A MULTIAGENT SYSTEM FOR NEGOTIATING CONSTRUCTION BIDDING DECISIONS

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Competitive bidding is the most commonly adopted method to determine which contracting firm to be awarded a construction project. Depending upon the market condition and their existing workload, a contractor would have to make decisions on (i) bid or no bid; (ii) direct and indirect costs; and (iii) mark-up level. With the reliance on subcontracting system and the amount of materials involved in a construction project, decisions on the three crucial steps mentioned above cannot be made without first consulting and negotiating with the relevant S/Cs and suppliers. The problem is aggravated when various in-house departments participated in the decision making process. Careful negotiation on time, cost, resource allocation, quality standard, and so on during the bidding stage would, therefore, be paramount important as this could reduce the likelihood of disputes and project failure. Unfortunately, the negotiation process is normally carried out in a manual and unstructured manner. In an absence of time for thorough negotiation during the bidding stage, the results could be far from ideal. In this paper, The Multi-Agent System (MAS) approaches are applied to model the negotiation process during the bidding stage. The model (i) analyses the characteristics of negotiation at this process; (ii) identifies suitable problem to be solved; and (iii) selects the appropriate negotiation mechanisms for solving those problems. It is envisaged that, by adopting this distributed coordination methodology, the response time could be much reduced while the expected profit could be maximized.

Key words: Multi-agent System (MAS), bidding decision, negotiation mechanism, construction management

INTRODUCTION

Construction bidding is a crucial process that could determine the success of a project. Contractors are confronted with many critical decisions including decision to bid and the level of mark-up in order to maximise their profit should they win the project. However, the number of participants involved in bidding process could give rise to conflicts and problems in coordination. Negotiation not only plays an important role throughout the sourcing and auctioning of material suppliers and subcontractors (S/Cs), but would also be essential for co-ordinating various internal departments involved in the bidding process. Until now, negotiation is carried out manually and in an unstructured manner, and this could be extremely tedious and ineffective. Submitting accurate bids in a timely manner may not be realised.

This paper focuses on the negotiation among main contractor, S/Cs and suppliers during the competitive bidding process let by traditional design-bid-build delivery option. Under this type of project delivery system, the optimal bid should be made up of two components: the estimated cost of executing the project, and a strategy for maximizing profit constituting the mark-up. As a result, the whole process of bidding can be divided into three stages: (i) to bid or not to bid; (ii) estimation of costs; and

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(iii) determining the mark-up. In the first stage, negotiation takes place between various departments within the organisation, e.g. on resource availability and the attractiveness of the project. During mark-up stage, little or no negotiation would exist between the main contractor (MC) and other supply chain members. Since researchers (Harris et al 1988) argued that an accurate estimation of direct costs is more important than the mark-up decision if maximum profit margin is targeted, this paper will emphasise on the negotiation during the second stage. Under the usual practice, the MC will seek quotations from suppliers and S/Cs. This could require a lengthy negotiation process. Therefore, a model that could facilitate bid negotiation would be indispensable.

Of various information technology approaches which aim for facilitating negotiation, a subset of the distributed artificial intelligence (DAI) known as the multi-agent system (MAS) has a good avenue in providing a platform for a group of agents to interact with each other. The MAS technology establishes a series of agents mimicking the participants involved in the bidding process, such as the employers, main contractors, suppliers and sub-contractors, through which agents could negotiate directly with each other to achieve their goals.

The MAS approaches would be applied to model the bid negotiation process discussed earlier. The model (i) analyses the characteristics of asking price submitted by the suppliers and S/Cs; (ii) identifies suitable problem(s) to be resolved; and (iii) selects the appropriate negotiation mechanisms for resolving those problems. By adopting this distributed coordination methodology, the response time could be much reduced while the expected profit could be maximised.

NEGOTIATION THEORY AND NEGOTIATION STRATEGY

Negotiation involves an exchange of views between parties and a reconciliation of their differences in order to come up with a settlement. There are different forms of negotiation, such as fighting, facilitation, mediation, arbitration and adjudication. According to Z.Ren et al (2003), several negotiation theories have been developed, such as the game theory, economic theory, and behavioural theory have been proposed to address the complex technical and human issues in negotiation. It is important to identify a suitable negotiation strategy to suit the problem (Pena-Mora and Wang 1998). As rightly pointed out by Kraus (1996), inefficiency is a common problem in negotiation. From several previous studies on MAS, there was a significant improvement in efficiency should an appropriate negotiation strategy be adopted.

On an abstract level, a negotiation strategy specifies what the agent should utter and when in a negotiation interaction (Rahwan et al 2003). Recent research has demonstrated that MAS can be applied to negotiations. Examples of these include the agent-mediated electronic commerce (Chris and Carlos 2002; Gustavo et al 2001; Konming 2001); requesting help education system (Vassileva and Mudgal 2002); project schedule changes coordination (Keesoo and Boyd 2003); and construction claims negotiation (Ren et al 2003). While various negotiation strategies were adopted in these systems, the selection of negotiation strategy was based on the characteristics of the problem domain. In this study, the factors influencing the design of negotiation strategies for the bidding process one identified and shown in Table l (Rahwan et al 2003).

Table 1: Factors influence the design of negotiation strategies of an agent

Factor	***Description***
Goals	What objectives or goals the agent wishes to achieve from undertaking a negotiation interaction over these resources with these other agents at this particular time
Domain	According to the nature of resources under negotiation, task-oriented domain (TOD), state-oriented domain (SOD) and worth-oriented domain (WOD) are identified.
Protocol	The nature of interaction protocol used for the negotiation.
Capabilities	The capabilities of the agent within the interaction.
Values	The values of the agent.
Counterparts	The nature of the other participants in the interaction, as perceived by the agent
Resources	The time and resources available to the agent, including computational, memory and other resources, such as expert advice.
Alternatives	The nature of any alternatives to resolution available to the agents

CHARACTERISTICS OF NEGOTIATION IN ESTIMATING

In the bidding process, the MC would estimate their direct costs in the specified short period upon receiving the invitation to bid, and the accuracy of this estimate is crucial to the success of his bid and project completion. However, in order to spread the risks, and due to the existence of some specialised works, it is not uncommon for the MC to subcontract part of the works. Because of that, they will simply ask for a flotation instead of working out the direct costs themselves. The nature of negotiation is indeed quite different from other problem domains, and it is necessary to analysis of the characteristics of the bidding problem first. The nature of construction bidding can be summarised in the following sections.

Partially Combined-Interest Relationship

During the bid preparation stage, the negotiation between the MC and S/Cs is carried out without any contractual obligations. The negotiation can be terminated at any time without penalty although it could affect the one’s future tendering opportunity. Both parties will seek their own interest as well as the combined interest, i.e. to win the bid. An unreasonably high subcontract price could in turn result in failure in securing the project. In other words, each participant should do their best to attain a “win-win” agreement, as both parties would like to establish a good long-term relationship and avoid getting into any possible conflicts.

Parallel Bargaining Process

In practice, the MC would negotiate with a several S/Cs at the same time to ensure a low subcontract deal can be obtained. Each of these negotiations can be seen as a bargain, which is bilaterally monopolised and can be characterised as the convergence of offers and counteroffers over time within a contract zone. The cognisance of incomplete information can also be learned to facilitate the parallel process as showed in Figure l.

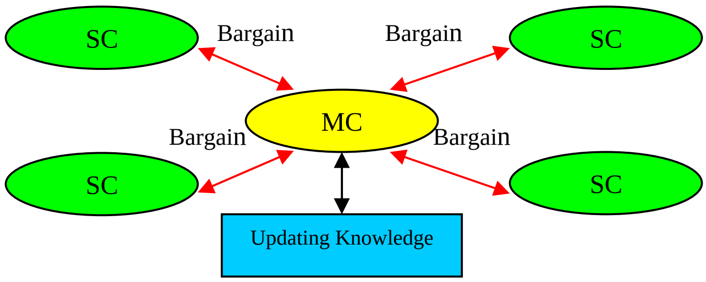

Figure 1: Parallel bargaining process

Strategy-Influenced Process

As Samuel and Edward (1981) stated, bargaining is a process of tactical action and bargain power is the essence of the process. By adopting different strategies, the MC and S/C will attack the opponent's definition of the power situation by manipulating information, bluffing, and so on. Since the two parties will process information imperfectly continuously, all their estimates about the others will be changed by the opponent's strategy. Furthermore, the influence on each other in the parallel bargaining process makes this point more important.

Subjective Non-monetary Value Seeker as the Agent

The goal of the MC in the negotiation process is not to obtain the lowest price for a certain portion of work, as they may also consider many non-monetary factors that could influence the final success of the project, e.g. the quality, chance of completing on time, and other market conditions. On the other hand, S/Cs may also consider factors other than price, such as long-term business opportunity, resource availability, etc. The preference of stakeholder is likely to have a nonlinear relationship to the monetary value (Pen 1952).

Time-Important Factor

As stated earlier, the time for negotiation process is a crucial factor determining the final outcome. The MC has a time pressure in finishing the estimate and submitting the bid to clients within a specific time. Likewise, the S/C would also be bound by the time factor, as the more time they consumed before an agreement is reached, the higher possibility that the MC would accept another subcontract bid. As a result, each party can utilise the time strategy to attack their opponents.

DESIGN OF AN NEGOTIATION STRATEGY

Negotiation Goals

The goals of negotiation for the MC would be as follows: (i) to understand the preference of S/C on the price under some conditions for future cooperation; (ii) to obtain the most preferred offer from S/Cs with the maximum ophelimity value, which Pareto defines as a subjective utility; and (iii) to establish and maintain a good relationship with the S/Cs concerned.

Negotiation Protocol

The proposed negotiation protocol is largely inspired by the Contract Net Protocol (CNP) (Smith 1980) and Monotonic Concession Protocol (MCP) (Rosenschein and Zlotkin 1994). Since the negotiation of subcontract price is a multilateral negotiation process that can be seen as several parallel bargaining processes, a protocol that combines the CNP and MCP might be useful. In the proposed protocol, negotiation would be divided into two levels. In the first level, the MC agent will ask for proposals from several S/C agents, and the subcontracts agent can choose to submit an offer or otherwise. Once sufficient numbers of S/Cs have accepted the invitation, the next negotiation process, i.e. the parallel bargaining process, will take place. In each bargaining process, one would propose a deal to the other in a sequence of rounds. In each round, participants may repeat the offer they have just made, or make a new offer which is closer to the opponent's end of the single dimension (i.e. they may concede). If neither agent concedes at a given round, the interaction terminates without a deal, a situation is referred as a conflict deal. However, if the proposed deals at any round overlap, the interaction would end with a deal. When this happens, the MC agent will make a new offer with the same price to the S/C agent in another bargain processes. If the S/C agent cannot accept this offer in the next round, the MC agent will terminate the process. The MC will acknowledge all the accepted offers and add those agents to the post-negotiation list for negotiation of subcontract details after the bid is awarded as shown in Figure 2.

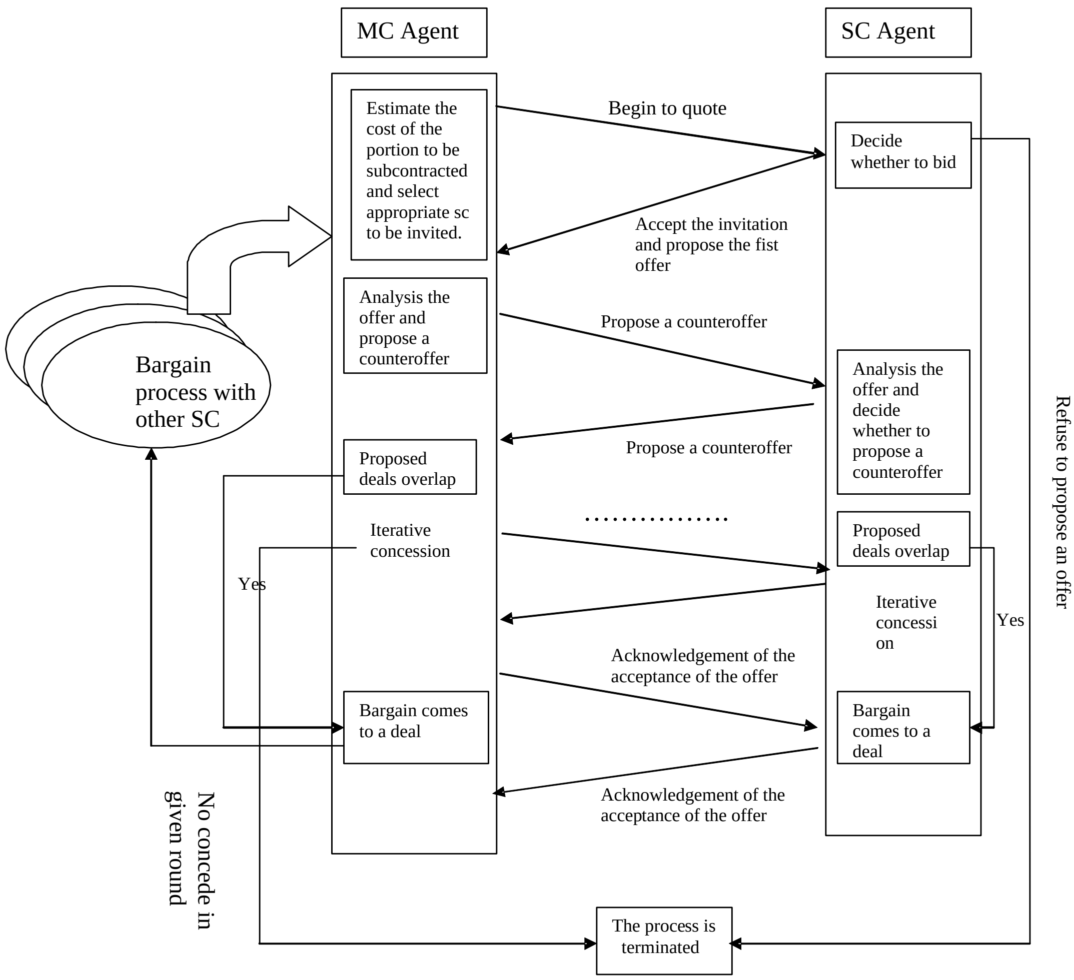

Figure 2:Negotiation Protocol for Single Process in Parallel Bargaining

Concession Mechanism

Zeuthen's bargain strategy is adopted so that the bargaining process can be conceptualised as series of successive decision points confronting bargainers with the choice of reiterating their previous demand or making a concession. Zeuthen (1975) found that the criterion rational bargainers would use for decision making involves the risk of conflict, or more precisely, the risk that a party subject itself to when it rejects itself to when it rejects the other's offer and remains firm on its own most recent offer.

Zeuthen's basic proposition is that bargainers will not yield or make concessions unless the risk of conflict becomes unacceptable. Given each agent is willing to take a certain level of risk, agent who is less willing to accept risk will make a concession. The criteria for risk evaluation can be formulated into the following equations:

$$P_{m\max} = \frac{U^t{}_{mm} - U^t_{ms}}{U^t_{mm} - U_m(C)}\ ;\ P_{s\max} = \frac{U^t{}_{ss} - U^t_{sm}}{U^t_{ss} - U_s(C)} \quad (1)$$

where,

$P_{m\max}$ = the maximum likelihood of risk acceptance to the MC;

$P_{s\max}$ = the maximum likelihood of risk acceptance to the S/C;

$U^t{}_{mm}$ = MC agent's utility based on its offer in 't' iteration;

U^t_{ms} = MC agent's utility based on the lowest S/C agent's offer in 't' iteration;

$U_m(C)$ = MC agent's utility for a conflict deal

$U^t{}_{ss}$ = S/C agent's utility based on its current offer in 't' iteration

U^t_{sm} = S/C agent's utility based on the MC agent's offer in 't' iteration

$U_s(C)$ = S/C agent's utility for a conflict deal

In each iteration, each agent calculates its own P_{max} and compares it with that of its opponents. The agent with a higher P_{max} will make the next concession. Based on the simple approach of decision in concession rate as suggested by Rosenschein and Zlotkin (1994), the step an agent concedes should be the minimum sufficient to make its opponent's maximum risk acceptability smaller than or equal to him own. Before the beginning of the negotiation, the quality level of each S/C should be known by the main contractor. The coefficient of quality is to adjust the utility based on the S/C's offer, and it is assumed that the time penalty for the MC agent is 2% utility reduction per iteration and 4% for the S/C agent.

LEARNING MECHANISM

When negotiating the subcontract price, each party would have little information about the other, which makes uncertainty a crucial feature of this process. Since Zeuthen's model was established based on complete information, it is necessary to introduce a learning approach for updating the agent's knowledge on the others. In this model, the Bayesian framework is used to update the knowledge and belief that an agent possesses about the environment and other agents. To illustrate the concept, the negotiation process only considers the viewpoint of the MC and assumes that the relevant information set Ω is comprised of only one item: i.e. the belief about a supplier's reservation price – the threshold of acceptable offer. Typically, the reservation price is exclusive to each agent, and the reservation prices of different agents may not be the same. As shown in Figure 3, when the S/C's reservation price RPSC is lower than that of the main contactor RPMC, any point within the "zone of agreement 11 could be a candidate solution.

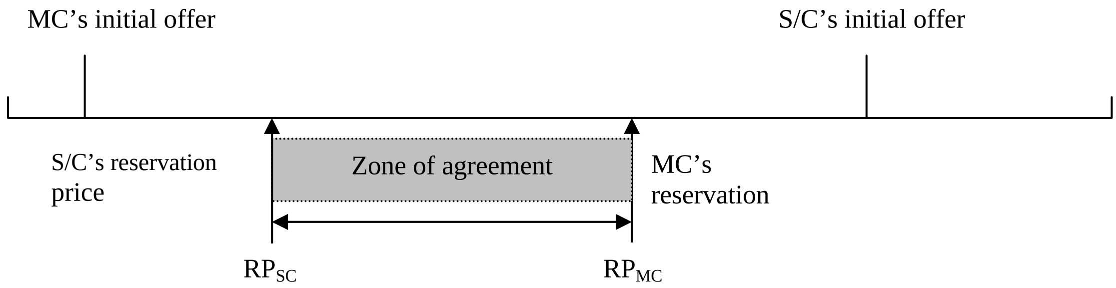

Figure 3: An example of reservation prices and "zone of agreement"

Within the "zone of agreement", the parties will make concessions from their initial proposals; by which the main contactor will increase his initial proposal while the S/C will decrease theirs. Eventually, a proposal that is within the "zone of agreement" and is acceptable to both would be reached. Although an agent has a good idea about their own reservation price, the precise value or even the "zone of agreement" of the one they are negotiating with is unknown to them. Nevertheless, the MC should be able to update their belief regarding S/C's "zone of agreement" based on their interactions and domain knowledge.

The main contractor's partial belief about RPSC can be represented by a set of hypotheses Hi, i=1,2…n. For instance, H1 can be "RPSC=$100.00; H2 can be "RPSC =$90.00". An a priori knowledge held by the MC can be summarised as a probabilistic evaluation P over the set of hypotheses {Hi} [e.g. P(H1)=0.2, P(H2)=0.35]. The Bayesian updating occurs when the MC has received new signals from the outside environment (other bargain processes) or from the S/C they are bargaining with. Along with the domain-specific knowledge, these new signals enable the MC to acquire new insights about RPSC in the form of posterior subjective evaluation over Hi. The offers and counteroffers from the S/C comprise the incoming signals, while the domain knowledge can be an observation like "usually people in the construction industry would inflate their bid by 10% over their reservation price, and this can be represented by a set of conditional statements of similar form, such as: P(e1/H1)=0.30, where e1 represents "OfferSC=110.00", and H1 "RPSC =$100.00". Given the encoded domain knowledge in the form of conditional statements and the signal in the form of offers made by the S/C, the MC could use the standard Bayesian updating rule to revise his belief about RPSC:

$$P(H_i \mid e) = \frac{P(H_i)P(e \mid H_i)}{\sum_{k=1}^{n} P(e \mid H_k)P(H_k)} \quad (2)$$

Through an iterative update of belief, an agent can finally get a relatively accurate estimate about the opponent's reservation amount even if its initial domain knowledge is not so accurate (Ren et al 2002).

CONCLUSIONS

In this paper, the Multi-Agent System (MAS) approaches are applied to model the negotiation process during the bidding stage. The model (i) analyses the characteristics of negotiation at this process; (ii) identifies suitable problem to be solved; and (iii) selects the appropriate negotiation mechanisms for solving those problems. The study will provide a foundation to develop a distributed agent-based system to assist all the parties involved in the bidding process, especially during the stage of estimation to coordinate and work towards a common goal in a timely manner.

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