AGREEMENT OPTIONS FOR VALUE-BASED GROUP DECISION ON BUILDING SYSTEM SELECTION

by Christiono Utomo[a]

ABSTRACT

This paper presents a conceptual model of agreement options on negotiation support to facilitate the solving of group choice decision making problems in civil engineering. Group decision in construction is very complicated since many parties involved. 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 preferences, experiences, and background. Such civil engineering solutions as alternatives are referred to as agreement options, this paper describes a process of group decision and negotiation on building system selection for highway guardrail by assuring safety to provide barrier. The decision consists of three alternatives solution, three stakeholders and ten criteria. 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 option; ahp; multi criteria; game theory; coalition.*

INTRODUCTION

Value-based decision[1] is an organized effort directed in value analysis techniques to analyze the functions of systems. As a systematic, multi disciplinary and structured methodology, value analysis aims to improve the value through identifying opportunities to remove unnecessary costs. Over few years, significant progress has been made in performance evaluation techniques, including analytical and simulation methods.

The rationality of negotiating is implemented with a utility function given by Analytical Hierarchy Process (AHP)2. The enumeration of alternatives and the development of decision hierarchy help the group to debate the problem. Agreement options process provides addition functionalities to negotiate a joint representation of the problem. All stakeholders share the same goal but each of them has its own set of activities, alternatives (ai) or criteria (Ci). Model for identifying agreement options acts as a solution filter, so that only promising solution (agreement options) are availed to stakeholders for detail negotiation.

Formation of coalition for executing tasks is useful both in multi agent system (MAS) and distributed problem solving (DPS) environments[3]. 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.

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RESEARCH SIGNIFICANCE

Decision algorithms were based on the cooperative game theory to develop the agreement options and coalition formation. Similar researches were done in this area but this research is the first to apply value analysis of function and cost as a basis for trade off analysis.

The methodology in this research can assist to conduct negotiation process in practices. It means that this methodology contributes to the body of knowledge by adding a negotiation process to the practice. The results from its application on building system selection also contribute to the group decision and negotiation process of the American Society for Testing and Materials (ASTM) Standard, Book of Building Economics[25].

The coalition algorithms developed in this research can be used for any development research on group decision and negotiation within the construction industry. Negotiation support model arising from this research gives contribution for a better application of multi-discipline and teamwork in building system selection.

VALUE-BASED DECISION

Kirk, et al[4] 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[5] and Kelly[1] wrote that value analysis is an integrated full team approach to identifying the need of the project and developing alternative ways of delivering these needs at the appropriate price.

Value analysis identifies the criteria to determine whether or not a function is being performed correctly. Each criterion then needs to be weighted according to its importance to purpose. Clemen[6] argued that decision analysis techniques can then applied to determine the relative value of the alternative solutions for performing the function. Weighting and scoring technique are relevant in value analyses exercise[7] where a decision needs to be made in selecting an option from a number of competing options. A paired comparison is held to determine the weighing to be given to each attribute[8]. Many studies in value-based decision as a decision alternative using multi criteria decision making, such as Al-Hammad and Hassanain[9] in assessment of exterior

Table 1. Computer Aids in Value based Group Decision

Name and Description	Year	Application
Shen and Brandon[13] ESVMDOB (Expert System for Value Management in the Design of Office Building)	1991	Expert system
Yip Man Kit [14] ESPASD (An Expert System for Preliminary Air Conditioning System Design). It uses selection decision methods such as VE, QFD and MCDM.	2000	CLIPS
M A. Dahim Hussein[15] VEESSHD (Value Engineering Expert System in Suburban Highway)	2001	ANN, CLIPS
Qiping Shen, J Chung, H. Li, LiYin Shen[16] GSS for VE (Group Support System for Improving Value Management Studies in Construction)	2004	Web-based. HTML and ASP language.
Shicao Fan, Qiping Shen, John Kelly[17] Interactive Value Management System), a GDSS (group decision support system)	2008	Web-based electronic brainstorming

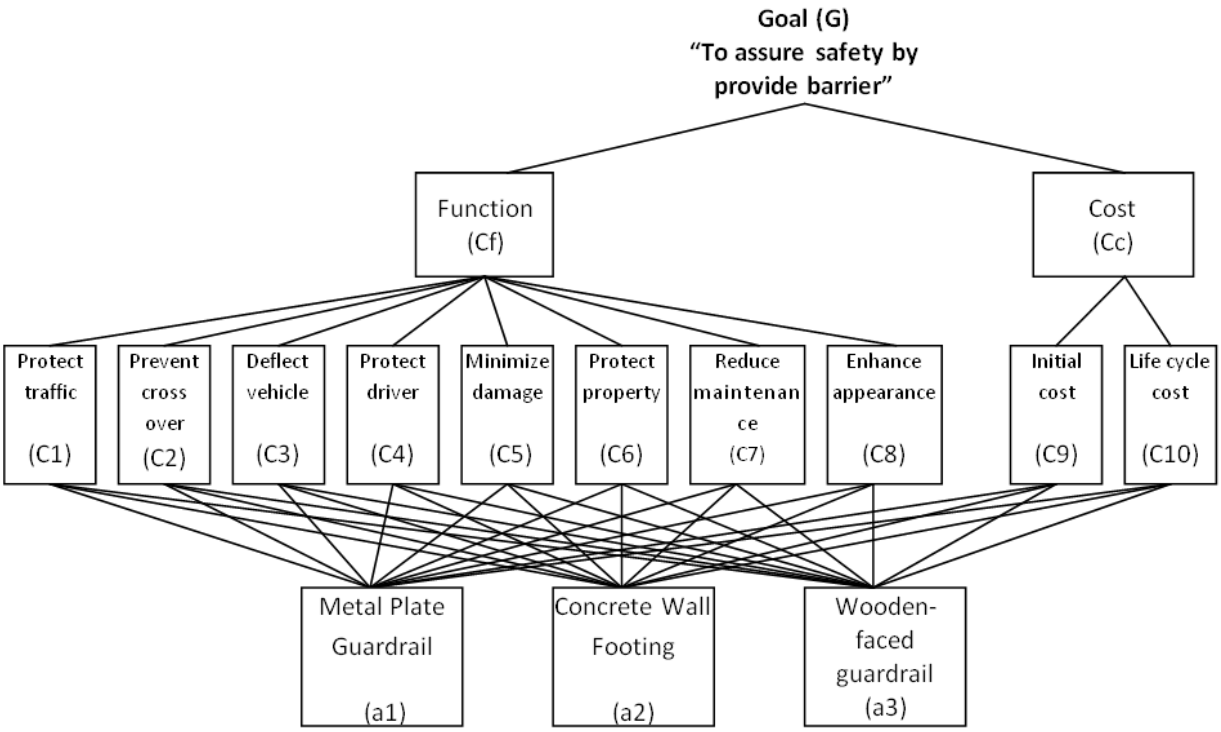

Fig.1. Decision hierarchy to choose guardrail as a function to assure safety by provide barrier

building wall system, Aiyin Jiang[10] in steel structure supply chain, Qingan, Qing and Hong[11] in material design of concrete and Fisher[12] in the modification of value engineering and its decision in the petrochemical industry. Many researchers did by using computers to support value-based decision (Table I). They consist of knowledge based system, expert system and internet-based. Nevertheless none of them discussed negotiation support on group decision.

DECISION MODEL FORMULATING

The AHP[2] 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. The AHP also can be used successfully with a group[18] and negotiation[19].

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 four level of decision hierarchy. The goal of the problem (G ="To assure safety by provide barrier") is addressed by some alternatives (A = a1; a2; a3). The problem is split into sub-problems: function (Cf) and cost (Cc) which are criteria evaluating alternatives. These criteria (C) are split in sub-criteria (c1; c2; c3; c4; c5; c6; c7; c8; c9; c10). Then implementation of analytical hierarchy can be started with compilation of the hierarchy model.

Second step: making judgments

The relative importance of pair wise comparison could be[2]: 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 pair wise comparisons between *n* similar activities with respect to the criteria 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 eigen-value can be calculated using the right eigenvector method by employing the following equation:

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

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

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

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

$$w_i = \frac{\bar{w}_i}{\sum_{i=1}^{n} \bar{w}_i} \quad i = 1, 2, ..., n \qquad (3)$$

Third step: Judgment Synthesis

The AHP[2] 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

$$A^* AHP-score = \max_i \sum_{j=1}^{n} a_{ij} w_j, \quad \text{for i = 1,2,3,…,m} \qquad (4)$$

Aggregation for group decision

Group decision making (GDM) is the process of making a judgment based upon the opinion of different individuals. Such decision making is a key component to the functioning of value-based decision process, because the selection performance involves multidisciplinary. Moving from a single decision maker to a multiple decision-maker introduces a great deal of complexity. In this system, the method of calculating the group utility (group composite score) of alternative a_i (for i=1,2,…,N) is as follows: For each attribute C_j (for j=1,2,…,M) the individual weights of importance of the attributes are aggregated into the group weights w_j (for j=1.2,…,M):

$$w_j = \frac{\sum_{k=1}^{n} 1_{g(k)} w_j}{\sum_{k=1}^{n} 1_{g(k)}} \qquad j=1,2,…,M \qquad (5)$$

The group qualification Q_{ij} of the alternative a_i against the attribute C_j is:

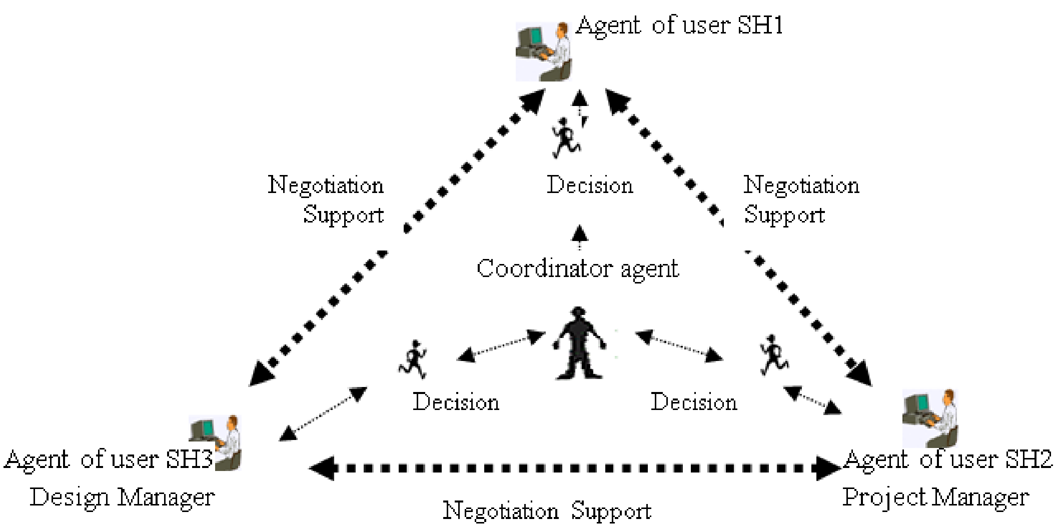

Fig.2. System architecture negotiation (Adapted from Morge and Beaune[21]).

$$Q_{ij} = \frac{\sum_{k=1}^{n} \frac{1}{g(k)} m_{ij}}{\sum_{k=1}^{n} \frac{1}{g(k)}} \qquad j=1,2,\ldots,M;\ i=1,2,\ldots,N \qquad (6)$$

The group utility P_i of alternative a_i is determined as the weighted algebraic mean of the aggregated qualification values with the aggregated weights

$$P_i = \frac{\sum_{j=1}^{M} w_j Q_{ij}}{\sum_{j=1}^{M} w_j} \qquad i=1,2,\ldots,N \qquad (7)$$

The best alternative of group decision is the one associated with the highest value of P_i. Table 2 presents the judgment analysis based on three stakeholders and the aggregation.

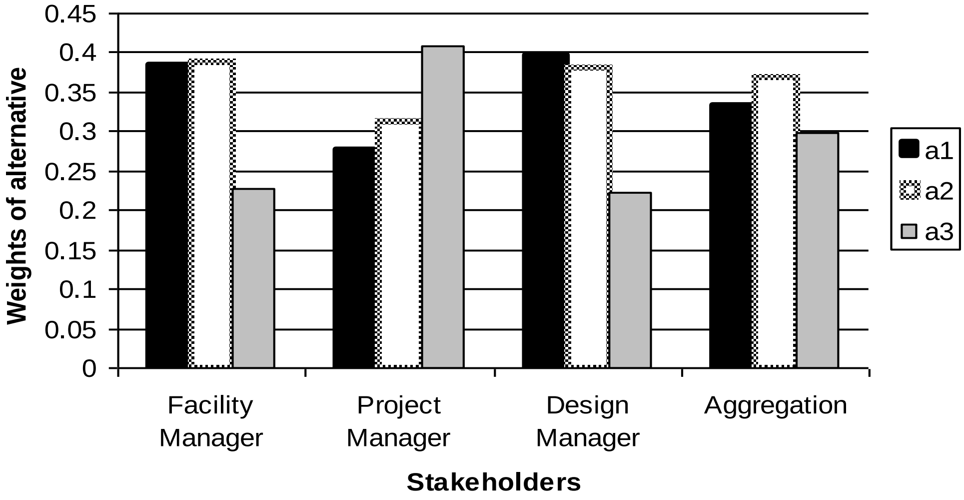

Fig. 5. weighting factor of every alternative for each stakeholder

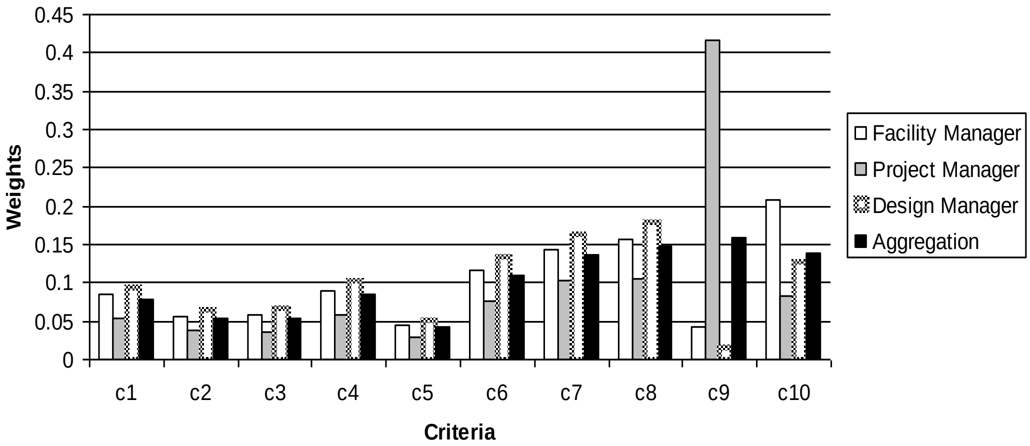

Fig. 3. Weight of preferences for each stakeholder

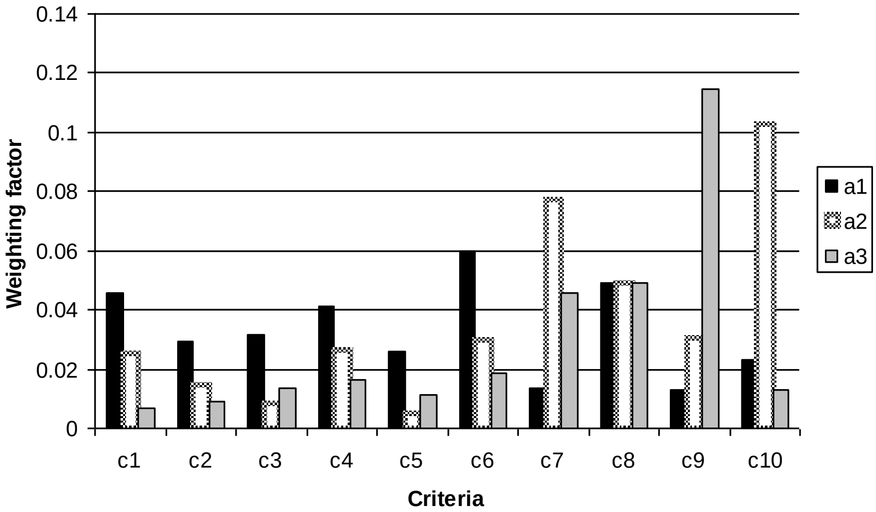

Fig. 4. Weighting factor of every alternative for each criteria

Table 3. Weighting factor of each alternative to each stakeholder

Alternative ranking and coalition	Priorities		
	a1 (Metal)	a2 (Concrete)	a3 (Wood)
SH 1 (FacilityManager)	2nd	1st	3rd
SH 2 (Project Manager)	3rd	2nd	1st
SH 3 (Design Manager)	1st	2nd	3rd
Aggregation	2nd	1st	3rd
Coalition SH1 and SH2	2nd	1st	3rd
Coalition SH1 and SH3	2nd	1st	3rd
Coalition SH2 and SH3	2nd	1st	3rd
Grand coalition	2nd	1sd	3rd
RESULT	2nd	1sd	3rd

											0.276
a2	0.018	0.012	0.005	0.017	0.004	0.020	0.060	0.031	0.088	0.060	0.314
a3	0.005	0.007	0.009	0.010	0.008	0.011	0.032	0.035	0.286	0.008	0.410
Stakeholder 3 (Design Manager)											
a1	0.053	0.037	0.041	0.059	0.034	0.076	0.015	0.060	0.001	0.019	0.397
a2	0.031	0.017	0.009	0.030	0.006	0.035	0.096	0.060	0.003	0.096	0.382
a3	0.009	0.011	0.016	0.015	0.011	0.023	0.053	0.060	0.012	0.012	0.221
Aggregation											
a1	0.046	0.029	0.031	0.041	0.026	0.060	0.013	0.049	0.013	0.023	0.332
a2	0.025	0.015	0.008	0.026	0.005	0.030	0.077	0.049	0.031	0.103	0.370
a3	0.007	0.009	0.013	0.017	0.011	0.019	0.045	0.049	0.114	0.013	0.298

RESULTS AND DISCUSSION

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[20]. Three stakeholders are involved and gave their own preference. Fig. 2 illustrates the system architecture negotiation adapted from Morge and Beaune[21]. Here, SH1, SH2, SH3 are stakeholder in facility management, project management, and design management domain, respectively. Stakeholders present different side of preference. Nevertheless the protocol of negotiation in this group decision was developed as a cooperative environment.

In this system, negotiation consists in an exchange of proposals. 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.

Determination of agreement options

As the negotiation progress, the agent user preferences of the evaluation criteria change, leading to changing score of the alternative highway guardrail, and changing membership and size of the set of agreement options. Three stages are conducted to determine agreement options which are;

Determine the weighting factor (weight of preferences) of criteria for each stakeholder and the aggregation. Fig.3 reveals different preferences between stakeholders.

Grade of alternative for each evaluation criteria. Fig.4 presents that a1 is the ‘best fit’ for c1, c2, c3, c4, c5, and c6. The ‘best fit’ solution for c9 is a3, and a2 for c7, c8, c10.

Score of every alternative for every stakeholder. Fig.5 shows that stakeholders have different best option as a solution alternative.

ANALYSIS OF AGREEMENT OPTIONS AND COALITION

Coalition formation in characteristic function game includes three activities:

1. Coalition structure generation:

Agents within each coalition coordinate their activities. This game with three agents, there are seven possible coalitions: {1}. {2}. {3}. {1,2}, {2,3}, {3,1}, {1,2,3}.

2. Solving the optimization problem of each coalition:

This means pooling the tasks and resources of the agents in the coalition, and solving joint problem. The coalition's objective is to maximize value.

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 rather than move out it. Several ways of dividing payoffs have been proposed in the literature[22].

By adapted model from Wanyama[23], coalition formation model on this paper 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. Table 3 shows the alternative ranking from possibility of coalition between stakeholders.

Wanyama and Far[24] wrote that sets of activities could move, expand and, retract during negotiation. Stakeholder of multi criteria decision problems such as selecting the best of highway guardrail usually evaluates the solution from different perspective. 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.

FURTHER RESEARCH

Generally, it is important that research continues in the area of value analysis, operation research and agent-based technology in construction. The recommended future work associated with the research reported in this paper is to extend the framework of technical solution to address the issue of selecting multiple building system products alternatives to perform the function. It will be run concurrently between satisfying games method to reduce the number of technical solution and optimization games method to select the best fit for the technical solutions. Research and practice in the objectives area of decision making science and value analysis to reduce alternatives are still in the qualitative stages, such as advantage and disadvantages analysis, and benchmark analysis. It is also to continue working on multi-attribute decision making, specifically on the process of eliciting user preference models such as neural network application and value function, and on establishing expert quantitative data from qualitative description of the feature of the alternative solution. A mathematical proof research for an unlimited multi-person decision maker in a project involving a whole community as in many infrastructure and civil projects today will be an interesting research since value analysis becomes a wider application in many fields as a construction of infrastructure projects becomes more complex.

CONCLUSIONS

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. The negotiation support was based on the coalition algorithms which adopts the value criteria as validated through feedback of stakeholder preferences. The result indicates that the framework for negotiation support improve the satisfaction level of all the stakeholders on group decision making. Therefore, it is concluded that the proposed model provides a structured methodology which can lead to a systematic support system for building system selection.

REFERENCES

1. Kelly, J., Male, S. and Graham, D. "*Value Management of Construction Project"*. Blackwell Science, 2004.
2. Saaty, T.L.. "The Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process", volume IV of AHP Series. RWS Publications, Pittsburg, 1996.
3. Sandholm, T.W. and Lesser, V.R. "Coalitions among computationally bounded agents". *Artificial Intelligence*, 94(1), 1997, pp. 99-137.
4. Kirk, S.J., Turk, R. G. and Hobbs, R. W. "*Value Based Team Design Decision Making*" The American Institute of Architects, 2007.
5. Thomas, G. and Thomas, M. "*Constructing Partnering and Integrated Team working,"*. Blackwell Publishing, 2005.
6. Clemen,R.T. "*Making Hard Decisions*," 2nd edition. Duxbury Press, Belmont, 1996.
7. Nassar, et al. "A Procedure for multi-criteria selection of building assemblies". *Automation in Construction* 12, 2003, pp. 543-560.
8. Sanchez, M., Prats, F., Agell, N. and Ormazabal, G.. "Multiple-criteria evaluation for value management in civil engineering". *Journal of Management in Engineering* 21(3), 2005, pp. 131-137.
9. Al-Hammad, A and Hassanain, MA "VE in the assessment of exterior building wall system" *Journal of Architectural Engineering* 2 (3), 1996, pp. 115-119.
10. Jiang, A. "A Decision Support Model for Cost and Activity-Based Performance Measurement in Steel Construction," Unpublished dissertation. University of Florida, 2005
11. Qingan, M., Qing, M. and Hong, Y. 'Value analysis application in material design of concrete'. *SAVE International Conference Proceeding*, 1999.
12. Fisher. J. M. "The Modification of Value Engineering for Application in the Petrochemical Industry," Unpublished thesis. University of Calgary, Alberta, 1999.
13. Shen, Q. and Brandon, P.S. "Can expert systems improve VM implementation?" *International conference of the society of American value engineer proceedings*, 1991, pp.168-176.

14. Kit, Y.M. "*ESPASD: an expert system for preliminary air conditioning system design*," Unpublished dissertation. The Hong Kong Polytechnic University, 2000.
15. Hussain M.A.D. "*VE Expert System in Suburban Highway Design (VEESHD),"* Unpublished issertation. University of Pittsburg, 2001.
16. Shen, Q., Chung, J.K.H, Heng, L, Shen, L. "A group support system for improving value management studies in construction," *Automation in Construction* 13, 2004, pp. 209-224.
17. Fan, S., Shen, Q., Kelly, J. "Using Group Decision Support to Support Value Management Workshop," *Journal of Computing in Civil Engineering* 22(2) 2008, pp. 100-113.
18. Wanyama, T. "*Decision support for COTS selection"*. Unpublished dissertation. University of Calgary, 2006.
19. Wang, J. and Zionts, S. "Negotiating wisely, considerations based on MCDM/MAUT". *European Journal of Operation Research* 188, 2008, pp.191-205.
20. Kraus, S. "Strategic Negotiation in Multi-agent Environment," MIT Press, 2001.
21. Morge, M. and Beaune, P. "A Negotiation Support System Based on Multi-agent System: Specify & Preference Relation on Arguments," *ACM Symposium on Applied Computing*, 2004, pp. 474 – 478.
22. Kahan, J.P. and Rapoport, A. "*Theories of coalition formation*," Lawrence Erlbaum Associates Publishers. 1984.
23. Wanyama, T. "*Static and dynamic coalition formation in group-choice decision making,"* V. Torra, Y. Narukawa, and Y. oshida (Eds.): MDAI 2007, *LNAI 4617*, Springer-Verlag Berlin Heidelberg. 2007. pp. 45–56.
24. Wanyama, T. and Far, B.H. "A protocol for multi-agent negotiation in a group-choice decision-making," *Journal of Network and Computer Applications* 30, 2007, pp.1173-1195.
25. ASTM, *ASTM Standards on Building Economics*: 5^{th} edition. ASTM International, 2004.