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Negotiation Support for Value-based Decision in Construction

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***Abstract*—**A Negotiation Support is required on a value-based decision to enable each stakeholder to evaluate and rank the solution alternatives before engaging into negotiation with the other stakeholders. This study demonstrates a process of negotiation support model for selection of a building system from value-based design perspective. The perspective is based on comparison of function and cost of a building system. Multi criteria decision techniques were applied to determine the relative value of the alternative solutions for performing the function. A satisfying option game theory are applied to the criteria of value-based decision which are LCC (life cycle cost) and function based FAST. The results demonstrate a negotiation process to select priorities of a building system. The support model can be extended to an automated negotiation by combining value based decision method, group decision and negotiation support.

***Keywords*—** NSS, Value-based, Decision, Construction.

I. INTRODUCTION

FRAGMENTATION is one of the major problems in the construction [1]. Often geographically distributed and different project participants need to collaborate to perform various activities. Collaboration needs negotiation used to be a more specifically conflict resolution and decision making [2, 3]. One of the problem arise is in the field of design decision management using a value analysis tool. As a process of multi disciplines and teamwork, negotiation becomes an important role in the process of value-based decision.

The research objective is to develop a conceptual modeling of negotiation system in multi criteria group decision making to the fundamental problems involved value-based decision of construction project, utilizing the multi agent system. Achieving the objective will give some significance and contribution, which are to provide an approach to better decision that will reduce cost and improve the value of construction projects and to contribute to the body of knowledge in decision science domain by make an advanced tools using negotiation for many decision tools. Another is in value management domain as an advanced method for creativity and analysis phase, since the practice of this knowledge is team work-based.

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II. THEORETICAL BACGROUND

A. Multi-Agent System

Multi-Agent System (MAS) is a fast developing information technology (IT) where a number of intelligent agents (IA), representing real world entities, co-operate or compete to reach the desired objectives of their owners [4]. Agents can be understood as an incremental extension of previous software technologies (Table I).

TABLE I
AGENT IN HISTORICAL PERSPECTIVE

Programming	How does a unit behave?	What does a unit do when it runs?	When does a unit run
Monolithic	External	External	External
Structured	Local	External	External
Object-oriented	Local	Local	External
Agent-oriented	Local	Local	Local

Source: Parunak, Baker, Clark [5]

Agents can be applied to filter data, interpret information, decision support, etc. There are various applications of agent technologies reported in many engineering fields in recent years. Nevertheless, there is very little research related to the applications of multi agent systems to problems in the construction. The research ranges from collaborative automated design [6, 7, 8,] to automated claim negotiation [9, 10]. Other applications are project performance [11] to project management [12, 13]. From the little amount of applications, none of them applied agent software to the problem of group choice in multi criteria decision making. Thus it still remains a theoretical and empirical gap between automated negotiation and automated group decision.

B. Negotiation Support System

Negotiation is the interactive communication among agents to facilitate a distributed search process. It can be used to effectively coordinate the behavior of agents in multi agent system [14, 15]. The automated negotiation means all parties involved are software agents while most current negotiation online still depends on human activities. Game theory based negotiation and multi-attribute utilizing theory based negotiation [16, 17] are theoretical approaches for automated negotiation. Morge and Beaune [18] wrote that a negotiation support system provides three kinds of functionality. Firstly, it facilitates the exchange of information among users. Secondly, it provides decision modeling or group-decision techniques. Finally, it provides negotiation support. All agents are registered by a middle agent transmitting proposals and counter proposals to other agents.

C. Value-based Decision

Value-based decision is an effort of Value Management (VM) process [19]. It improves the value of a facility through identifying opportunities to remove unnecessary costs [20]. VM is a structured and analytical process that seeks to achieve value by identifying all necessary functions at the lowest cost, while maintaining with the required levels of quality and performance [21]. It also means that VM identifies and eliminates unnecessary cost based on function analysis [22]. Unnecessary cost is the nature of design process. VM has been widely adopted in many countries over several decades as a very effective tool to meet the increasing demands for value enhancement by clients [23].

Kirk, et. al. [19] describes value based approach as new approach and methodology that involves using a multidisciplinary team including representatives of the owner, user, facility manager, and constructor. Thomas and Thomas [24] and [20] wrote that value analysis is an integrated full team approach. In the natural characteristic of construction, it means that a tool for decision team is necessary. Cooperation is the nature in team work on VM workshop [21]. Clemen [25] argued that decision analysis techniques can then applied to determine the relative value of the alternative solutions for performing function. Weighting and scoring technique are relevant in value analyses exercise [26] where a decision needs to be made in selecting an option. A paired comparison is held to determine the weighing to be given to each attribute [27]. Many studies in value-based decision apply multi criteria decision making, such as in assessment of exterior building wall [28], in material design of concrete [29] and in a modification of value engineering in petrochemical industry [30].

III. Methodology

The methodology for value-based group decision [31] combines value-based processes, multi-criteria decision-making process, and negotiation base coalition process. Fig. 1 represents these processes. It consists of three stages base on the process. The first two stages are referred to [32] and the last stage is based on coalition formation on Game Theory [33], [34].

The selection of roof system in this paper undergoes the following steps:

Stage 1: Determining the function and cost of each technical solution for roof system,

Stage 2: Each decision maker sets the weight of each criterion (win condition). Using Analytical Hierarchy Process (AHP) [35], every decision maker evaluates and ranks the support bridge options based on his/her win conditions and

Stage 3: Identifying agreement options that reflect the combined preferences of all decision makers by coalition. Finally, determining the 'best fit' options for each coalition on first negotiation round.

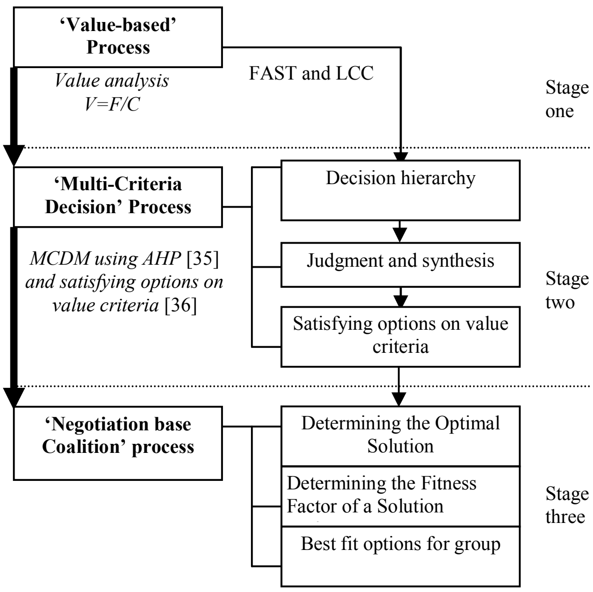

Fig. 1 The methodology for automated negotiation on value-based decision

IV. Result and Discussion

This case study involved making decision on highway guardrail model in a big housing complex developed by a private company. The decision attributes were set based on previous studies and standard function analysis in [32]. In this case, a highway guardrail was selected [37]. Five decision makers were involved namely Estate Manager, Project Manager, QS, In-house Designer, and Engineer. The original design was concrete guardrail with faces on both sides, reinforced with concrete footing. The guardrail composed of two elements: concrete and stone. The use of concrete in guardrail is to "ensure safety" and the causative function is to "provide barrier", while the use of stone is mainly only to "enhance appearance". After studying numerous possible functions of the guardrail, it was determined that the guardrail should fulfill the followings:

a. Protect traffic.
b. Prevent crossover by errant driver.
c. Deflect vehicle by minimizing (vehicle) damage.
d. Protect property.
e. Enhance appearance.
f. Reduce maintenance.

Since the face of the guardrail that is facing the road receives the impact of vehicle it is assigned the function "deflect vehicle". This face should be readily replaceable after damage. The "deflect vehicle" function could be accomplished at a lesser cost by using concrete. Since all functions are equally important, therefore the cost will be equally divided. However, if one function is significantly more important than the others then the total cost is assigned to that function and other functions will be assigned zero. On the other hand, if each function is weighted differently than the cost will be allocated according to their weightage. The cost of the concrete wall was divided into three functions, which were to protect traffic, prevent crossover, and reduce maintenance. The metal plate guardrail could achieve "protect traffic" on lower level roadway. The concrete wall footing was built below the grade to eliminate settlement by frost action, and the cost for it was allocated to the function "reduce maintenance".

A. Function Analysis and Life Cycle Cost

Function analysis of highway guardrail is presented in Fig. 2. It consists of four sequential steps in a function analysis. Figure 2 presents the FAST diagram of highway guardrail that consists of six functions to ensure safety by providing barrier. The functions are 'protect traffic', 'prevent crossover', 'deflect vehicle', 'protect property', 'reduce maintenance', and 'enhance appearance'.

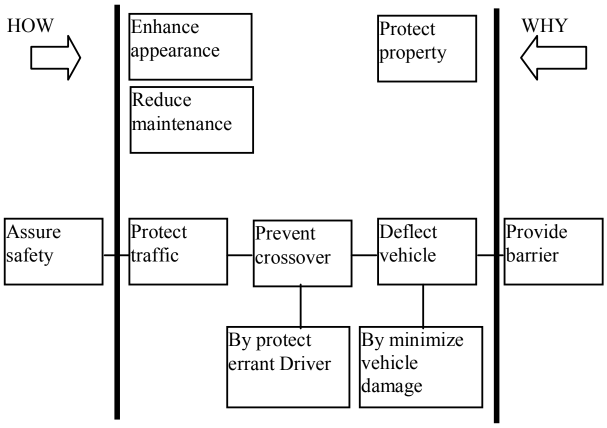

Fig. 2 FAST Diagram of Highway Guardrail

TABLE II
COST OF HIGHWAY GUARDRAIL

Cost category	Present Worth (1000USD)		
	a1 (metal plate)	a2 (concrete wall)	a3 (wooden-faced)
Initial	4900	2200	3400
LCC	160000	220000	350000

A cost driver of highway guardrail was calculated. Table II presents LCC and the initial cost.

B. Highway Gurdrail Selection

Fig. 3 shows that the goal of the problem on highway guardrail selection (G ="to assure safety by provide barrier") is addressed by some alternatives (A = a1; a2; a3) which are metal plate guardrail, concrete wall footing, and wooden-faced guardrail. The problem is split into evaluating criteria (f1; f2; f3; f4; f5; f6; c1; c2) which are protect traffic, prevent crossover, deflect vehicle, protect property, reduce maintenance, enhance appearance, initial cost and Life Cycle Cost (LCC). The result from the decision is presented in Table A-16. It shows the ranking of each guardrail solution based on individual stakeholder. Group ranking based on aggregation value of all stakeholder value is also presented in this table. This aggregation value will be compared with the value from the coalition formation among stakeholder.

C. Satisfying Option on Value Criteria

In this case study, initial cost and LCC are identified as 'Cost' and the other six functions which are 'protect traffic', 'prevent crossover', 'deflect vehicle', 'protect property', 'reduce maintenance', and 'enhance appearance' as 'Function'. Table III shows the selectability (Ps) and rejectability (Pr) that represent function and cost of technical solution of highway guardrail respectively. Based on the result presented on Table III, Fig. 4 provides a cross plot of function of the technical solution options. In this case the highest basic value is a2.

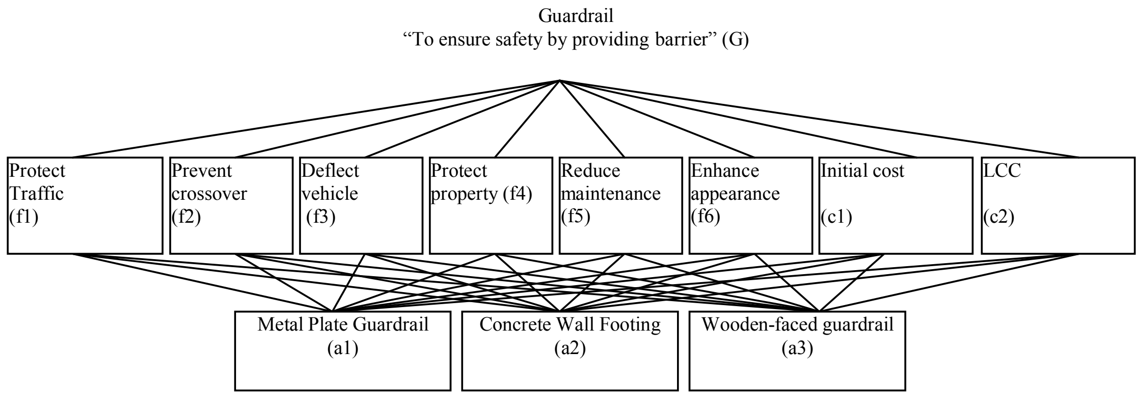

Fig. 3 Decision Hierarchy

TABLE III
COST AND FUNCTION OF HIGHWAY GUARDRAIL OPTIONS

	Cost				Function						Normalization	
	c1	c2	Total	Loss	f1	f2	f3	f4	f5	f6	Cost (Pr)	Function (Ps)
a1	0.230	0.581	0.811	0.378	0.277	0.633	0.297	0.122	0.633	0.122	0.241	0.347
a2	0.648	0.309	0.957	0.232	0.595	0.260	0.164	0.230	0.260	0.230	0.148	0.290
a3	0.122	0.110	0.232	0.957	0.129	0.106	0.539	0.648	0.106	0.648	0.611	0.363

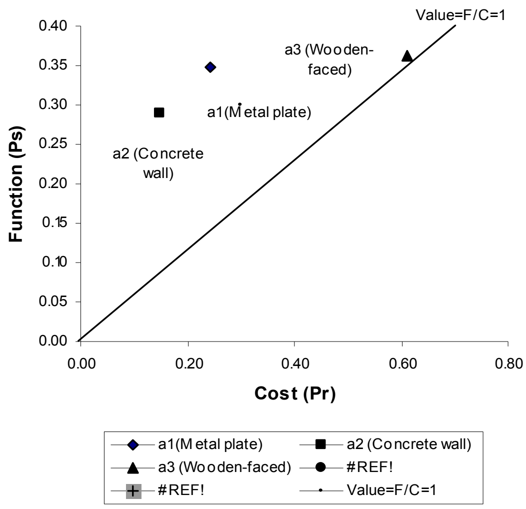

Fig. 4 Basic Value of Highway Guardrail Options

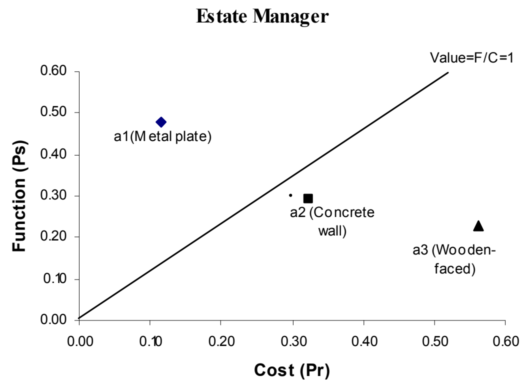

Fig. 5 Value of Highway Guardrail Options for Estate Manager

Fig. 5 provides cross plots of function and cost for Estate Manager, one of the five stakeholders. It means that the basic value of technical solution presented in Fig. 4 will be changed by preferences of stakeholders.

A. Agreement Options and Coalition

First step is determining the weighting factor (weight of preferences) of criteria for each stakeholder. Fig. 6 reveals different preferences among stakeholders

Second step is grading alternative for each evaluation criteria. Fig. 7 shows that a3 is the 'best fit' for f3, f4, and f6 meanwhile a1 is the 'best fit' for f2, f5, and c2. The 'best fit' solution for f1 and c1 is a2.

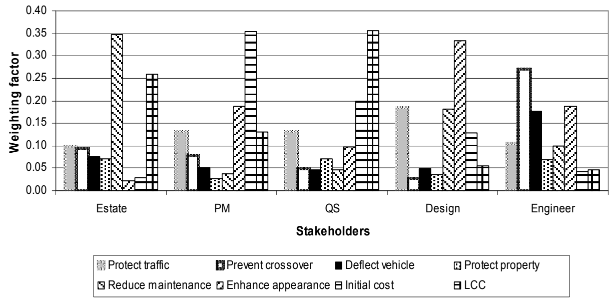

Fig. 6 Weight of Preferences for Each Stakeholder

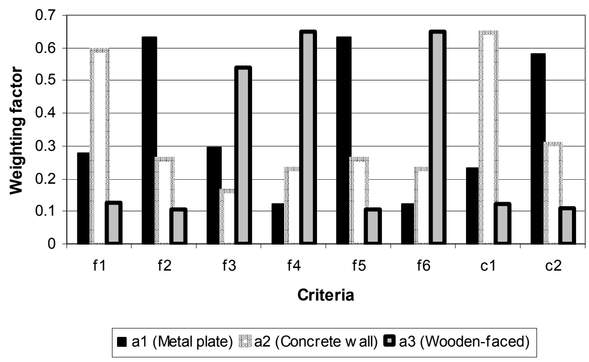

Fig. 7 Weighting Factor of Every Alternative for Each Criteria

Third step is scoring every alternative for each stakeholder**.** Fig. 8 shows that each stakeholder has different best option as a solution alternative.

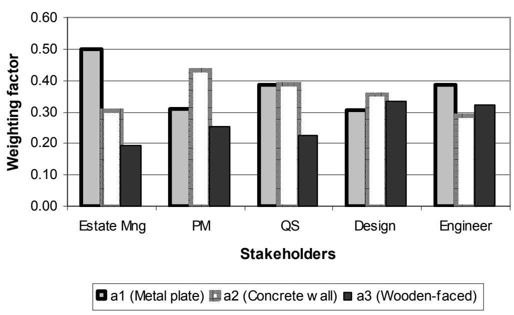

Fig. 8 Weighting Factor of Every Alternative for Each Stakeholder

Fourth step is determining payoff optimum. Table VI shows process and result for Cost payoff optimum.With the same method, Function payoff optimum is also resulted.

TABLE VI
COST PAYOFF OPTIMUM

Coalition	Alternatives			Payoff Optimum	
SH1+2+3+4+5	a1	a2	a3	Max-min	Optimum
SH1	0.442	0.225	0.333	0.217	0.442
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.503
SH4	0.491	0.085	0.423	0.406	0.491
SH5	0.567	0.137	0.297	0.430	0.553
	2.363	0.865	1.772		2.363
SH1+2	a1	a2	a3	Max-min	Optimum
SH1	0.442	0.225	0.333	0.217	0.428
SH2	0.360	0.266	0.374	0.108	0.374
	0.802	0.491	0.707		0.802
SH2+3	a1	a2	a3	Max-min	Optimum
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.489
	0.863	0.418	0.719		0.863
SH3+4	a1	a2	a3	Max-min	Optimum
SH3	0.503	0.152	0.345	0.351	0.503
SH4	0.491	0.085	0.423	0.406	0.491
	0.994	0.237	0.769		0.994
SH4+5	a1	a2	a3	Max-min	Optimum
SH4	0.491	0.085	0.423	0.406	0.491
SH5	0.567	0.137	0.297	0.430	0.567
	1.058	0.222	0.720		1.058
SH1+2+3	a1	a2	a3	Max-min	Optimum
SH1	0.442	0.225	0.333	0.217	0.428
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.503
	1.305	0.643	1.052		1.305
SH2+3+4	a1	a2	a3	Max-min	Optimum
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.489
SH4	0.491	0.085	0.423	0.406	0.491
	1.354	0.503	1.143		1.354
SH2+3+5	a1	a2	a3	Max-min	Optimum
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.489
SH5	0.567	0.137	0.297	0.430	0.567
	1.430	0.554	1.016		1.430
SH2+4+5	a1	a2	a3	Max-min	Optimum
SH2	0.360	0.266	0.374	0.108	0.360
SH4	0.491	0.085	0.423	0.406	0.491
SH5	0.567	0.137	0.297	0.430	0.567
	1.418	0.488	1.094		1.418
SH3+4+5	a1	a2	a3	Max-min	Optimum
SH3	0.503	0.152	0.345	0.351	0.503
SH4	0.491	0.085	0.423	0.406	0.491
SH5	0.567	0.137	0.297	0.430	0.567
	1.561	0.374	1.066		1.561
SH1+2+3+4	a1	a2	a3	Max-min	Optimum
SH1	0.442	0.225	0.333	0.217	0.428
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.503
SH4	0.491	0.085	0.423	0.406	0.491
	1.796	0.728	1.476		1.796
SH2+3+4+5	a1	a2	a3	Max-min	Optimum
SH2	0.360	0.266	0.374	0.108	0.374
SH3	0.503	0.152	0.345	0.351	0.489
SH4	0.491	0.085	0.423	0.406	0.491
SH5	0.567	0.137	0.297	0.430	0.567
	1.921	0.640	1.439		1.921

Last step is analyzing the best fit options for every coalition and grand coalition**.** The results of analyzing the best fit option using coalition algorithm are presented on Table VII. It shows the priorities that followed the 'best fit' options process including the priorities of the technical solution for highway guardrail in the first negotiation round.

TABLE VII
RANKING OF THE SOLUTION FOR EACH COALITION

	Alternative ranking and coalition	Alternatives		
		a1	a2	a3
1	0	0	0	0
2	SH 1 (Estate Manager)	1st	2nd	3rd
3	SH 2 (Project Manager)	2nd	1st	3rd
4	SH 3 (QS)	2nd	1st	3rd
5	SH 4 (In-house Designer)	3rd	1st	2nd
6	SH 5 (Engineer)	1st	3rd	2nd
7	Coalition SH1 and SH2	3rd	2nd	1st
8	Coalition SH1 and SH3	2nd	3rd	1st
9	Coalition SH1 and SH4	1st	3rd	2nd
10	Coalition SH1 and SH5	3rd	2nd	1st
11	Coalition SH2 and SH3	3rd	1st	2nd
12	Coalition SH2 and SH4	3rd	2nd	1st
13	Coalition SH2 and SH5	3rd	1st	2nd
14	Coalition SH3 and SH4	1st	2nd	3rd
15	Coalition SH3 and SH5	1st	2nd	3rd
16	Coalition SH4 and SH5	1st	2nd	3rd
17	Coalition SH1, SH2, and SH3	3rd	2nd	1st
18	Coalition SH1, SH2, and SH4	3rd	1st	2nd
19	Coalition SH1, SH2, and SH5	3rd	1st	2nd
20	Coalition SH1, SH3, and SH4	1st	2nd	3rd
21	Coalition SH1, SH3, and SH5	3rd	2nd	1st
22	Coalition SH1, SH4, and SH5	1st	3rd	2nd
23	Coalition SH2, SH3, and SH4	3rd	1st	2nd
24	Coalition SH2, SH3, and SH5	2nd	1st	3rd

25	Coalition SH2, SH4, and SH5	2nd	3rd	1st
26	Coalition SH3, SH4, and SH5	1st	2nd	3rd
27	Coalition SH1, SH2, SH3, SH4	3rd	1st	2nd
28	Coalition SH1, SH2, SH3, SH5	3rd	1st	2nd
29	Coalition SH1, SH2, SH4, SH5	1st	2nd	3rd
30	Coalition SH1, SH3, SH4, SH5	1st	3rd	2nd
31	Coalition SH2, SH3, SH4, SH5	3rd	1st	2nd
32	Coalition SH1, SH2, SH3, SH4, SH5	3rd	1st	2nd
RESULT		2nd	1st	3rd

V. Conclusion

In this paper, concrete wall footing (a2) was the best technical solution for 'ensuring safety by providing barrier' a2 was the 'best fit' solution for the group. The result from the first round of negotiation indicates that all solutions are chosen by more than one stakeholder and coalitions. This means that all solutions become possible solution for the highway guardrail. Observed on a3 (wooden-faced guardrail), the result is interesting. Even though this solution has no first priority by any stakeholder, this solution is chosen by many coalitions as the best fit option. On the next round of negotiation, stakeholder 1 and 5 can offer different preference by trade-off process. They can also decide to accept a2 as the best fit solution. Under this condition where all stakeholders agree with the result from first round, negotiation end.

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