World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:3, No:2, 2009

Agreement Options on Multi Criteria Group Decision and Negotiation

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***Abstract*—**This paper presents a conceptual model of agreement options on negotiation support for civil engineering decision. The negotiation support facilitates the solving of group choice decision making problems in civil engineering decision to reduce the impact of mud volcano disaster in Sidoarjo, Indonesia. The approach based on application of analytical hierarchy process (AHP) method for multi criteria decision on three level of decision hierarchy.

Decisions for reducing impact is very complicated since many parties involved in a critical time. Where a number of stakeholders are involved in choosing a single alternative from a set of solution alternatives, there are different concern caused by differing stakeholder preferences, experiences, and background. Therefore, a group choice decision support is required to enable each stakeholder to evaluate and rank the solution alternatives before engaging into negotiation with the other stakeholders. Such civil engineering solutions as alternatives are referred to as agreement options that are determined by identifying the possible stakeholder choice, followed by determining the optimal solution for each group of stakeholder. Determination of the optimal solution is based on a game theory model of n-person general sum game with complete information that involves forming coalitions among stakeholders.

***Keywords*—**Agreement options, AHP, agent, negotiation, multi criteria, game theory, and coalition.

I. Introduction

THE mudflow disaster in Porong Sidoarjo, East Java, Indonesia, has implicated many parties. For almost three years, a sea of hot mud has been gushing from the ground in Sidoarjo, East Java. The Friends of the Earth International [1] reported that infrastructure has been damaged extensively, including power transmission systems, toll roads, gas pipelines and national artery roads. Approximately 600 ha of land and villages were submerged, farmland was ruined, businesses and schools closed. Moreover, irrigation channels have been swamped by the mud, and drainage and drinking water pipes affected. Containment 'basins' or 'ponds' enclosing areas of land within earth walls were built. They were not a sustainable solution as heavy rains in the rainy season would cause the walls to collapse and ponds to overflow caused the flooding of more land and damaging infrastructure. As it became clear that construction of containment ponds couldn't keep up with the rate the mud was gushing from its underground source, it was decided to channel the mud into the Porong River and on to the sea (Madura Strait). Pumping of sludge into the sea, but the mud's viscosity hindered efforts to channel it into the sea.

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Decisions for reducing impact is very complicated since many parties involved in a critical time. Where a number of stakeholders are involved in choosing a single alternative from a set of solution alternatives, a group decision support is required to facilitate the solving problems in selection the best alternative decision for reducing impact of mud disaster. It based on a hybrid of analytic and artificial intelligent techniques. The analytic component utilizes a game theory model [2], [3] of an n-person-general sum game with complete information to determine the agreement option, while the knowledge-based (artificial intelligent) component is similar to the strategic negotiation proposed by Kraus [4].

II. Decision Model Formulating

The analytical hierarchy process (AHP) [5] is a powerful and flexible decision process. By reducing complex decisions to a series of one-on-one comparison, then synthesizing the result, AHP provides a clear rationale for it being declared the best decision. The AHP is a framework of logic and problem resolving achieved by organizing perceptions, feelings, judgments, and memories into a hierarchy of forces that influences decision result [6]. The AHP also can be used successfully with a group [7] and negotiation [8].

A. First Step: Constructing Decision Hierarchy

To obtain a good representation of a problem, it has to be structured into different components called activities. Fig. 1 shows that the goal of the problem (G ="to select the best alternative decision for reducing impact of mud disaster") is addressed by some alternatives (A = a1; a2; a3; a4; a5; a6) i.e. possible solutions. Each alternative are presenting combination of preference, + means good, - means bad and 0 means average. In this decision, +C1 means that the alternative is technically good, +C2 means that the alternative is not expensive, and +C3 means that implementation of the alternative will give good impact socially and environmentally. The problem is split into sub-problems (C1; C2; C3) which are criteria evaluating alternatives.

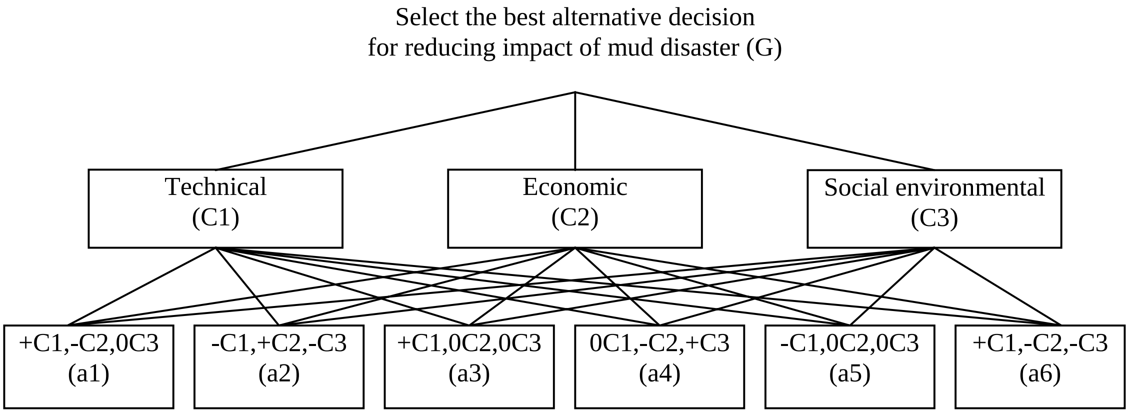

Fig. 1 Decision hierarchy to select the best alternative decision for reducing impact of mud disaster

TABLE I
STAKEHOLDERS DECISION BASED-ON THEIR OWN PREFERENCES

Stakeholder 1 (Community) weighting criteria		Alternatives					
		a1	a2	a3	a4	a5	a6
C1-technical	0.231614	0.063074	0.005492	0.039682	0.045996	0.015102	0.062267
C2-economic	0.071855	0.003848	0.037449	0.011846	0.004062	0.010472	0.004177
C3-socio-enviro	0.696531	0.10219	0.023156	0.105575	0.343326	0.091167	0.031118
SH1 weighting and rating of alternatives		0.169113	0.066097	0.157104	0.393384	0.116741	0.097562
		2nd	6th	3rd	1st	4th	5th
Stakeholder 2 (Government) weighting criteria		Alternatives					
		a1	a2	a3	a4	a5	a6
C1-technical	0.348304	0.094852	0.008259	0.059675	0.06917	0.02271	0.093639
C2-economic	0.148449	0.007951	0.077368	0.024474	0.008391	0.021635	0.00863
C3-socio-enviro	0.503247	0.073833	0.01673	0.076279	0.248054	0.065869	0.022483
SH2 weighting and rating of alternatives		0.176635	0.102357	0.160427	0.325616	0.110214	0.124751
		2nd	6th	3rd	1st	5th	4th
Stakeholder 3 (Engineer) weighting criteria		Alternatives					
		a1	a2	a3	a4	a5	a6
C1-technical	0.709338	0.19317	0.01682	0.12153	0.140868	0.04625	0.1907
C2-economic	0.21409	0.011466	0.111578	0.035296	0.012102	0.031202	0.012445
C3-socio-enviro	0.076572	0.011234	0.002546	0.011606	0.037743	0.010022	0.003421
SH3 weighting and rating of alternatives		0.21587	0.130944	0.168433	0.190713	0.087474	0.206566
		1st	5th	4th	3rd	6th	2nd
Stakeholder 4 (Sponsor) weighting criteria		Alternatives					
		a1	a2	a3	a4	a5	a6
C1-technical	0.083308	0.022687	0.001975	0.014273	0.016544	0.005432	0.022397
C2-economic	0.723506	0.038749	0.377073	0.119283	0.040898	0.105444	0.042059
C3-socio-enviro	0.193186	0.028343	0.006422	0.029282	0.095223	0.025286	0.008631
SH4 weighting and rating of alternatives		0.089779	0.385471	0.162837	0.152665	0.136162	0.073086
		5th	1st	2nd	3rd	4th	6th
Stakeholder 5 (NGO) weighting criteria		Alternatives					
		a1	a2	a3	a4	a5	a6
C1-technical	0.167946	0.045736	0.003982	0.028774	0.033352	0.01095	0.045151
C2-economic	0.080673	0.004321	0.042045	0.0133	0.00456	0.011757	0.00469
C3-socio-enviro	0.75138	0.110237	0.024979	0.113889	0.370361	0.098346	0.033568
SH5 weighting and rating of alternatives		0.160294	0.071007	0.155963	0.408274	0.121054	0.083409
		2nd	6th	3rd	1st	4th	5th

B. *Second Step: Making Judgments*

The relative importance of pairwise comparison could be: equal (1), moderate (3), strong (5), very strong, demonstrated (7) or extreme (9). Sometimes one needs compromise judgments (2; 4; 6; 8) or reciprocal values (1/9; 1/8; 1/7; 1/6; 1/5; 1/4; 1/3; 1/2). For pairwise comparisons between *n* similar activities with respect to the criterium c_k, a matrix Ac_k is a preferred form. If there are "*n*" items that need to be compared for a given matrix, a total of *n*(*n*-1)/2 judgments are needed. For each set of factors, a matrix "A" of pair-wise comparison can be derived. From the pair-wise comparison matrix, the eigenvector and the maximum eigenvalue can be calculated using the right eigenvector method by employing the following equation:

$$\lambda_{\max} = \sum_{j=1}^{n} \frac{AW}{nw_i} (i = 1,2,...,n)$$

Then the vector $\bar{w}_i$ is derived by the following equations:

$$\bar{w}_i = \sqrt[n]{m_i} \left(i = 1,2,...,n\right)$$

Afterwards, the normalization of vector $\bar{w}_i$ will determine the weights of alternatives and decision criteria by:

$$w_i = \frac{\bar{w}_i}{\sum_{i=1}^{n} \bar{w}_i} (i = 1,2,...,n)$$

C. *Judgment Synthesis*

The AHP [5] measures the overall consistency of judgments by means a consistency ratio: CRA_{ck} = CIA_{ck} =RC_n. The higher the consistency ratio, the less consistent the preferences are. The value of the consistency ratio should be 10% or less. Under this condition the priorities can be calculated.

According to the AHP the best alternative (in the maximization case) is indicated by the following relationship.

$$A*_{AHP-score} = \max_i \sum_{j=1}^{n} a_{ij} w_{j}, \quad \text{for } i = 1,2,3,\ldots,m$$

TABLE I shows the result from stakeholder judgment and the synthesis from AHP.

III. Negotiation Process

Negotiation support is the interactive communication to facilitate a distributed search process. It can be used to effectively coordinate the behavior of agents in multi agent system [9,10,11]. Five stakeholders are involved and gave their own preference. Kraus [12] wrote that two approaches use to the development of theorems relating to the negotiation process. The first is informal theory, which attempt to identify possible strategies for a negotiator and to assist a negotiator in achieving optimal results. The other approach is the formal theory of bargaining originating with the work of John Nash, who attempted to construct formal models of negotiation environments. Fig. 2 illustrates the system architecture negotiation adapted from Morge and Beaune [13]. Here, SH1 is stakeholder in community domain, SH2 is stakeholder in government domain, SH3 is stakeholder in expert engineer domain, SH4 is stakeholder in sponsor domain, and SH5 is stakeholder in NGO (Non Government Organization) domain. Stakeholders present different side of preference. Nevertheless the protocol of negotiation in this group decision was developed as a cooperative environment.

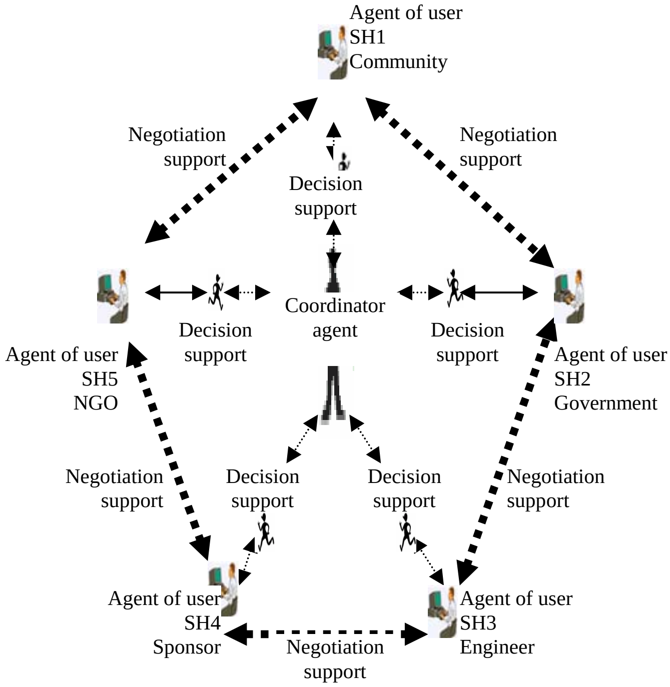

Fig. 2 System Architecture Negotiation (Adapted from Morge and Beaune, [13])

A. *Distributed Rational Decision Making*

In this system, negotiation consists in an exchange of proposals between agents. The agent *i* propose its alternative to agent *j*. This alternative should be the most preferred alternative for agent *j* (with the highest priorities with respect to the goal) to be immediately accepted. If not, agent *j* tries to change the preference order of alternatives by adjusting judgments in pairwise comparison matrixes. If the proposal is not accepted, it will send a counter-proposal. The negotiation will be stopped, when an alternative is approved unanimously.

B. *Determination of Agreement Options*

As the negotiation progress, the agent user preferences of the evaluation criteria change, leading to changing score of the alternative civil engineering solution for reducing impact disaster, and changing membership and size of the set of agreement options. Three stages are conducted to determine agreement options that are;

(1) Determine the weighting factor (weight of preferences) of criteria for each decision-maker. Fig.3 reveals different preferences between stakeholders.

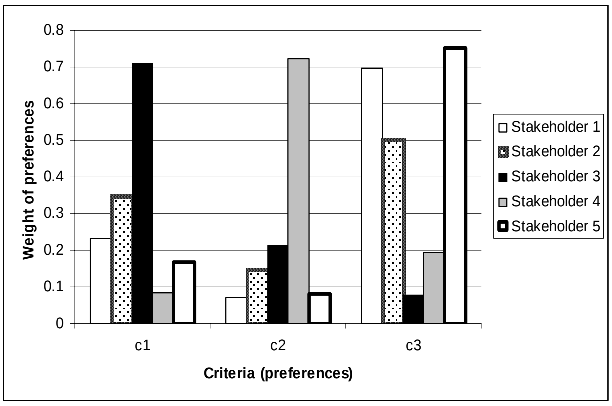

Fig. 3 weight of preferences for each stakeholder

(2) Grade of alternative for each evaluation criteria. Fig. 4 presents that on criteria technical, alternative 1 and 5 are the best. It is different for criteria economic and social environmental which are alternative 2 and alternative 4 as the best for economic and social environmental consideration respectively.

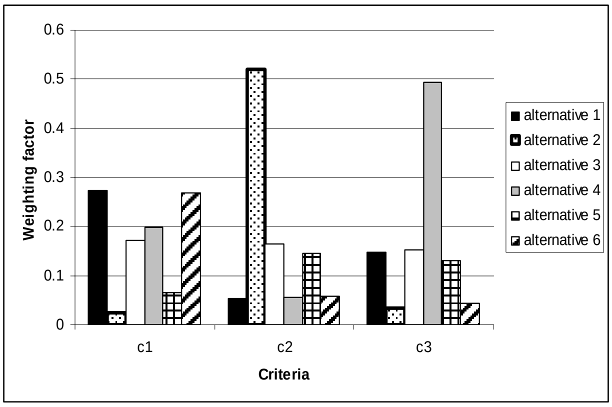

Fig. 4 Weighting factor of every alternative for each criteria

(3) Score of every alternative for every decision-maker. Fig.5 shows that stakeholders have different best option as a solution alternative. But only three alternatives as the best options, that are a1, a2, a4.

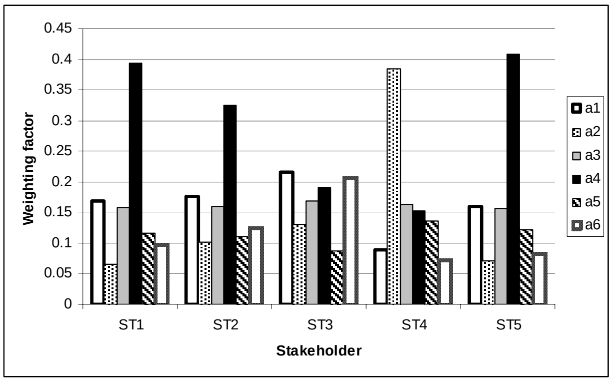

Fig. 5 weighting factor of every alternative for each stakeholder

C. Analysis of Agreement Options and Coalition

Each of decision-maker uses an alternative solution as a baseline. They usually use the best for the decision-maker. However they can also provide other solution as the baseline performance. Formation of coalition for executing tasks is useful for distributed problem solving (DPS) environments [12]. It is common for the stakeholders to form coalition during negotiation in order to increase their individual welfare. Game theory techniques for coalition formation have been applied. Work in game theory describes which coalition will form in n-person games under different setting and how the players will distribute the benefits of the cooperation among themselves. Instead of the strategic approach that uses equilibrium analysis, coalition formation is often studied in a more abstract setting called a characteristic function game [14]. Coalition formation in characteristic function game includes three activities:

1. Coalition structure generation:
   This game with five agents, there are 24 possible coalitions: {1}, {2}, {3}, {4}, {5}, {1,2}, {1,3}, {1,4}, {1,5}, {2,3}, {2,4}, {2,5}, {3,4}, {3,5}, {4,5},{1,2,3}, {1,2,4}, {1,2,5}, {1,3,4}, {1,3,5}, {1,4,5}, {1,2,3,4}, {1,2,3,5}, {1,2,3,4,5}.
2. Solving the optimization problem of each coalition.
   The coalition's objective is to maximize value. Under unlimited and costless computation, each coalition would solve its optimization problem, which would define the value of that coalition.
3. Dividing payoff/the value of the generated solution among agents in a fair and stable way so that the agents are motivated to stay with the coalition structure rather than move out it. Several ways of dividing payoffs have been proposed in the literature [15].

By adapted model of coalition formation from Wanyama [16] and Wanyama and Far [17], on this paper, coalition formation model works in the context of multi-criteria group decision making. Agents select the solutions with the highest score as the offers to their negotiation opponents. At the end of every negotiation round, each agent adjusts its preference value function in a way so to increase the utility associated with the solution that the agent regards to be the "best-fit" for its coalition.

The coalition table (TABLE II) reveals starts of the first negotiation round. Some of solutions will not an option if no individual stakeholder or coalition of stakeholders desires to select it. In this case alternative solution a5 and a6 are not an options. And table also indicates the alternative solution that will be determined to be the best fit solution. In this problem on the first negotiation round, a3 is the 'best fit' solution. In the context of Game theory, Bialas [18] present proof that the information of coalition among stakeholders provides a means for achieving Pareto-optimality, since every member of a coalition acts in such a way as to benefit the entire coalition.

TABLE II
WEIGHTING OF EACH ALTERNATIVE AND COALITION

Alternative ranking and coalition	Alternatives					
	a1	a2	a3	a4	a5	a6
SH 1 (Community)	2nd	6th	3rd	1st	4th	5th
SH 2 (Government)	2nd	6th	3rd	1st	5th	4th
SH 3 (Engineer)	1st	5th	4th	3rd	6h	2nd
SH 4 (Sponsor)	5th	1st	2nd	3rd	4th	6h
SH 5 (NGO)	2nd	6h	3rd	1st	4th	5th
Coalition SH1 and SH2	1st	6th	2nd	4th	3rd	5th
Coalition SH1 and SH3	3rd	4th	1st	2nd	6th	5th
Coalition SH1 and SH4	4th	5th	1st	2nd	6th	3rd
Coalition SH1 and SH5	3rd	4th	2nd	1st	5th	6th
Coalition SH2 and SH3	3rd	2nd	1st	5th	4th	6th
Coalition SH2 and SH4	3rd	6th	1st	5th	2nd	4th
Coalition SH2 and SH5	3rd	6th	1st	5th	2nd	4th
Coalition SH3 and SH4	3rd	6th	1st	2nd	4th	5th
Coalition SH3 and SH5	3rd	6th	1st	5th	2nd	4th
Coalition SH4 and SH5	4th	6th	1st	5th	3rd	2nd
Coalition SH1, SH2, and SH3	2nd	4th	1st	5th	3rd	6th
Coalition SH1, SH2, and SH4	4th	5th	1st	6th	2nd	3rd
Coalition SH1, SH2, and SH5	2nd	5th	3rd	1st	4th	6th
Coalition SH1, SH3, and SH4	3rd	5th	1st	6th	2nd	4th
Coalition SH1, SH3, and SH5	4th	3rd	1st	6th	2nd	5th
Coalition SH1, SH4, and SH5	4th	5th	1st	6th	2nd	3rd
Coalition SH1,2,3,4	4th	5th	1st	6th	2nd	3rd
Coalition SH1,2,3,5	6th	3rd	1st	5th	2nd	4th
Coalition SH1,2,3,4,5	2nd	5th	1st	6th	4th	3rd

IV. DISCUSSION

The rationality of negotiating is implemented with a utility function given by AHP [5]. The enumeration of alternatives and the development of decision hierarchy help the group to debate the problem. This agreement options process provides addition functionalities to negotiate a joint representation of the problem. All stakeholders share the same goal (G = c0) but each of them has its own set of activities, alternatives (Ai) or criteria (Ci). Wanyama and Far [19] wrote that sets of activities could move, expand and, retract during negotiation.

a. Stakeholder of multi criteria decision making problems such as selecting the best civil engineering solution for reducing impact disaster usually evaluate the alternative solution from different perspective, making it possible to have a dominant solution among the alternatives.
b. Each stakeholder needs to identify the goals that can be optimized, and those that can be compromised in order to reach agreement with other stakeholders.
c. Model for identifying agreement options acts as a solution filter, so that only promising solution (agreement options) are availed to stakeholders for detail negotiation.

V. CONCLUSION

This agreement options can help stakeholders to evaluate and rank the solution alternatives before engaging into negotiation with the other stakeholders. Based on a cooperative environment, a negotiation support can be developed. Future research in the application of this methodology in many field of engineering decision will build a wide range of knowledge to solve the theoretical and practical gap in decision and negotiation

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