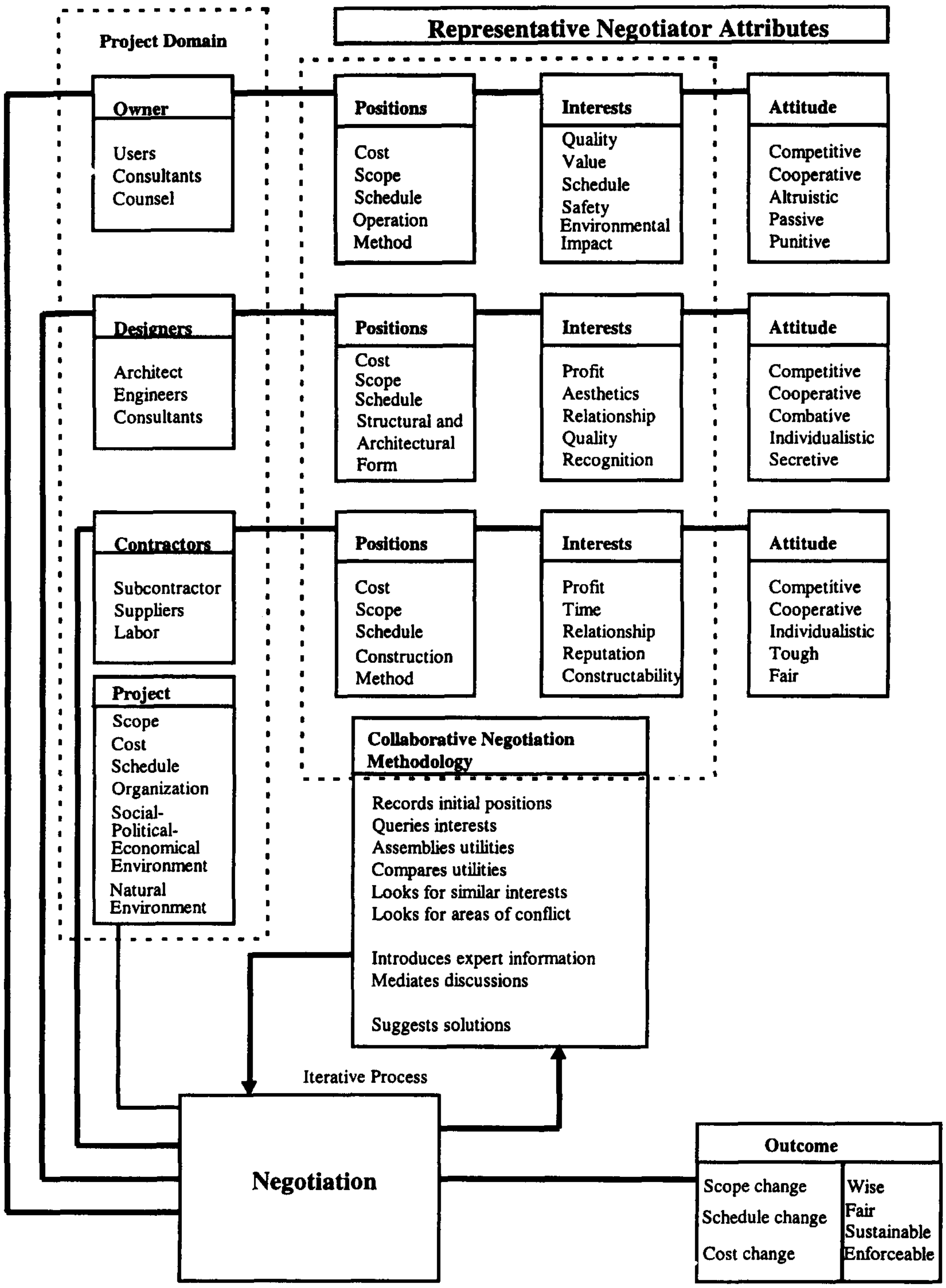



**FIG. 3. Generic Negotiation Model for A/E/C Domain**

of maximum payoff being held by a few players. Therefore, players in a negotiation process may have both cooperative and competitive characteristics (Brandenburger and Nalebuff 1996).

*Domain dependence.* Game theory assumes that every player has some common knowledge (Kuhn and Tucker 1953). The player's rational decision is based on the common information shared among participants. After the common information is shared, players can optimize their moves by trying to predict other players' moves. However, there are many specialists in large civil engineering projects whose knowledge is unfamiliar terrain for others. For example, it may be hard for a contractor to understand all the decisions or actions of the geotechnical engineer because of their different fields of expertise. Therefore, each player has his own specialty but is not completely familiar with other specialties. In the A/E/C industry, architects are experts in the aesthetics and comfort of the working or living environment, engineers are specialists in the safety and reliability of the project, and the contractors specialize in practical construction and on-site experience. These three main players have important individual riches but may not be able to switch positions. When they interact, the domain-dependent characteristics appear, and the game should be conceptualized as incomplete information game (Kuon 1994).

*Influence of strategy.* In the games of the real world, unlike those of the theoretical world, many different strategies are used for negotiation. For example, one player can exaggerate his or her situation in order to make other players compromise and get an expected outcome. If there is not enough information to identify the exaggeration, the strategy may not be perceived by other participants. Chatterjee and Samuelson (1983) have shown in a simple example that players must exaggerate their positions to influence a possible settlement to their advantage. Thus, incomplete information and different strategies can influence the payoffs (Kennan and Wilson 1992; Bacharach and Lawler 1981).

The game in the A/E/C project can be analyzed as a cooperative and non-cooperative game of incomplete information, influenced by strategy. Next, this paper will incorporate these game interpretations in the methodology.

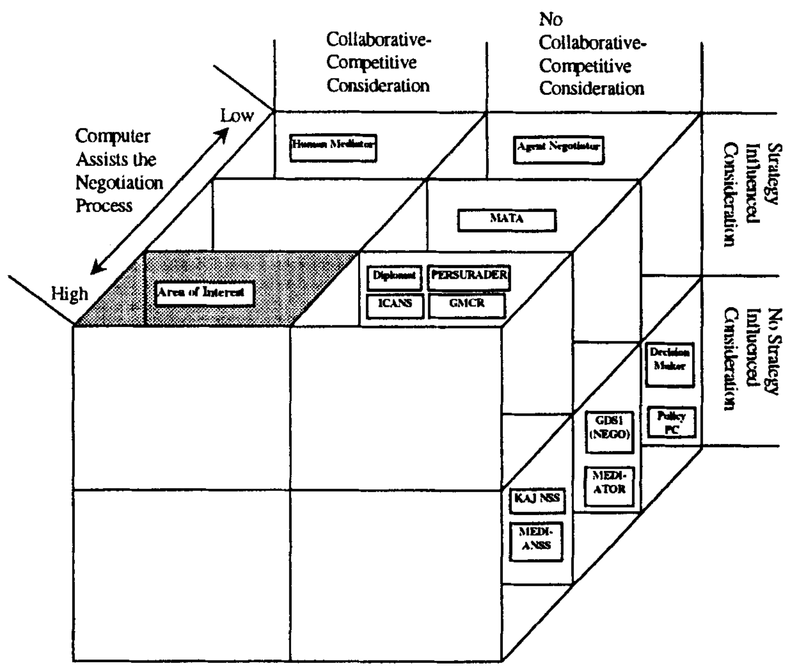
## SURVEY OF CURRENT RESEARCH ON COMPUTER-SUPPORTED CONFLICT RESOLUTION

To address these three areas—cooperation-competition, domain dependence, and the influence of strategy—the focus of the research was on computer-mediated collaborative negotiation in the A/E/C industry, using a combination of game and negotiation theories. However, there have been extensive research on agent (machine, software) negotiation and computer-supported human negotiations that also applies those two theories. This research was surveyed to determine how the present study is distinctive and yet builds on previous studies.

The agent negotiation category is aimed at resolving conflicts between autonomous agents. Researchers in this area have developed an entire framework for agent negotiation on the basis of game theory (Ephrati and Rosenschein 1993; Rosenschein and Zlokin 1994). They have identified three different domains: task-oriented domain (TOD), state-oriented domain (SOD), and worth-oriented domain (WOD). These domains are used to discuss how agents can negotiate to divide and perform their tasks with maximum efficiency. In addition, research has been performed on how agents can cooperate with each other to achieve mutual gains through short-term coalitions (Sandholm and Lesser 1995a,b). When and how agents should form a coalition, how contracting should be done, and how a contract should be executed are also very important issues that need to be explored in terms of their applicability to large-scale infrastructure projects. Finally, the issue of a language for agent communication has been addressed in the negotiation language and the DIPLOMAT agent developed by Kraus (Kraus and Lehmann 1995; Kraus 1988).

Fig. 4 shows how different systems in the area of negotiation support system (NSS) (Wheeler 1995) score with respect to the issues that are relevant on large-scale infrastructure projects. The three axes stand for the three issues important to resolving conflicts in large-scale civil engineering and architectural projects, which are plotted in a three-dimensional graph to show the position of current research. The first issue is whether computers can greatly assist in the negotiation process. Computers should provide suggested settlements, negotiation information, preparation, and support for the process that should be followed. The second issue is how a methodology takes into consideration the collaborative-competitive nature of negotiator interactions. The third issue relates to whether a methodology takes into account the strategies used in the A/E/C industry.

Based on a review of that literature, it was determined that some concepts in the rules of agent encounters can be implemented in the computer-supported collaborative negotiation field. First is the concept of utility and cost functions. A utility function in the agent negotiation field is used to measure the satisfaction level of an agent upon partial completion of the goal. It can be used in the computer-supported negotiation to evaluate a human being's satisfaction level. Cost functions can also be incorporated in the computer-supported human negotiation field to help to evaluate the cost of executing different levels of a task to eliminate the uneven settlement of negotiation. The method of evaluating deceptions (i.e., strategies) can also be applied to computer-supported negotiation. Issues




Reference:

Decision Maker: Waterloo Engineering Software, 1989
GDS1: Kersten G., 1988
GMCR: Kilgour M. et. al., 1995
DIPLOMAT: Kraus and Lehmann, 1995
ICANS: Thiessen E. and Loucks D., 1992
KAJ NSS: Anson, R. Jelassi M., 1989
MATA: Cavuchi, 1997
MEDINESS: Carmel, E. and Herniter, B., 1989
MEDIATOR :Jarke, M., Jelassi, M. and Shakun M., 1987
PERSURADER: Sycara K., 1991
Policy PC: Executive Decision Services, Inc., 1988

FIG. 4. Area of Current Research Compared to Other Negotiation Systems

of coalition and negotiation language can become really important in human negotiation. Therefore, the adoption of these concepts by the computer-supported collaborative negotiation is of great value. However, the problem is that human beings are not always rational and have constant strategies. Moreover, their strategies are more complex than the ones identified in previous research efforts. As previous studies have identified, applications of the game theory to human negotiations in many ways fall short: "humans do not always appear to be rational beings, nor do they necessarily have consistent preferences over alternatives" (Rosenschein and Zlokin 1994). However, the work on negotiation theory in the areas of facilitation, mediation, and non-binding arbitration tries to overcome some of those deficiencies. Providing a process by which humans can conduct their interactions as well as generate alternatives under mutual consent brings human negotiators to think of the overall situation rather than only of their individual interests. The research presented in this paper brings that component into the methodology so that some of the power of the game theory is realized in human negotiations.

## METHODOLOGY FOR COLLABORATIVE CONFLICT RESOLUTION

Collaborative conflict negotiation is a systematic method for assisting human negotiation in the A/E/C industry. In addition to the assistance typically provided by the methodology, such as outcome prediction and decision support, the version of the methodology presented here is especially aimed at forecasting the interaction between decisions and outcomes, and incorporating the special characteristics of the A/E/C industry. The game and negotiation theories, and a generic negotiation model characteristic of the A/E/C industry, presented in the previous sections, serve as the foundation of this methodology. To illustrate how these fundamental theories work within the methodology, a five-step process is proposed next.

### Collaborative Conflict Resolution Methodology

The collaborative conflict resolution methodology is composed of the following five steps: (1) build decision/game trees from players' decisions; (2) select payoff function form and weighting for all players; (3) finding maximum payoff combinations; (4) obtain suggested outcome using backward induction; and (5) judge whether the outcome is influenced by insufficient knowledge and strategies. Fig. 5 is a graph of the five steps. Detailed descriptions of the steps are given in the following five subsections.

#### *Build Decision Trees*

There are several issues that have to be decided by the players before negotiation starts. The preferences of some or all of the players are influenced by those decisions. For example, if some obstacle hinders the progress of a project, the owner may have to decide at first whether to change the scope of the project. The contractor's payoff may become higher because he or she prefers many change orders. On the other hand, the designer may not prefer changes in scope. Thus his or her payoff may become lower.

Decision trees (or game trees) are built according to the issues that have to be addressed. Each node of the tree represents a set of answers to the yes or no questions or alternatives. After the tree is built, the next four steps can be used to calculate the maximum total payoff and settlement for each end node. The backward induction method (Selten and Harsanyi 1965) in game theory is then used to find the optimum decision set.

#### *Select Payoff Function Forms and Weighting for All Players According to Game and Generic Negotiation Models*

After the game trees are built, payoff function forms and weighting for each issue can be selected to represent the preferences of each player. The choice of payoff functions is based on the following assumptions (Kuon 1994; Darling and Mumpower 1990):

- A player always makes positive concessions to others, and those concessions are made without regret.
- The marginal payoff of the concession process decreases iteratively because rational players always attempt to maximize their payoff. They are more willing to make the first concessions than the second, more willing to make the second than the third, and so on.

Although past research efforts have also mentioned these two rules, it has not defined the properties of the function shape. Yet, it is possible to assume the properties of the function based on these assumptions about concession behavior. To translate these into the mathematical forms, the following constraints are considered:

- The first derivative of the payoff function is less than zero, which means that the payoff is always reduced when positive concessions are made: $dP/dx < 0$, where $P$ is the payoff value and $x$ is the concession value.
- The second derivative of the payoff function is less than or equal to zero, which means that the marginal payoff in the concession is decreasing: $d^2P/dx^2 \leq 0$, where $P$ is the payoff value and $x$ is the concession value.

The following boundary conditions apply:

- The concession value is between 0 and 100 as a result of normalization: $0 \leq x \leq 100$.
- The payoff value is between 0 and 100: $0 \leq P \leq 100$.
- If a concession with value 0 is made, 100% payoff is obtained: $P(0) = 100$. However, if a 100% concession is made, a 0% payoff is obtained: $P(100) = 0$.

Based on these two constraints and three boundary conditions, two sets of generalized function forms can be obtained simply by solving the polynomial function

$$P_1 = (100 - x)^n/100^{n-1} \quad (1)$$

$$P_2 = 100 - (x^n/100^{n-1}) \quad (2)$$

where $P_1$, $P_2$ = payoff value; $n$ = power of payoff function; and $x$ = concession value of payoff function. Eqs. (1) and (2) satisfy the previous constraints and boundary conditions: $\{P_1 | dP_1/dx < 0,\ d^2P_1/dx^2 \leq 0$ for all $0 \leq x \leq 100$, and $1 \geq n \geq 0\}$ and $\{P_2 | dP_2/dx < 0,\ d^2P_2/dx^2 \leq 0$ for all $0 \leq x \leq 100$, and $n \geq 1\}$.

The graphs of the concession functions are shown in Fig. 6. Fig. 6(b) has been chosen for the function form representing the players' preferences because there is an obvious flat area in the initial part of the graph. The flat area in the graph means there is no feeling of loss in that area. The players can easily make concessions from one end of the flat area to the other. In addition, Fig. 6(b) is more closely related to the real world because people feel total loss (0% payoff) if things turn out against them (concession 100%). Fig. 6(a) does not necessarily represent that condition since the payoff in this graph may not be zero at the 100% concession point. The other benefit of using the function shown in Fig. 6(b) is that it is easier to recognize the payoff function of players. For example, if a player feels that he or she can give up to 10% concession

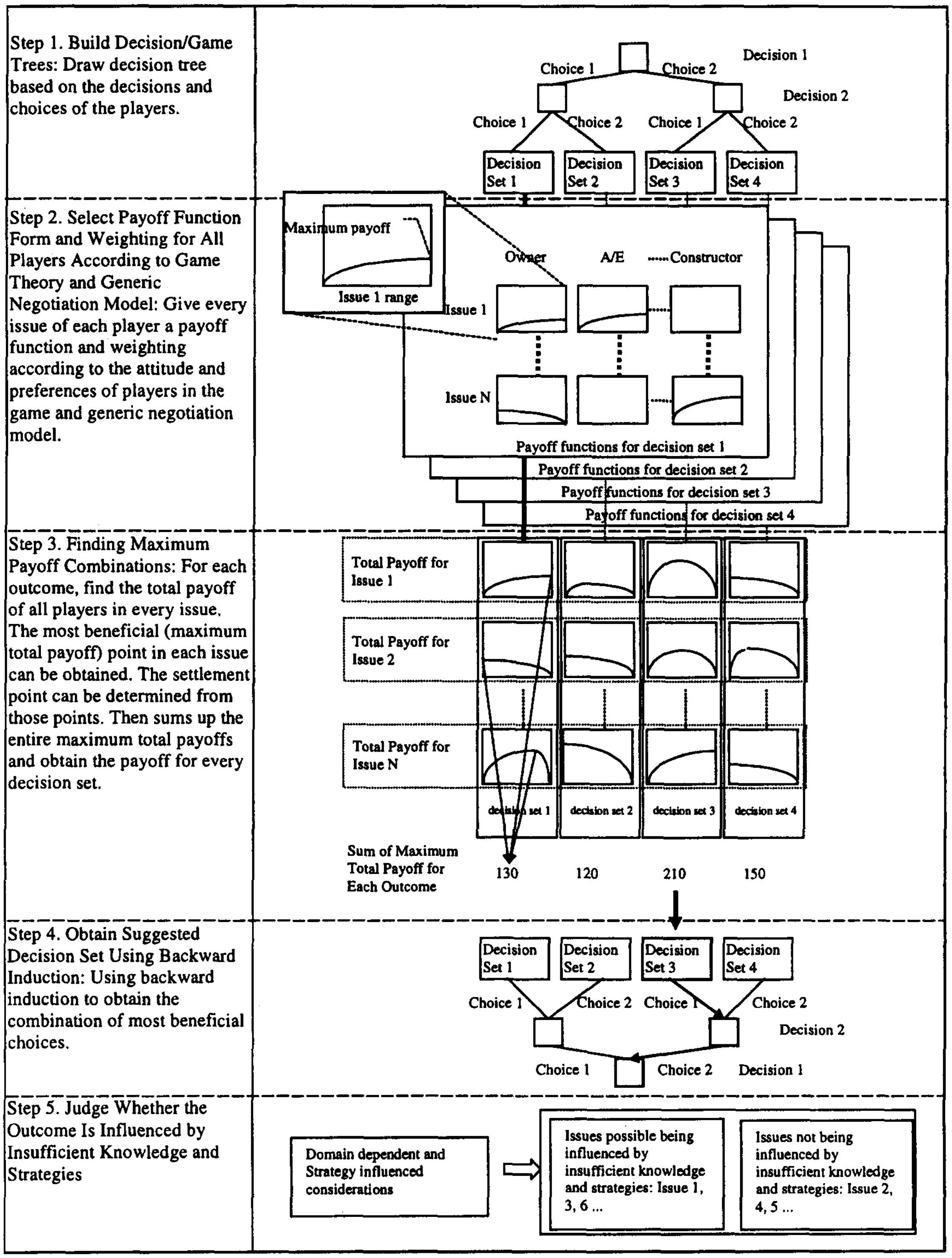



**FIG. 5. Five Steps in Methodology for Collaborative Conflict Resolution**

without detriment to his or her position, the function $N = 5$ in Fig. 6(b), $P = 100 - (x^{2.5}/100^{1.5})$, should be chosen. This decision is considered a good one since the payoff stays at approximately 100, which is the highest level for a concession between 0% and 10%.

However, one may argue that if a player exaggerates his or her position, then a 100% concession may stand for a 60% payoff instead of 0%. In real situations, players certainly do not reveal the truth if they will still have payoffs when they make a 100% concession. Therefore, the exaggeration problem needs to be addressed in the function property of Fig. 6(b). The section entitled Judge Whether Outcome Is Influenced by Insufficient Knowledge and Strategies presents a mechanism to address the problem of possible exaggeration by players.

Once a payoff function has been selected, another function form is needed to represent players' opposite perspectives. Different function forms need to stand for different perspectives, such as the mirror imaging function of $P_2$, since they must represent the same properties but with opposite preference values. For example, when the player represented by function $P_2$ has 100% satisfaction with the $N$ value of an issue, the player with the different perspective should have 0% satisfaction with that value. Thus the relationship between $P_2$ and the function with different perspective $P_3$, is as follows:

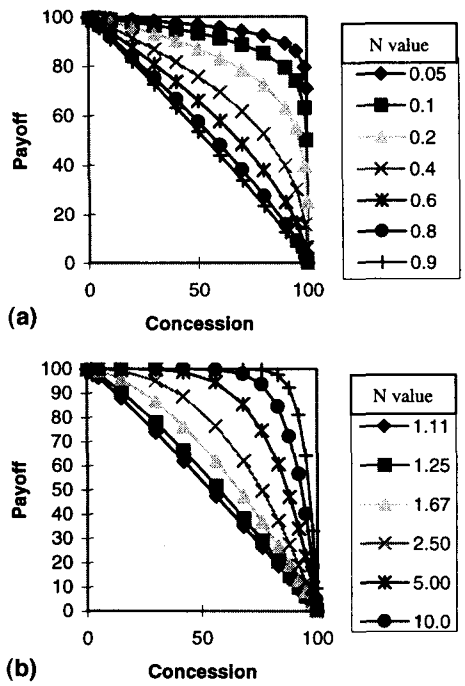



**FIG. 6. (a) Concession Function $(100 - x)^n/100^{n-1}$ of Different $n$ Values; (b) Concession Function $100 - (x^n/100^{n-1})$ of Different $n$ Values**

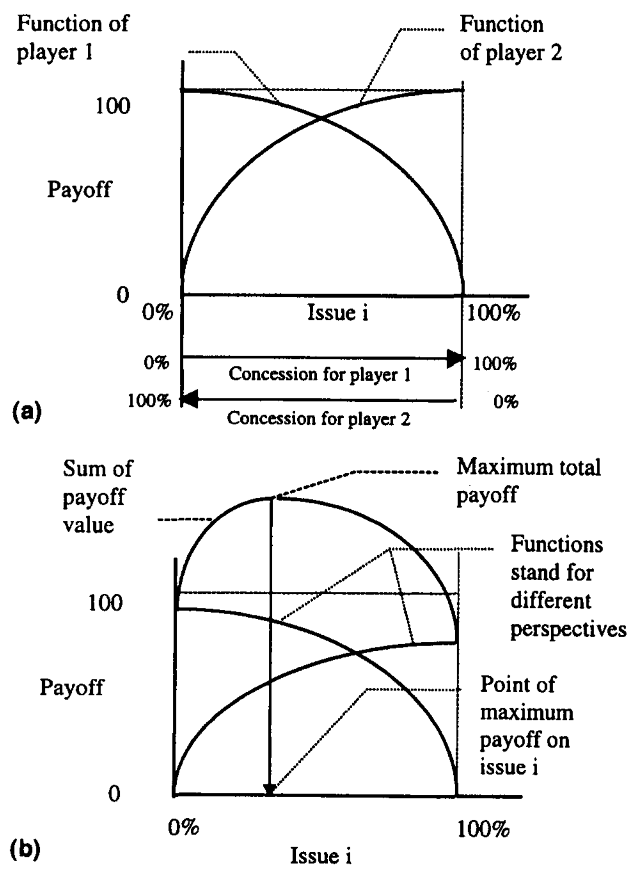



**FIG. 7. (a) Payoff Functions from Different Perspectives; (b) Sum of Payoff Functions**

$$P_3(x) = P_2(100 - x) \tag{3}$$

The concession functions of the different players mirror each other [Fig. 7(a)] if based within a certain range of an issue. The function form of the other perspective is described by the following formula:

$$P_3 = 100 - [(100 - x)^n/100^{n-1}] \tag{4}$$

Eq. (4) satisfies the following constraints: $\{P_3 | dP_3/dx < 0, d^2P_3/dx^2 \le 0$ for all $0 \le 100$, and $n \ge 1\}$.

After these function forms are determined, the game and generic negotiation attributes of players can be applied to define the payoff functions and weighting of players. If there are players with opposite perspectives, then different types of functions should be applied. An example of selecting payoff functions is given in the section entitled Implementation of Computer Supported Collaborative Conflict Resolution.

Several similar methods of obtaining participant preference have been developed by other researchers. Zionts (1981) and Koksalan (1984) developed interactive approaches for the case of an underlying linear utility function. Korhonen (1988) also developed a visual interactive approach without making any assumptions about the utility function and let the decision-maker search for the preferred alternatives with the aid of computer graphics. One of the most recent procedures was developed by Koksalan and Sagala (1995), which allows users to interactively select alternatives with any kind of monotone utility functions. However, these methods compare multiple criteria and satisfaction level, which is different from the needs of the research on collaborative negotiation. In collaborative negotiation, the important issues are the criteria used and the explicit connection to satisfaction.

Although these previous efforts are not readily applicable to the present problem domain, some of the methods used by those researchers, such as the method for eliminating the inferior frontiers of the preference function, can be adapted. A complementary method used in the research for obtaining the participant's preferences is explained in the following sentences. First, preference level data for certain settlement points of an issue are obtained from the user by: (1) asking the user for his or her criteria and satisfaction level associated with several settlement points given by the computer; or (2) letting the user input both. Second, the points that are less preferred are eliminated. Through elimination of these points, the preference of the participant can be maximized by removing all points that fall under the cone of inferior solutions.

### *Find Maximum Payoff Combination*

After payoff functions are selected, each player's preferences for different issues are transformed into different function forms. The next step is to determine the settlement points of all the issues by making these payoff functions represent different players. To determine the settlement points, the collaborative-competitive character of the A/E/C industry is applied. As mentioned previously, participants in the A/E/C industry basically collaborate, and their competition will not hurt the collaborative nature of the project. Therefore, all participants are assumed to pursue the highest payoff for the project group. This means that they will try to find the settlement point that maximizes the sum of their payoffs for the same issue.

The methodology proposed here presents a way to obtain the sum of the participants' payoffs. First, different functions for the different perspectives of all players are drawn together in one coordinate system based on the same issue. [In Fig. 7(b), two players with different perspectives on issue $i$ are drawn.] Then the payoff values for all players can be added, based on all possible settlement points of an issue. The maximum sum of the payoff is determined as the point of agreement because it stands for the highest degree of satisfaction for the project team. The graph representation of the method is shown in Fig. 7(b), and the mathematical representation is presented in (5)

$$\bar{P}_i(x_i) = \sum_{j=1}^{k} W_{ji}P_{ji}(x_i) \tag{5}$$

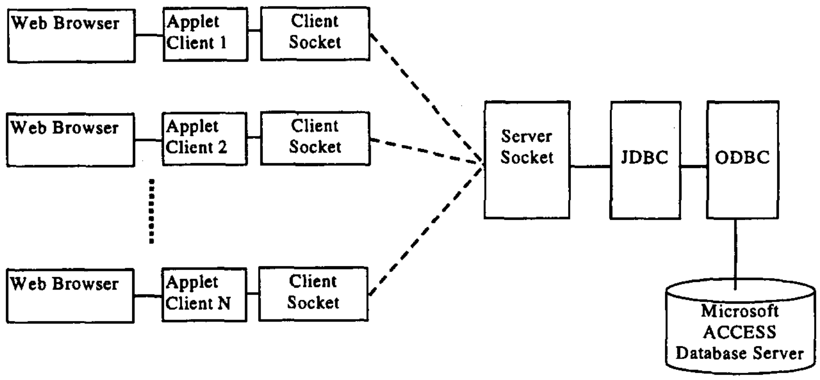



**FIG. 8. Client-Server Implementation of CONVINCER**

where $k$ = total number of participants; $\bar{P}_i$ = sum of payoff functions for issue $i$; $W_{ji}$ = weighting for issue $i$ of participant $j$; $P_{ji}$ = payoff function for issue $i$ of participant $j$; and $x_i$ = variable stands for scale of issue $i$. Therefore, the problem can be defined as follows: Maximize $\bar{P}_i$ subject to $X_1 \leq x_i \leq X_2$, where $X_1$, $X_2$ = lower and upper bounds, respectively, of the issue.

According to the maximum total payoff point, the settlement point of the negotiation of certain issues can be found on the horizontal axis. In mathematical form, it means that $x_i$ can be solved in the optimization problem. The settlement point stands for the final result of the negotiation process on a certain issue. If several different issues are to be negotiated, the payoff functions of different players have to be determined, and then the settlement points can be found through the same process.

### *Obtain Suggested Decision Set Using Backward Induction*

Backward induction is used when all the consequences (or payoffs) of the alternatives are known. If the participants are rational, they will choose the alternative that gives the best payoff. When all the payoffs are known, the participants can choose the alternative with the maximum payoff.

The backward induction method can be used to determine the best decision set, given all the payoffs. After all predictions have been made based on all the decision sets in the tree nodes, all possible decision sets are compared. The decision set with the maximum total payoff value, calculated in the previous step, is selected. Then backward induction is performed to trace all the choices that should be made in order to reach the maximum payoff.

### *Judge Whether Outcome Is Influenced by Insufficient Knowledge and by Strategies*

Domain-dependent barriers and strategies influence the outcome of negotiation. Usually, participants exaggerate about, or there is an impasse on, the issues others do not understand well. The settlement favors the participants who exaggerate. Consequently, participants should examine the issues that they are not familiar with in a particular case. If the settlement of an unfamiliar issue is too far from the desired point or gives a very low payoff to a player, then the player should negotiate the issue with other participants to obtain other perspectives and/or concessions. If other perspectives are not acceptable and the other participants are unwilling to concede, the player may create an impasse on the issue to manipulate the settlement in his or her favor.

The proposed methodology also provides a warning mechanism to help negotiators to overcome domain-dependent and strategy-influenced problems in a negotiation. As stated previously, exaggeration and impasse strategies are very easily conducted when opponents are not familiar with the issues. Therefore, the first step of the warning mechanism is to discover which of the issues is unfamiliar to a participant. The next step is to determine whether those issues are influenced by strategy. The issues that are possibly exaggerated are identified by the preference function forms used by opponent participants. If any other participant chooses the function forms that represent "stay with the issue"—that is, the power of the preference function is near ±1—then the agent will warn the disadvantaged participant. This warning takes the shape of informing the disadvantaged participant which of the other, more knowledgeable participants will stay with the potentially exaggerated issue. After studying computer-suggested settlements, the participant who has been warned by the agent can

**TABLE 1. HiCon Performs Abatement Work and DesCon Performs Monitoring Work**

| | *N* Value | | | Weighting | | |
|---|---|---|---|---|---|---|
| (1) | HiCon (2) | DesCon (3) | State (4) | HiCon (5) | DesCon (6) | State (7) |
| Duration | −1.11 | 1.5 | 1 | 0.5 | 0.5 | 0.7 |
| HiCon compensation | 1 | 0 | −1.67 | 0.5 | 0 | 0.15 |
| DesCon compensation | 0 | 5 | −1.67 | 0 | 0.5 | 0.15 |

**TABLE 2. HiCon Does Not Perform Abatement Work and DesCon Does Perform Monitoring Work**

| | *N* Value | | | Weighting | | |
|---|---|---|---|---|---|---|
| (1) | HiCon (2) | DesCon (3) | State (4) | HiCon (5) | DesCon (6) | State (7) |
| Duration | −3.33 | 1.5 | 1 | 0.5 | 0.5 | 0.7 |
| HiCon compensation | 5 | 0 | −1.67 | 0.5 | 0 | 0.15 |
| DesCon compensation | 0 | 5 | −1.67 | 0 | 0.5 | 0.15 |

**TABLE 3. HiCon Does Perform Abatement Work and DesCon Does Not Perform Monitoring Work**

| | *N* Value | | | Weighting | | |
|---|---|---|---|---|---|---|
| (1) | HiCon (2) | DesCon (3) | State (4) | HiCon (5) | DesCon (6) | State (7) |
| Duration | −1.11 | 0.6 | 1 | 0.5 | 0.5 | 0.7 |
| HiCon compensation | 1 | 0 | −1.67 | 0.5 | 0 | 0.15 |
| DesCon compensation | 0 | 1 | −1.67 | 0 | 0.5 | 0.15 |

**TABLE 4. HiCon Does Not Perform Abatement Work and DesCon Does Not Perform Monitoring Work**

| | *N* Value | | | Weighting | | |
|---|---|---|---|---|---|---|
| (1) | HiCon (2) | DesCon (3) | State (4) | HiCon (5) | DesCon (6) | State (7) |
| Duration | −3.33 | 0.6 | 1 | 0.5 | 0.5 | 0.7 |
| HiCon compensation | 5 | 0 | −1.67 | 0.5 | 0 | 0.15 |
| DesCon compensation | 0 | 1 | −1.67 | 0 | 0.5 | 0.15 |

begin communicating with the participants who had stayed with the issue and ask them to concede.

The benefits of applying this mechanism are manifold. First, computer agents do not have to introduce expert judgments and provide exact settlement suggestions. Instead, agents directly examine the preferences of players. If expert judgments are introduced, the preferences of the experts must be considered because the opinions and settlement predictions also come from the preference mechanisms of the expert. Furthermore, if the position of the expert is not neutral, then his or her position and preference should also be considered, and he or she should be treated as a participant. Therefore, it is better if the mechanism does not incorporate the preferences of other parties. Also, the participants can better understand the issues and more precisely define their preferences by thoroughly discussing the unclear issues and thus a more sustainable settlement can be obtained. Second, the mechanism does not reveal all preference information to other participants. The participants' preferences can still be kept secret. However, to achieve a more effective and sustainable result, an adequate amount of information should be revealed to prevent strategizing. The warning mechanism only suggests possible strategies of the participants instead of exposing the preference status of all the participants. The participants still have to communicate to reconcile their positions and concede to achieve an agreement. However, issues for negotiation are reduced, saving time for quality discussion.

## IMPLEMENTATION OF COMPUTER-SUPPORTED COLLABORATIVE CONFLICT RESOLUTION

To implement the collaborative conflict resolution methodology proposed in this paper, the rule of engagement has been embedded in a computer agent named CONVINCER. Because communication between participants is needed, the client-server architecture is applied via the Internet. CONVINCER is implemented using the highly portable Java language and the Internet technology. The agent requires a Microsoft Windows operating system in the server side and any kind of platform with Java virtual machines or Web browsers. The implementation of the client-server structure is shown in Fig. 8. Participants use Java applets embedded in Web browsers to communicate with the server. The server provides communication between clients and manages the system database through Java database connectivity (JDBC) and open database connectivity (ODBC) interfaces. These interfaces provide a distributed common interface for accessing heterogeneous structured query language (SQL) databases. For this prototype,

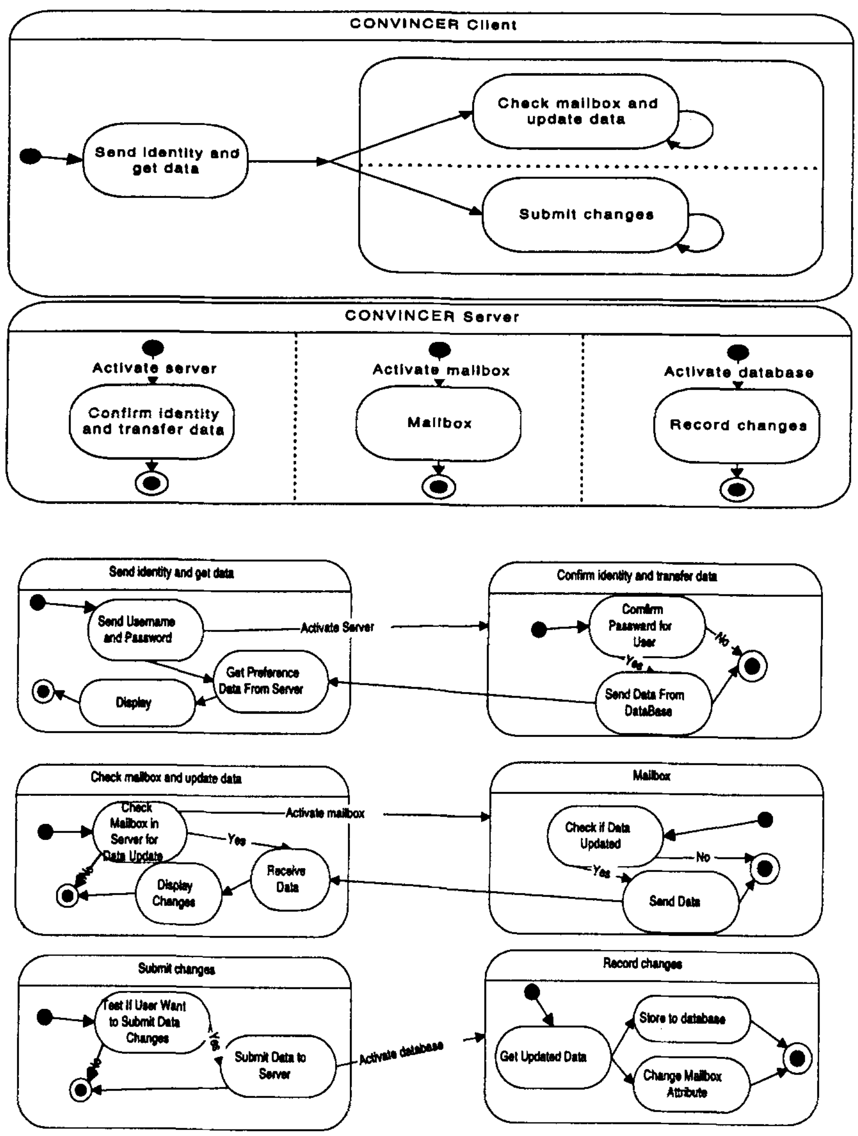



**FIG. 9. Dynamic Model of Client-Server Implementation**

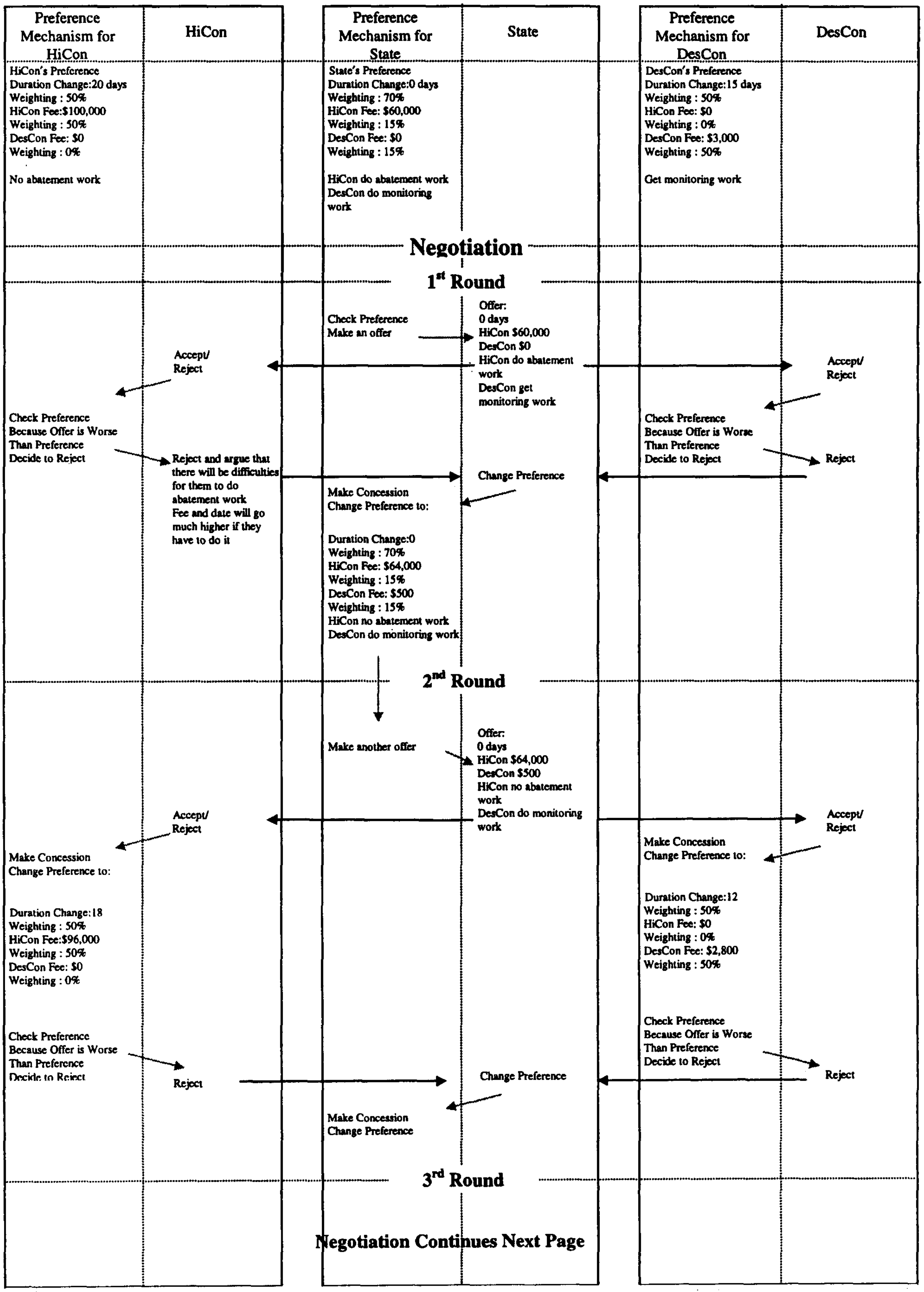



**FIG. 10. Negotiation without Facilitator**

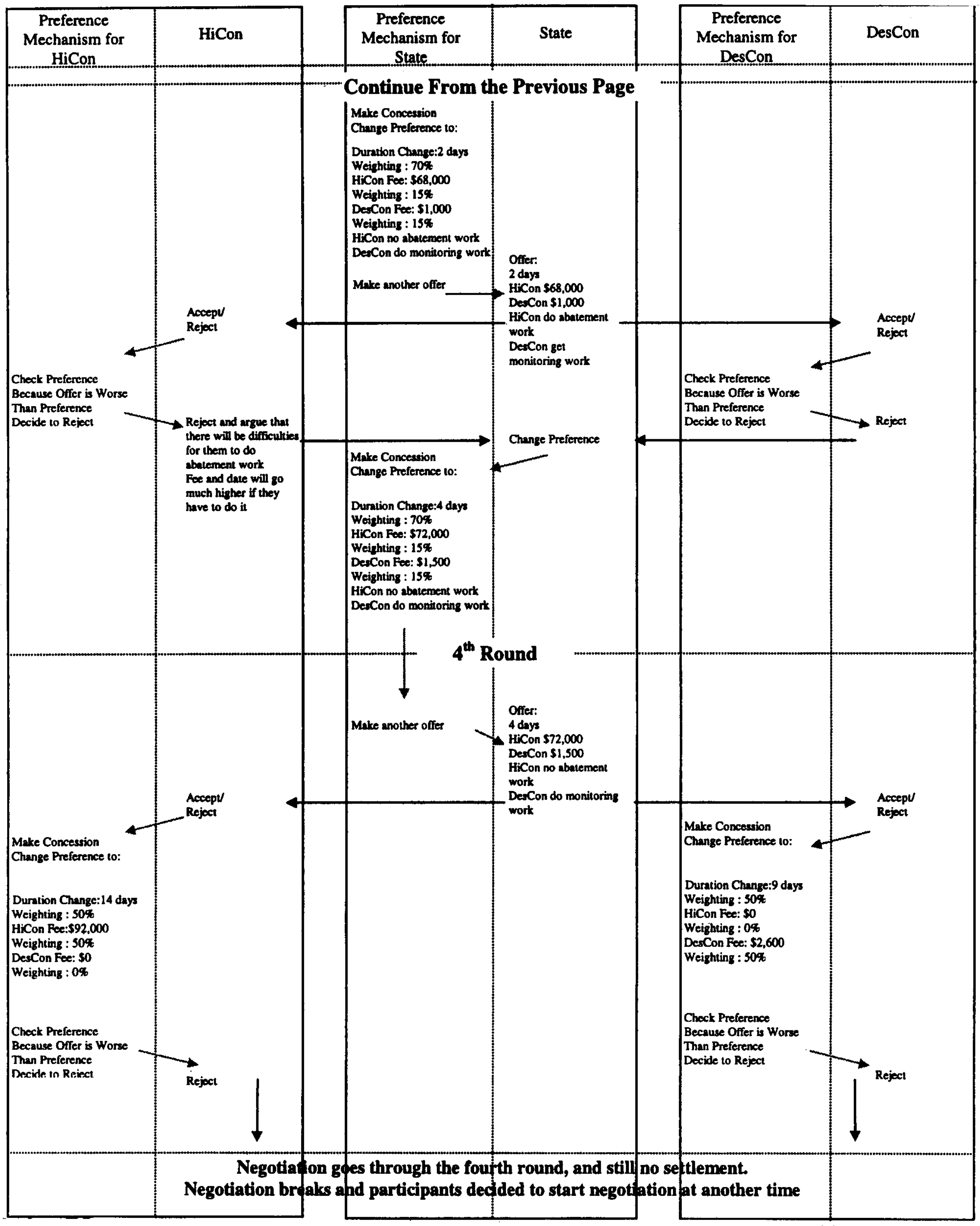



FIG. 10. (*Continued*)

Microsoft Access was used for storing the information generated by the different professionals involved in the negotiation (see Tables 1–4) due to its support of the connectivity interfaces. Through the use of a client-server architecture and the JDBC and ODBC interfaces, the data in the Microsoft Access database could be accessed from any Web browser that supports Java without losing the consistency of the data. This allowed all the professionals to negotiate on a consistent scenario.

The dynamic model of the client-server implementation is shown in Fig. 9. Three basic types of communication are needed for the implementation of the system. The first type is the log-on process. The client logs onto the server by entering his or her user name and password into the server. The server gives initializing data to the client after verifying the user password. The second type is similar to the broadcasting function. The client periodically checks the mailbox whether there is any change in the data. The server flags the mailbox of each client if the preference records have been renewed. The third type is data submission by the client to the server. The server informs the other clients that the data has been changed and restores the changes to the database.

The implementation of the computer-supported collaborative conflict resolution methodology within the agent is presented next (Fig. 9). To illustrate how the methodology works, the following simplified scenario has been developed. Clearly, real problems are more complicated, as will be actual case studies utilized in the future extensions of this research effort. This scenario, however, can highlight some of the concepts discussed and describe how the methodology addresses them to resolve the conflict satisfactorily for all participants.

## Example of Collaborative Conflict Resolution Methodology

An owner, the state highway department (State), is beginning to implement a large-scale upgrade of a 20 mi. section of a major expressway. Included in the scope of the overall project is the reconstruction of several ramps and bridges. The owner has prioritized the different projects within the overall program and has selected a designer for the first ramp section. The designer (DesCon), in turn, has completed the plans and specifications. The owner, who must by law use the design-bid-build delivery system for this type of public work, has awarded the contract for construction to the lowest bidder. That contractor (HiCon) has begun operations on-site, but has been forced to stop work because during digging an unexpected abandoned pipe and tank arrangement was discovered. After some investigation, it is concluded that the lines are old process piping for a factory that had once occupied the site. The pipe is insulated with asbestos wrapping and must be removed in order for the work to proceed.

A meeting is called to discuss the options, and all three parties attend. These parties must decide how to solve the technical problems associated with the abatement and removal, and the design issues regarding the proper preparation of the subsequent soil conditions. Additionally, they must discuss the schedule implications of the delay and address the additional scope and the payment for delay of the work owed to both the designer and the contractor. Work has stopped until the negotiation can be concluded.

In this scenario, the contractor has entered the negotiation with a "first offer" position that he requires \$100,000 for delay compensation, which he doubts that he can receive in full. In reality, he is most concerned with covering his true expenses due to the change, which are only \$60,000. He also has a strong interest in not performing the abatement work because he needs to retain bonding capacity for another bid and is nearing his aggregate limit. The designer, in turn, submitted a reasonable cost estimate of \$5,000 to the owner for additional design fees, yet carries a true interest of gaining the more lucrative monitoring fees. He knows that the monitoring fee could climb as high as \$20,000, with a guaranteed profit margin. Finally, the owner is under a crucial time restriction on the project because it is the first of many subsequent projects. A delay on this first one would be disastrous in the long run, and the highway department is willing to pay more money if both the designer and contractor can solve the problem in as little time as possible. A delay of more than one month would be unacceptable, and the shorter the duration of the work, the better. None of the three participants enters the negotiations with the intention of divulging true interests. To do so would put the participant at a disadvantage when it gets down to hard-nosed bargaining.

Based on this scenario, two types of negotiation processes

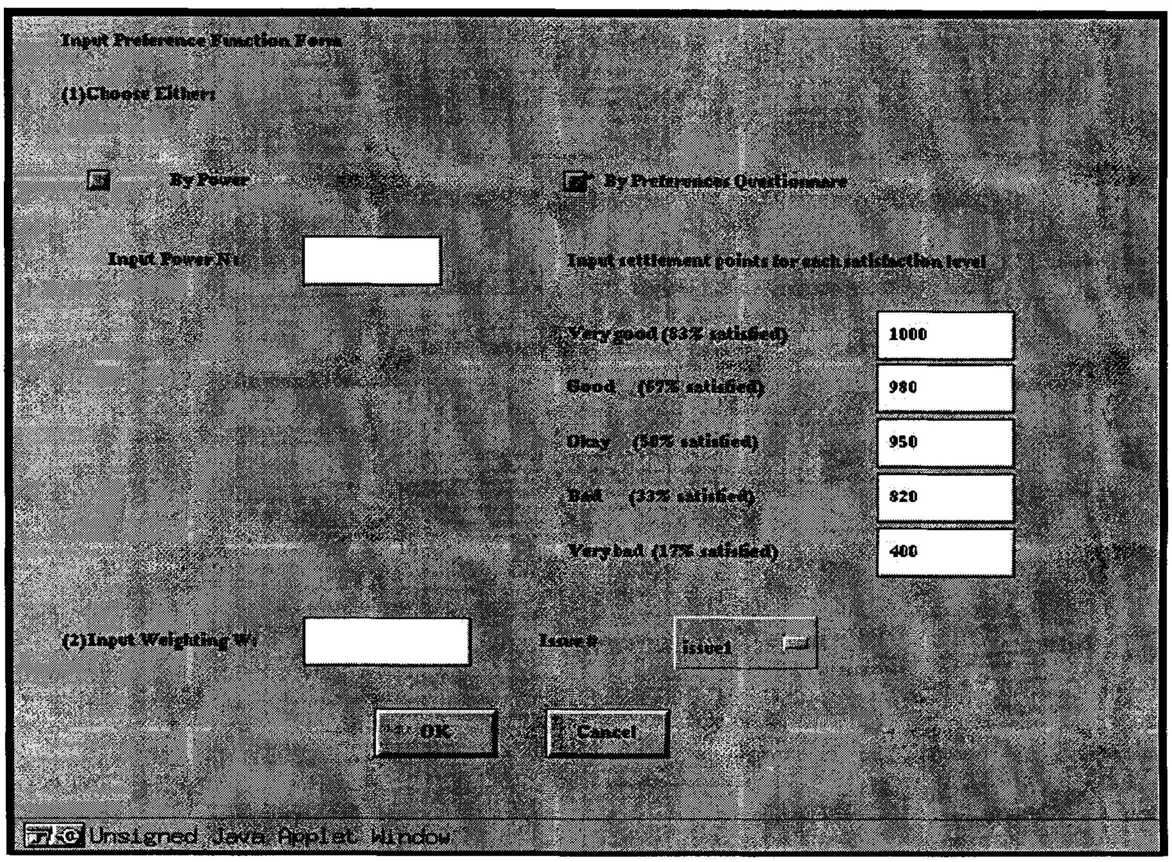



FIG. 11. GUI of Function Form Assignment

are illustrated: unsupported negotiation and computer-supported negotiation. Fig. 10 shows the negotiation process without the intervention of a facilitator. The three participants have their preferences in mind. When the owner gives an offer, the others start to evaluate it and decide whether to accept or reject the offer. This process is very time-consuming and easy to break, because all the negotiators have to go through a long trial-and-error process to reach an agreement.

As presented in Fig. 10, the participants go through four rounds of the concession process and still cannot reach a consensus. The participants acted normally and kept making concessions. However, because the negotiation lacks mechanisms to evaluate the participants' preferences and suggest a settlement point, consensus cannot be obtained more quickly. Therefore, the participants have to spend a large amount of time searching for an acceptable settlement.

## Steps in Computer-Supported Collaborative Negotiation Methodology

The steps in the computer-supported collaborative negotiation methodology implemented in the CONVINCER agent are presented in this section. The scenario continues to be used to illustrate how the steps are taken.

### *CONVINCER Obtains Players' Preferences*

Players input their preferences and weightings of all the issues subject to each individual's results in the decision tree.

**TABLE 5. Optimal Total Payoffs Table**

| DesCon performance (1) | HiCon Performance: HiCon performs abatement work (2) | HiCon Performance: HiCon does not perform abatement work (3) |
|---|---|---|
| DesCon performs monitoring work | Table 1: maximum payoff 228 | Table 2: maximum payoff 243 |
| DesCon does not perform monitoring work | Table 3: maximum payoff 201 | Table 4: maximum payoff 222 |

In this scenario, all the three participants (HiCon, DesCon, and the State) input their own payoff function forms and weightings to every issue to show their preferences. There are three issues to be negotiated and given different function forms for different participants: extended duration, compensation to HiCon, and compensation to DesCon. Issues are also reconsidered for each of the four different decision sets by all participants: HiCon performs the abatement work and DesCon performs the monitoring work; HiCon performs the abatement work and DesCon does not perform the monitoring work; HiCon does not perform the abatement work and DesCon performs the monitoring work; HiCon does not perform the abatement work and DesCon does not perform the monitoring work. Each decision set or each issue in those decision sets is given a different payoff function and weighting.

Two methods for obtaining participants' preferences are de-

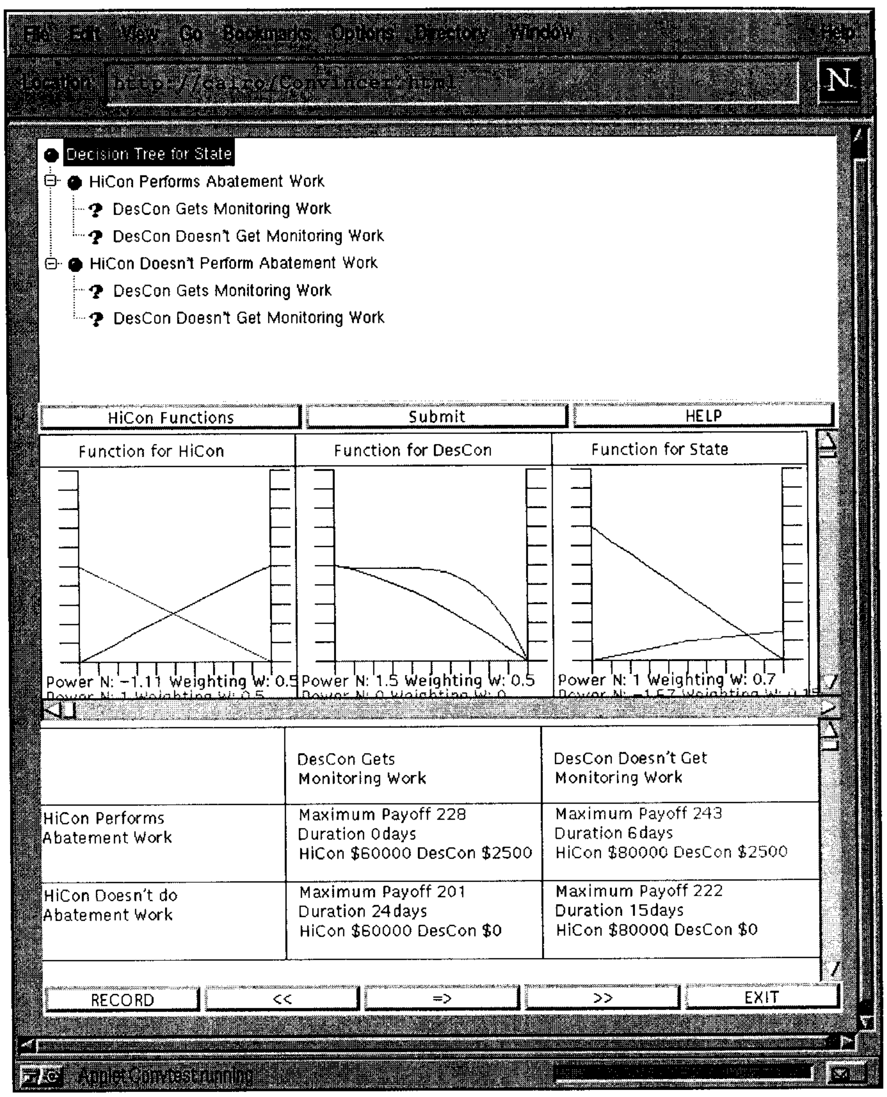



**FIG. 12. Screen Dump of CONVINCER Agent, Giving Suggested Settlement**

scribed in the section entitled Select Payoff Function Forms and Weighting for All Players According to Game and Generic Negotiation Models. The first method is to directly obtain the function powers and weightings from the user. The second method is to ask the user to input the settlement that he or she expects. Tables 1–4 show the function forms and weightings obtained from the participants with each decision set.

The function forms in Tables 1–4 are the functions $P_2$ and $P_3$ in (2) and (3). Power $N$ and weighting $W$ should be given in order to determine a payoff function. To distinguish $P_2$ from $P_3$, a negative sign is added to the $N$ value if the function adapted is $P_3$. All values in the tables are made by considering the preferences of the three participants with the following assumptions:

- The owner (State) is most concerned about the extended duration and is willing to make concessions on other variables in order to save time. Therefore, the weighting of the duration should be greater.
- The highway contractor (HiCon) doubts that he can get full compensation; therefore, there is a wider acceptable payoff range in the compensation. In other words, his $N$ power is high, and he is more willing to make concessions early, as long as it is above his threshold.
- HiCon has another bid in progress and therefore is not interested in the abatement work.
- The design consultant (DesCon) wants to get the monitoring fee and therefore has a wider acceptable payoff range in design fee, compensation, and time.

Also based on the description of the scenario, the concession ranges can be established as

Duration: $0 < x < 1$ month
Compensation to HiCon: $60{,}000 < x < 100{,}000$
Compensation to DesCon: $0 < x < 5{,}000$

The $N$ values and weightings are given in Tables 1–4 and were deduced from the following facts:

- HiCon has opposing preferences to State with respect to duration and pay. Thus, if the value of $N$ for State is positive, the value of $N$ for HiCon should be negative.
- HiCon is willing to make concessions without the abatement work. Therefore, the norm of the $N$ value will be much greater than 1 if HiCon does not have to do abatement work.
- DesCon has the same opinion as State if DesCon can obtain the monitoring fee. Therefore, if the $N$ value of State is positive, the $N$ value of DesCon should also be positive.
- The weighting of the duration (0.7) is greater for State than the issue of cost (0.15).
- In this scenario, both $N$ values and weights are established by approximation, to illustrate concepts. $N$ values represent concession patterns that in practice would need to be established through patterning negotiator behavior. Weight values would be established through querying the negotiators. $N$ values change depending on the preferences of the negotiators with respect to each possible situation, while weighting values reflect overall preferences of the negotiators and therefore remain the same throughout the negotiation.

The GUI to input those values is shown in Fig. 11. Two methods of obtaining preferences from the user are provided in the window. The left side of the window indicates how to obtain the function power and weighting from the user directly. The right-hand side of the window shows the part of obtaining user preference by the level of satisfaction. The user

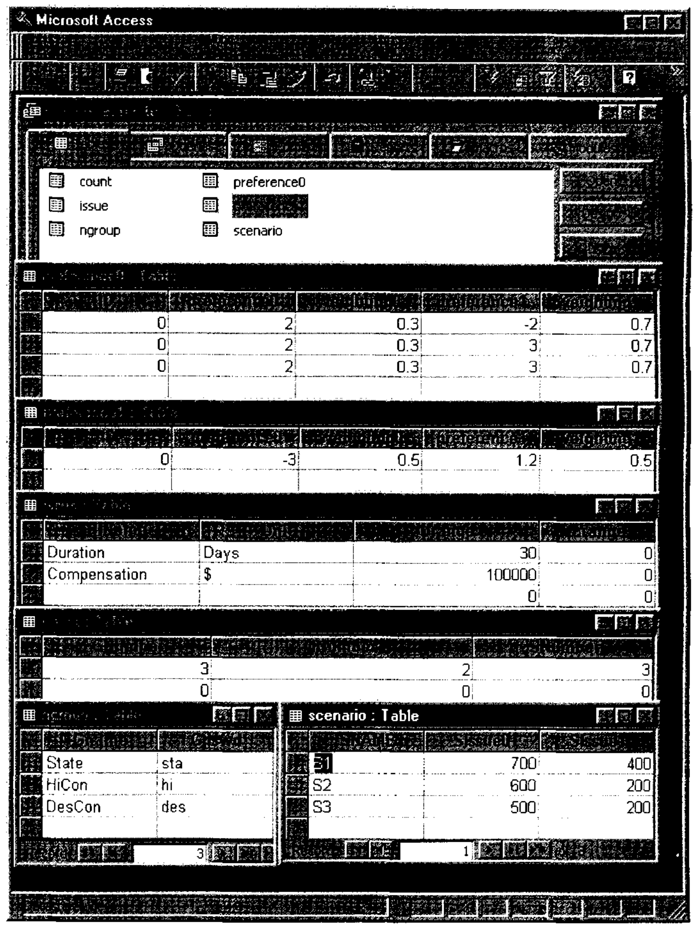



FIG. 13. Negotiation with CONVINCER

inputs five settlement points according to five satisfaction levels. The agent then calculates the function form according to the relationship of satisfaction level to the settlement point of an issue.

*CONVINCER Calculates Payoffs Based on Collaborative Conflict Resolution Methodology*

CONVINCER calculates the maximum payoffs based on the methodology presented in the section entitled Methodology for Collaborative Conflict Resolution. It calculates both decision choices and settlement prediction, using (5) and solving the optimization problem. After all the $N$ and $W$ values are applied to the equation, optimal total payoffs from different decision sets in different tables can be determined, as shown in Table 5.

*CONVINCER Gives Suggested Settlement to Players*

After the predicted outcome is obtained, CONVINCER broadcasts the suggested settlement to all participants. The suggested settlement includes both the suggested decision and the predicted negotiation settlement. Fig. 12 shows the screen dump of CONVINCER, giving the suggested settlement of the first round of negotiation. Fig. 13 shows the logic behind the suggested settlement.

*Participants Make Changes or Concessions According to Suggestion and Start to Negotiate*

After participants received the suggested outcomes, they made changes and concessions. Then they tried to negotiate a consensus. The process is shown in Fig. 14. In the first round of negotiation shown in Fig. 14, all three participants changed

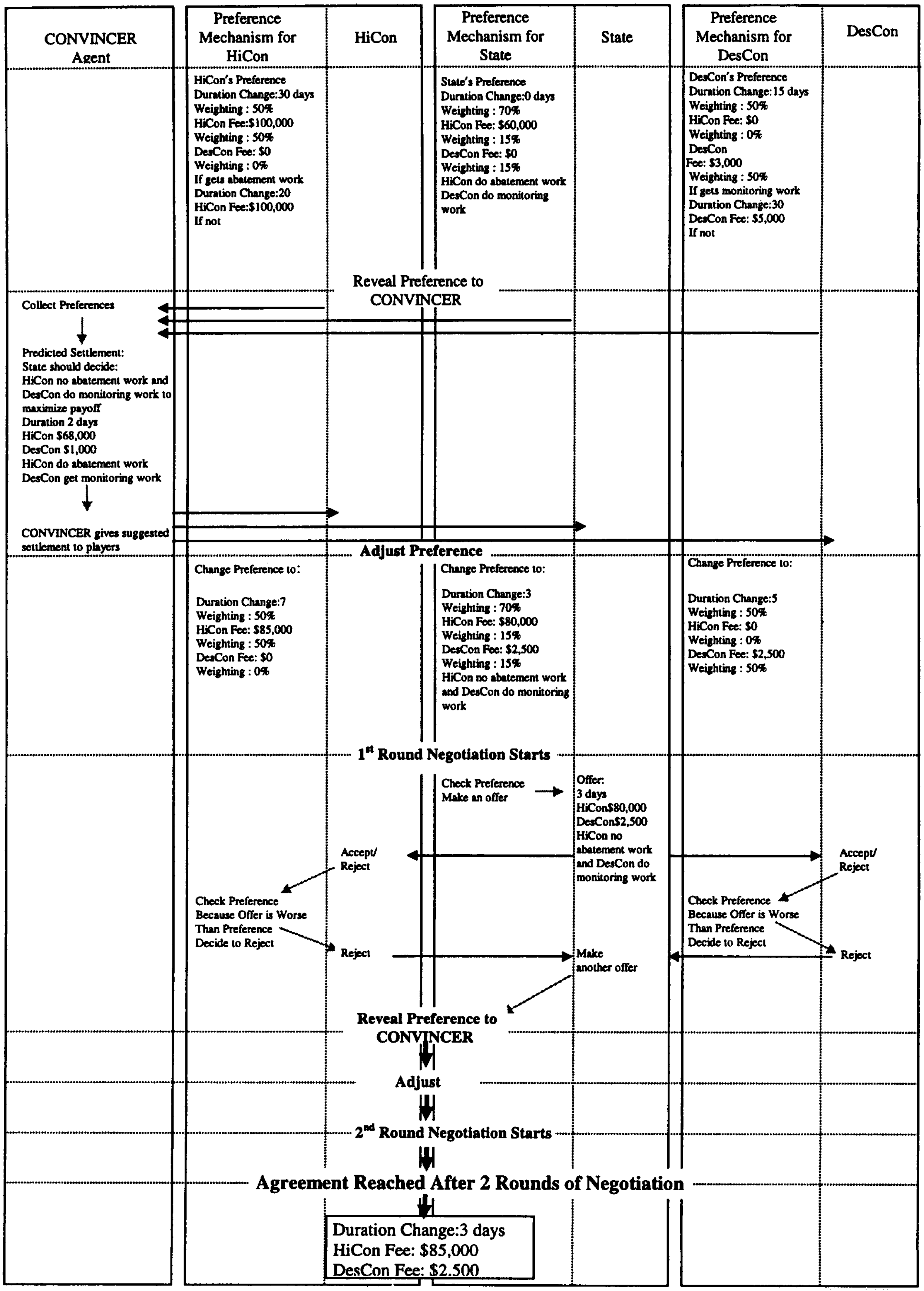



**FIG. 14. CONVINCER Database Structure**

their preferences and made concessions. Then State gave an offer to see whether they had reached a consensus.

*CONVINCER Receives Changes and Makes Another Settlement Prediction*

If consensus has not been reached among participants in the previous step, CONVINCER collects preferences again. CONVINCER then suggests the settlement according to the changes made by participants after the previous step. The players once again use the suggested outcomes to seek a possible settlement. This iterative process (shown in Fig. 14) continues until an agreement is reached.

Fig. 14 shows the negotiation process, with CONVINCER agent playing the role of facilitator. In this case, a participant gives the agent his or her preferences without revealing it to other participants. CONVINCER suggests a settlement according to the preferences. The participants then negotiate using the data obtained by the agent and stored in the database (see Fig. 14). Thus they get a better solution through a faster procedure. Since the computer gives a first approximation to a solution that takes into consideration past scenarios and the negotiators' preferences, it prevents the repetition of past mistakes and reduces the time needed.

## CONTRIBUTIONS

The collaborative negotiation methodology presented in this paper provides negotiation assistance with a primary focus on resolving conflict in the A/E/C industry. First, it proposes three major characteristics in the A/E/C industry that must be considered in a negotiation: the collaborative-competitive nature, the domain-dependent barrier, and the strategy-influenced outcome of the project. These characteristics are analyzed and incorporated into the methodology to provide strong assistance to negotiators in the A/E/C industry. Second, the collaborative negotiation methodology provides a suitable framework for negotiators in the A/E/C industry. CONVINCER, the computer agent implementing the methodology, works closely with the human negotiators. As demonstrated by the example provided in the section Implementation of Computer-Supported Collaborative Conflict Resolution, CONVINCER assists participants in the A/E/C industry in obtaining a sustainable settlement more effectively and efficiently.

The proposed methodology and CONVINCER also contribute to the field of negotiation support systems by providing a set of preference functions to model the preferences of negotiators. Different function forms and properties are discussed and used as the basis of representing human preferences. With a mechanism for obtaining maximum total preference, both optimal settlement prediction and optimal alternative selection are performed to help negotiators find their mutual interest immediately. A warning mechanism helps negotiators to find and avoid getting into an unwanted settlement influenced by opponents' strategies.

## FUTURE RESEARCH

The collaborative negotiation methodology and CONVINCER have started to construct a suitable framework for negotiation support in the large-scale civil engineering industry. The next step is to examine different negotiation scenarios and experiment with negotiators to obtain the real behaviors of human negotiators when interacting with the support of CONVINCER agents. The result can be applied to improving the methodology in the following ways:

- Obtain real preferences from human negotiators to determine whether the developed preference modeling mechanism is valid. If it is not, make the necessary corrections to the function form or develop a more suitable function form of preference modeling.
- Obtain real processes of human negotiation to determine whether the methodology can prevent strategizing and the manipulation of domain-dependent knowledge. Several strategies may be discovered and incorporated in the methodology.
- Obtain real settlements of human negotiation to determine whether the developed preference modeling mechanism is valid. Make corrections to the settlement prediction mechanism if needed.
- Study how human negotiators can be further supported by the methodology and agent (i.e., collaborate better and obtain effective, efficient, and sustainable settlement). Obtain the feedback regarding improvements of the methodology.

## ACKNOWLEDGMENTS

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