A Solution Generator Algorithm for Decision Making based Automated Negotiation in the Construction Domain

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Abstract

In this paper, we present our work-in-progress of a proposed framework for automated negotiation in the construction domain. The proposed framework enables software agents to conduct negotiations and autonomously make value-based decisions. The framework consists of three main components which are, solution generator algorithm, negotiation algorithm, and conflict resolution algorithm. This paper extends the discussion on the solution generator algorithm that enables software agents to generate solutions and rank them from 1st to nth solution for the negotiation stage of the operation. The solution generator algorithm consists of three steps which are, review solutions, rank solutions, and form ranked solutions. For validation purpose, we present a scenario that utilizes the proposed algorithm to rank solutions. The validation shows that the algorithm is promising, however, it also highlights the conflict between different parties that needs further negotiation action.

Keywords

Intelligent Software Agent, Multi-agent Systems, Agent and Negotiation, Automated Negotiation, Value Management.

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I. Introduction

In build engineering and construction domains, deciding on a new project depends upon a company's strategy. If the strategy is based on a decision by a stakeholder, then it takes a shorter time to decide. However, such decision has no significance in terms of value management, because the decision-making process does not include other experienced stakeholders that have different backgrounds.

A project manager usually cares more about the cost and schedule of a project than the function while a design manager is more concerned about the function than the cost. Thus, for any decision to be made regarding a new project, stakeholders must propose an optimal solution. However, a problem may arise when stakeholders propose many solutions. In such a situation, stakeholders need to negotiate on the proposed solutions and agree on an optimal solution. But the negotiation may not be easy and smooth because when stakeholders possess different backgrounds, often their views about an optimal solution for a particular project are different. Such differences cause conflicts in arriving at a decision. In addition, stakeholders may work at different branches throughout the country or other parts of the world which make a meeting for decision more difficult and costly. While applying Value Management on decision making in the construction domain is useful, it faces communication difficulties between stockholders and conflicting issues that require negotiation.

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We attempt to overcome these difficulties by developing a framework for automated multi-agent negotiation for decision making based on value management in the construction domain. This paper is an extension to our work in the concepts of automated multi-agent negotiation [1, 2, 29].

The framework in [1, 2, 29] enables software agents to conduct negotiations and autonomously make value-based decisions. The framework consists of three main components which are, solution generator algorithm, negotiation algorithm, and finally conflict resolution algorithm. This paper focuses and extends the discussion on the solution generator algorithm that enables software agents to generate solutions and rank them from 1st to nth solution for the next stage of the negotiation operation. The solution generator algorithm consists of three steps which are, review solutions, rank solutions, and form ranked solutions. For validation purpose, we present a scenario that utilizes the proposed algorithm to rank solutions. The validation shows that the algorithm is promising, however, it also highlights the conflict between different parties that needs further negotiation action.

While this work is inspired by the work of Utomo [3], his study is only in conceptual level and lacks a complete negotiation process that aids an agent to interact and negotiate with other agents and respond to its environment and eventually influences its autonomy level in decision making.

II. Related Work

In this section, we discuss two prominent topics of this research which are value management and application of negotiation in multi-agent systems.

Value Management (VM) is defined as “a structured, organized team approach to identify the functions of a project, product, or service that will recognize techniques and provide the necessary functions to meet the required performance at the lowest overall cost” [4]. Utomo et al. [3] defined VM as one of the decision methodologies that include a multi-disciplinary, team-oriented approach to problem solving [5]. Therefore, negotiation plays an important role on VM using a value-based group decision [3]. VM is based on a data collection method from reliable resources and functional requirements to fulfill the needs, wants and desires of customers [3].

The application of VM in decision making has been reported by many researchers [3, 6, 7]. One of the techniques that is relevant to VM is weighting and scoring in which a decision needs to be made in selecting an option from a number of competing options, and the best option is not immediately identifiable [3, 8, 9].

Intelligent software agents have been widely used in distributed artificial intelligence and due to their autonomous, self-interested, rational abilities [11, 12, 13, 14, 15, 16], and social abilities [17, 18, 19, 20], agents are well-suited for automated negotiation on behalf of humans [10]. According to Kexing [10], automated negotiation is a system that applies artificial intelligence and information and communication technology to negotiation strategies, utilizing agents and decision theories.

Numerous research have discussed negotiation on multi-agent systems in various domains [21, 22, 23, 24, 25]. Coutinho et al. [26] proposed a negotiation framework to serve collaboration in enterprise networks to improve the sustainability of interoperability within enterprise information systems. Utomo [3] presented a conceptual model of automated negotiation that consists of a negotiation methodology and an agent-based negotiation. Dzeng and Lin [27] presented an agent-based system to support a negotiation between constructors and suppliers via the Internet. Anumba et al. [28] proposed a collaborative design of light industrial buildings based on multi-agent systems to automate the interaction and negotiation between the design members. Ren et al. [22] developed a multi-agent system representing participants, who negotiate with each other to resolve construction claims.

III. A Conceptual Framework for Value Decision Making based Automated Negotiation

A decision made by an agent goes through several processes. These processes work by gradually reducing candidate solutions of a project until a single solution is reached. Consequently, in this work, the process of nominating a single solution from a set of solutions is called decision-making.

There are three main processes in decision-making for a specific project, which are propose solutions, negotiate solutions and handling conflicting outcomes (conflict resolution).

Figure 1 shows the flowchart of the decision-making process as described above. The process starts when agents receive a new project. The agents first propose solutions in ranked order. They then negotiate these solutions. If they agree upon a single solution, then the decision is made, otherwise, the conflict resolution process takes over to drop the weak and risky solutions. If the outcome of the conflict resolution process is a single solution then the decision is made. Otherwise, the agents negotiate the outcome of the conflict resolution process. Ultimately, one coalition’s solution is accepted.

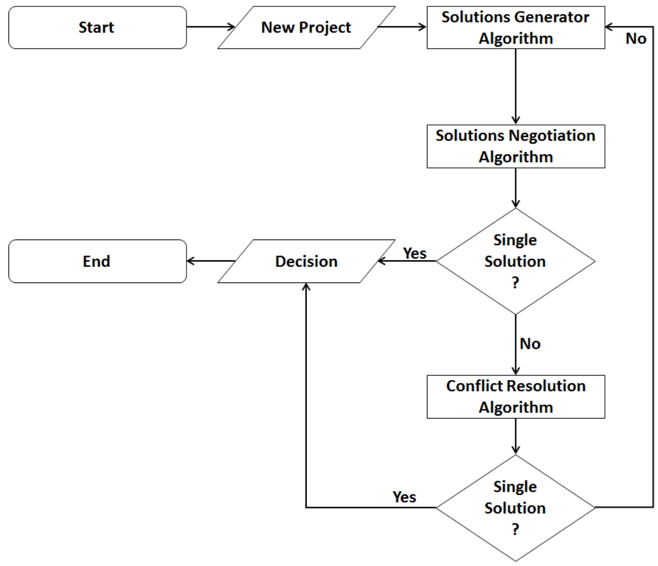

Fig. 1. Decision Making Process.

IV. Solutions Generator

A. Overview and Definitions

In this section, we discuss the preliminary issues in proposing an algorithm for software agents to generate solutions and rank them from 1st to nth solution for the negotiation stage of the operation.

The proposed solution generator algorithm (A_{SG}) is based on two parameters, which are Cost and Function. In real situations, various stakeholders have different level of interest about the cost and function parameters based on their positions and values they uphold. Thus, those stakeholders appraise their solutions based on their interest level on these parameters. For example, in the construction domain, a Design Manager cares more about the function in contrast with a Project Manager who cares more about the cost, while a Facility Manager’s interest is in between the Design and Project Managers’ interests. Therefore, the Design Manager normally attempts to find a solution that provides high function, whereas the Project Manager normally attempts to find a solution that provides low cost. The Facility Manager attempts to find a moderate solution that provides acceptable cost and function.

Definition 1: A Stakeholder, S, is a person that has an ability and authority to propose solutions for a particular issue and contribute in the decision for that issue’s solution. In this work, a software agent represents a stakeholder. If α_S is a stakeholder agent, D is a decision, L is a solution, then,

$$\forall \alpha_S \; \forall D \; \exists L \; (\text{generate}\,(\alpha_S, L) \land \text{contribute}\,(\alpha_S, D))$$

which means that for all stakeholder agents and for all decisions, there exist solutions, which stakeholder agents generate and contribute in the decision.

Definition 2: A Single Solution, L_S, is a result of agents’ negotiation to solve a particular problem. Initially, each agent ranks the proposed solutions from 1st to nth solution, where n is any natural number. After negotiation, the agents produce a single solution. The agents rank the solutions based on the parameters of cost and function.

Definition 3: A Cost, C, is the price of completing a specific item of a project. A Cost is ranked from low to high based on an original total amount of a project. The minimum (lowest) cost contributes to the highest rank in the solution and vice versa. If C_{MAX} is the maximum

1st (Optimal) CMIN , FMAX	2nd CMIN , FMAX-n	3rd CMIN , FMAX-2n	4th CMIN , FMIN
5th CMIN+n, FMAX	6th CMIN+n, FMAX-n	7th CMIN+n, FMAX-2n ...	8th CMIN+n, FMIN
. . .			
9th CMAX, FMAX	10th CMAX, FMAX-n	11th CMAX, FMAX-2n	nth CMAX, FMIN

Fig 2. Complete track of cost route.

1st (Optimal) FMAX, CMIN	2nd FMAX, CMIN+n	3rd FMAX, CMIN+2n	4th FMAX, CMAX
5th FMAX-n, CMIN	6th FMAX-n, CMIN+n	7th FMAX-n, CMIN+2n ...	8th FMAX-n, CMAX
. . .			
9th FMIN, CMIN	10th FMIN, CMIN+n	11th FMIN, CMIN+2n	nth FMIN, CMAX

Fig 3. Complete track of function route.

(highest) cost, C_{MIN} is the minimum (lowest) cost, n is any natural number, then,

$$C_{MIN}^{MAX} = C_{MIN} \quad C_{MIN+n} \quad C_{MIN+2n}, \ldots\ldots, \quad C_{MAX} \tag{1}$$

Definition 4: A Function, F, is the measure of usefulness of an entity in fulfilling its purpose. It is a solution's quality measurement for a specific project. A Function is ranked from high to low based on its useful effect on a solution. The maximum function contributes highly to the solution rank and vice versa. If F_{MAX} is the maximum function, F_{MIN} is the minimum function, then,

$$F_{MAX}^{MIN} = F_{MAX}, \ F_{MAX-n}, \ F_{MAX-2n}, \ldots\ldots, \ F_{MIN} \tag{2}$$

B. Solution Routes Method (SRM)

We identify three routes to generate ranked solutions, as follows:

- **Cost Route (R_C):** This route is preferred by agents (stakeholders) who care more about the cost, e.g. Project Manager. From Eq. 1 and 2 since this route emphasizes more on the cost, then the first rank solution starts with the minimum cost, C_{MIN}, and maximum function, F_{MAX}, as an optimal solution. However, the optimal solution (C_{MIN}, F_{MAX}) is the same for all agents' types e.g. Design Manager, Project Manager and so on, but it depends if such solution exists. If this solution does not exists, then the next optimal solution attempts to keep the cost low with reduced function (C_{MIN}, F_{MAX-n}). This route progresses with decreasing function until the minimum acceptable function is found (C_{MIN}, F_{MIN}). An alternative cost route increases cost to C_{MIN+N} while maintaining the maximum function F_{MAX}, (C_{MIN+N}, F_{MAX}). If no optimal solution is found, the cost cycle is repeated with reduced function. The completed track of cost route is as shown in Figure 2.
- **Function Route (R_F):** This route is preferred by agents that care more about the function, e.g. Design Manager. Since this route emphasizes more on the function, then the first rank solution starts with the maximum function, F_{MAX}, and minimum cost, C_{MIN} as an optimal solution. If the optimal solution is not found, the next optimal solution attempts to maintain the maximum function with increased cost (F_{MAX}, C_{MIN+n}). This route progressively increases the cost until an optimal solution is found or the maximum acceptable cost (F_{MAX}, C_{MAX}) is reached. An alternative function route progressively decreases function to F_{MAX-n} while maintaining the minimum cost C_{MIN}, (C_{MIN+n}, F_{MAX}). If no solution is found, the function cycle is repeated with reduced cost. The complete track of the function route is as shown in Figure 3.
- **Mixed Route (R_M):** This route is preferred by agents that moderately care about both the cost and function, e.g. Facility Manager. This route accepts both earlier mentioned routes' solutions. For example, the two solutions (C_{MIN}, F_{MAX-N}; F_{MAX}, C_{MIN+N}) are acceptable, an agent from this type selects the highest weightage solution (see (3)), which we shall discuss in the next section.

$$R_M = \left(R_C \vee R_F\right) \tag{3}$$

Figure 5 shows the solution routes where the blue line represents the function route, red line represents the cost route, and green line represents the mixed route. The function route takes the horizontal direction, the solutions' rank of which is represented by 1st, 2nd, 3rd in blue color. The cost route takes the vertical direction, the solutions' rank of which is represented by 1st, 2nd, 3rd in red color. The mixed route takes the oblique direction, the solutions' rank of which is represented by 1st, 2nd, 3rd in red and blue colors.

C. The Solutions Generator Algorithm (A_{SG})

The A_{SG} algorithm consists of three steps as shown in Figure 4. We present these steps as follows:

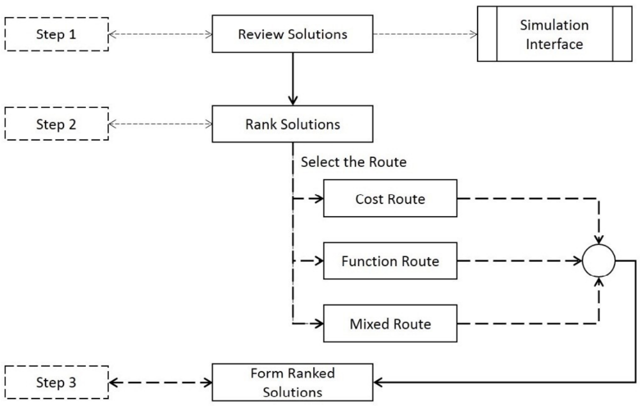

Fig. 4. The Solutions Generator Algorithm (A_{SG}) Process.

Step1: Review Solutions, agents first review solutions.

Step 2: Rank Solutions, each agent selects a suitable route by using the Solution Route Method (SRM) to rank solutions from 1st to nth.

Step 3: Form Ranked Solutions, after each agent has selected the suitable route according to its type and has ranked them, it forms the outcome as follows:

```
agentName (solutionNumber, solutionRank)
```

Algorithm 1 shows the process of Solution Generator Algorithm.

```
Begin
   ∃ α contributes in Decision Do
   exploit(α,A_SG),
   begin
      review(α, solutions)
         returns (∃ Solution, (C, F, T))
      rank(α, solutions)
         if care (α, C)
            grade (R_C , L_1^N ),
         else
         if care (α, F)
            grade (R_F , L_1^N ),
         else
         if care (α, (C,F))
            grade (R_M , L_1^N ),
         end if
   form(α, ranked solutions)
      agentName (solutionNumber, solutionRank)
   end
End
```

Algorithm 1. The Solution Generator Algorithm (A_{SG})

V. Scenario Validation

In this section, we present a scenario to clarify and validate the proposed Solution Generator algorithm. As the proposed algorithm is for the construction domain, we assume the task is building the Roof System. From the literature [3, 4], there are five possible solutions which are, Steel Structure, Pre-cast Structure, Timber System, Cast in Situ Reinforced Concrete, and Space Frame. In addition, the three characteristics, as defined in this paper, are Cost, Function, and Time and each characteristic has a value from low to high, 1 to 5. Three types of agents are simulated in this scenario, which are Design Manager, Facility Manager, and Project Manager. Figure 6 shows the set up specifications of the scenario.

Table 1 shows the assumed values of cost, function, and time for each solution,

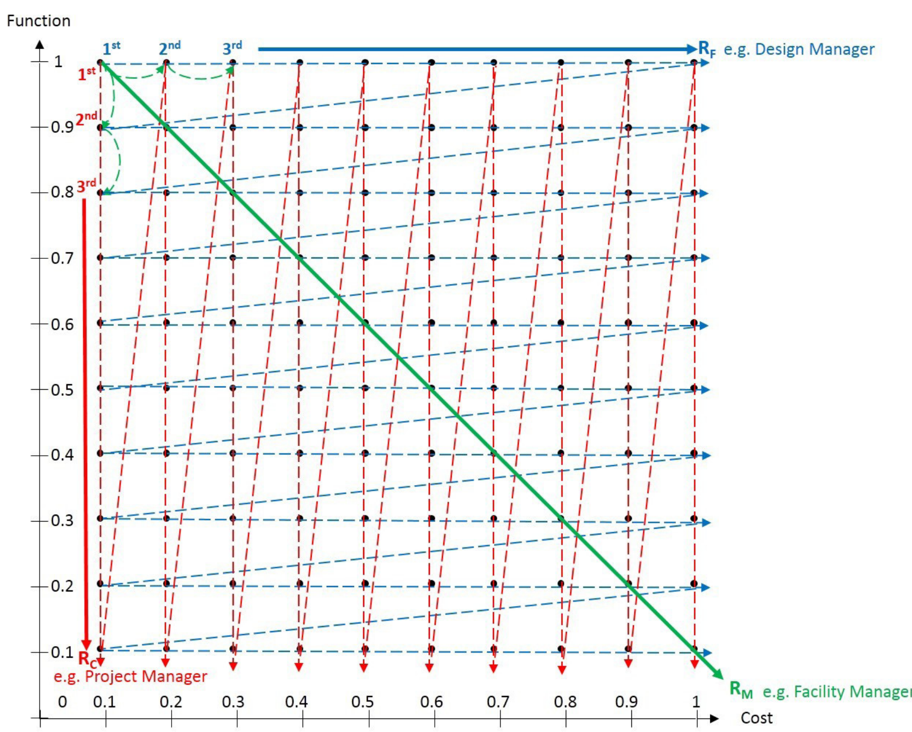

Fig. 5. Grid for Solution Algorithm.

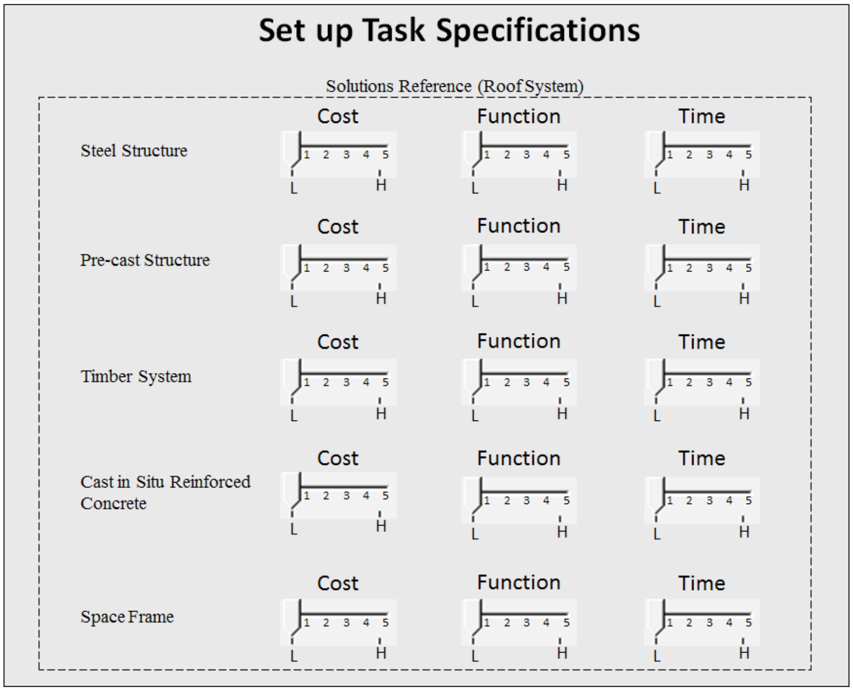

Fig 6. Set up task specifications.

TABLE I. The Assumed Values of Cost, Function, and Time for each Solution, the Scale from 1 represents Very Low to scale 5 represents Very High.

No	Solution	Cost	Function	Time
1	Steel Structure	4	5	5
2	Pre-cast Structure	3	2	4
3	Timber System	3	2	3
4	Cast in Situ Reinforced Concrete	5	3	4
5	Space Frame	4	4	3

According to [3, 4], a Project Manager cares more about the cost, and time, then function. While a Design Manager cares more about the Function then the cost and time. Facility manager has no conflict and can adapt with both Project and Design Managers. According to algorithm 1 and assumed values in Table 1, Table 2 shows the solutions ranking of each stockholder (agent).

Table 2 shows that the algorithm is able to rank the solutions according to each stakeholder/agent characteristic/ position. It also highlights a clear conflict between different stakeholders that needs further action.

VI. Conclusion and Future Work

This paper presents a solution generator algorithm to enable software agents to generate solutions and rank them from 1st to nth solution as preparation for the subsequent negotiation process. The developed algorithm consists of three steps which are, review solutions, rank solutions, and form ranked solutions. The algorithm works on ranking through three identified factors which are, the cost, function, and time and a stakeholder characteristic that inspired by the position e.g. Design Manager, Facility Manager, and Project Manager. We also present a validation scenario that deploys the developed algorithm to rank solutions. The validation shows that the algorithm is able to rank solutions according to each stakeholder/agent characteristic/position.

However, the scenario also highlights a clear conflict between different stakeholders/agents. Consequently, in our future work, we shall develop a negotiation algorithm and conflict resolution algorithm for agents to negotiate solutions and solve the conflict if any.

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