APPENDIX A

CASE STUDIES: DECISION AND COALITION

Case Study 1: High-rise Building Column Selection

1.1 Background

In this case study three decision makers namely Design Architect, Design Engineer and Construction Manager were involved in selection of high-rise building column of a marketing office building (Utomo, et al., 2009d). Columns are one of the most important structural systems in a building. Column design decomposes an element into a collection of system components. In new design, the column system selection can be part of the building design. For example, the building can be strengthened to support a heavy structural column system. The selection process is difficult because of the large number of factors, many of which are unrelated or conflicting with one another. A computer integrated knowledge based system would greatly benefit the selection process.

In this case, the optimum column was selected based on four possibilities of varying strength, size, reinforcement and shape. However, at certain level of the building, the strength requirement was ignored, because the construction manager wanted to use concrete of the same strength in the column as was used in the floor above. Also, the corner columns were all square, because it simplified the connection of the facing material. In addition, columns adjacent to stairs or elevators were square or rectangular. Nevertheless, in almost every column at every level, the optimization made some changes. By having knowledge of all the functions, a proper and reasonable decision was made. At certain levels, concrete strength variation was limited since same concrete strength was desirable in a floor. Also, column shape variation was not implemented in corner columns, since square columns were desired to fit plan.

With a general understanding of the available design options, considerations of the following technical and non technical criteria can lead to a selection of the most appropriate design for a project. The criteria are based on value analysis namely function and cost. Considering function, there are eight functions of optimizing column design as attributes of decision (Figure A.1). Those are satisfying décor, meet capacity and coordinate strength, maximize space, assure constructability, minimize/reduce creep, expedite design, reuse material, and minimize error. It is critical that the selected system sufficiently satisfies all of the criteria.

Column design selection criteria depend on the perspective of the individual decision makers. For example, a design architect might be more interested in satisfying decor function that will be influenced by column design whereas a design engineer is more interested in domain issues related to optimize design such as maximize space, minimize creep and expedite design. This makes it difficult for a decision maker to agree on the evaluation criteria. In this case study, there are four alternatives of column design as possible solution to be selected and be evaluated by eight criteria of function, two criteria of cost, and three decision makers. The alternatives are:

1. Alternative a1 (36x36; 6.0; 1.92), size: 36 x 36.
   Percent Steel : 1.92
2. Alternative a2 (40x40; 6.0; 0.95), size: 40 x 40
   Percent Steel : 0.95
3. Alternative a3 (32x32; 9.0; 1.07), size: 32 x 32
   Percent Steel : 1.07
4. Alternative a4 (36 diameters; 9.0; 0.99), size: 36 diameters
   Percent Steel : 0.99

The selection of column design for high-rise building and other case studies in this research report undergoes the following steps:

Step 1: Each decision maker defines his/her evaluation criteria and sets the weight of each criterion (win condition).

Step 2: Using AHP, every decision maker evaluates and ranks the column design alternatives based on his/her win conditions.

Step 3: The ranking of the column design alternatives with respect to different decision makers are generated and compared in order to identify conflict.

Step 4: Identify agreement options, as well as a column design alternatives ranking that reflects the combined preferences of all decision makers (coalition).

Step 5: Determine the ‘best fit’ options for each coalition on first negotiation round.

1.2 Function Analysis of Building Column

This process provides an organized approach for determining the needs and desires of the stakeholders during value analysis of a project. The attribute of decision was set based on previous studies and standard function analysis in American Society for Testing and Material (ASTM) 2004, book of Building Economics. Function analysis consists of four sequential steps: (1) determination of project function, (2) examination and sorting of these functions into categories, (3) selection of critical functions and arrangement into a logical order, and (4) analyzing the importance of the function. Functions are analyzed through a structured logical format called Function Analysis System Technique (FAST). FAST is a diagramming technique that specifically illustrates the relationship and interrelationship of all functions within a specific project using a “How-Why” logic pattern.

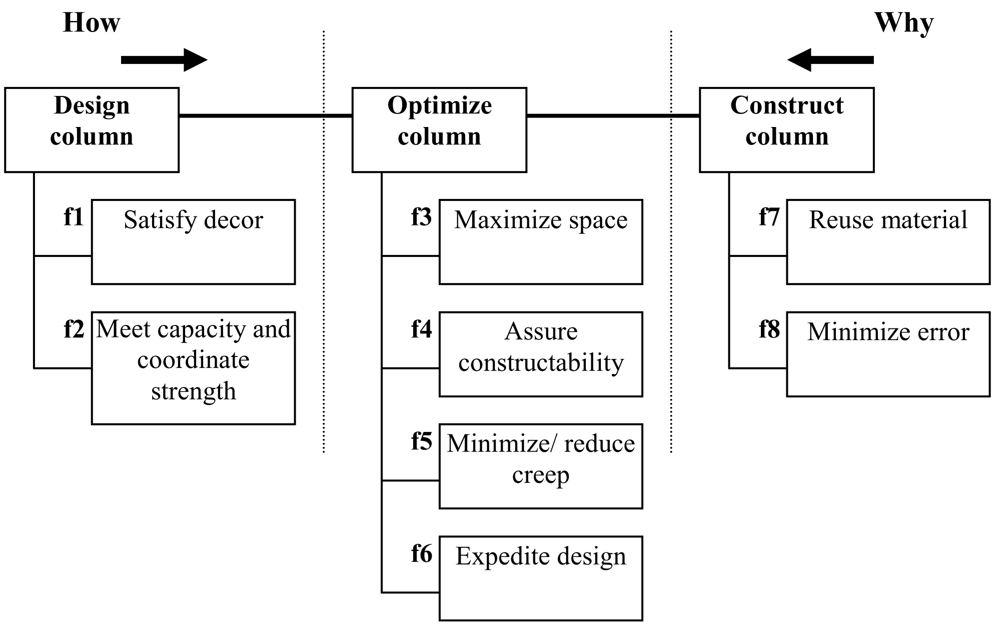

Figure A-1 FAST Diagram of Optimizing High-rise Building Column

1.3 Life Cycle Cost of Building Column

A proper selection of the higher order basic function can affect cost. Major elements that contribute to the cost of a column are:

a. Size of concrete column.
b. Strength of column.
c. Vertical column formwork (temporary).
d. Reinforcement.

The major part of the load is carried by the concrete, but for alternative a1, two thirds of the cost is for other items. The cost of reinforcement and temporary formwork should therefore be reduced proportionally. When construction managers instructed their design engineer, they focused on how to design column that will support the load. On alternative a2 the higher order function column design was changed to optimize column. Cost was inserted in the main critical path rather than as an all-the-time function. The column design fitted design criteria such as size, strength and percent of reinforcement. For alternative a3 the higher order function was changed to construct design. The a1, a2, a3 were proposed by design architect, design engineer and construction manager respectively, while the a4 was proposed as opponent of previous alternatives. It was based on the possibility of varying size, strength, reinforcement and shape.

Formwork is a necessary part of a concrete column that contributes nothing to load carrying capacity. Logically, its cost should be minimized. The shape of a column directly affects the ratio of the amount of formwork (circumference) required to the load carrying capacity (area). Circular and square shapes have equal circumference/area ratio, while rectangular columns have ratio greater than circular or square columns of the same area. Therefore, rectangular columns are less economical. Furthermore, circular columns are now being furnished in one-piece reusable (rentable) units, thus optimizing the cost of fabrication. Therefore, circular columns are most economical. Table A-1 presents the cost of each alternative of columns in a high-rise office building based on material category including concrete column and reinforced (main vertical, dowels, and ties). Construction cost category consists of temporary formwork.

Table A-1 Cost of High-Rise Building Columns

Cost category	Cost of each solution in Present Worth (10,000USD)			
	(a1): 36x36 1.92	(a2): 40x40 0.92	(a3): 32x32 1.07	(a4): 36 dim 0.99
Material	698.3	598.7	521.6	533.9
Construction	272.2	302.4	241.8	98.3
TOTAL	970.4	901.1	763.5	632.2

1.4 Building Column Selection

The decision hierarchy on this case consists of four levels. Level 1 is set of goal. The goal of the problem (G ="To optimize high-rise building columns") is addressed by some alternatives (A = a1; a2; a3; a4) at level 4. The problem is split into sub problems: f1, f2, f3, f4, f5, f6, f7, f8, c1 and c2, which are the evaluation criteria that will be used to select the best column. Level 3 of the decision hierarchy is a set of sub criteria derived from function analysis in Figure A.1 Level 2 of the decision hierarchy is selection criteria which are function and cost.

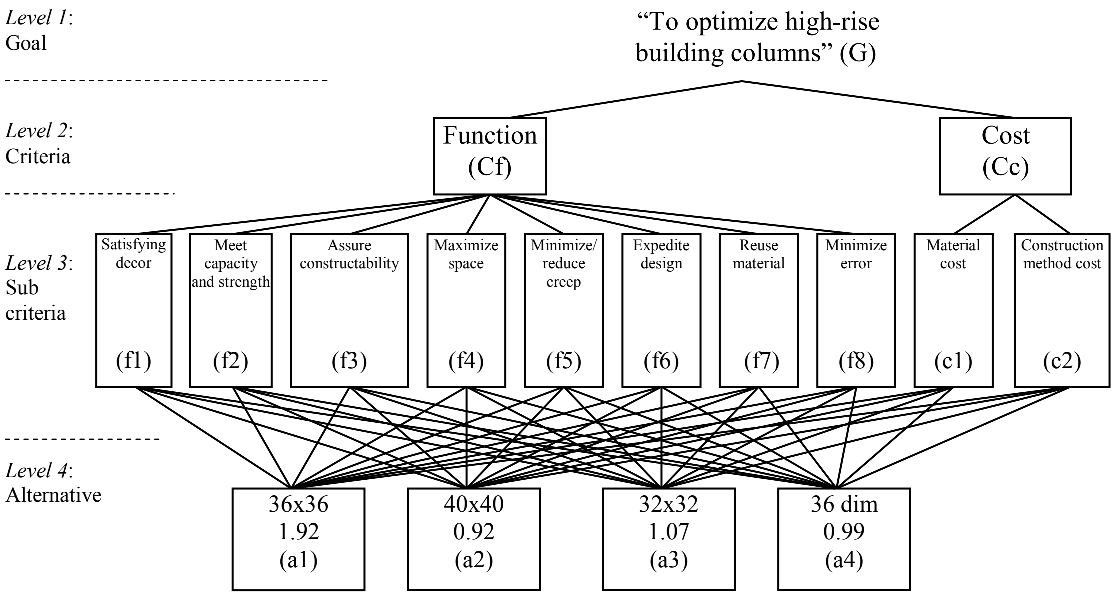

Figure A-2 Decision Hierarchies for Optimizing High-rise Building Column

Table A-2 below presents the ranking of high-rise building column options for each decision maker or stakeholder. Analytical Hierarchy Process (AHP) method is used to determine the ranking.

Table A-2 Weighting Factor of Each Alternative to Each Stakeholder

Designer	Weighting factor for each alternative in each criteria for design architect (λ=8.688172, CI=0.09831, CR=0.069724)											
	C1 (0.289)	C2 (0.217)	C3 (0.080)	C4 (0.144)	C5 (0.040)	C6 (0.057)	C7 (0.025)	C8 (0.023)	C9 (0.104)	C10 (0.021)	Σ	Ranking
a1 (36x36; 6.0; 1.92)	0.130	0.060	0.013	0.024	0.009	0.015	0.005	0.006	0.009	0.002	0.272	1st
a2 (40x40; 6.0; 0.92)	0.052	0.084	0.018	0.017	0.019	0.026	0.007	0.012	0.015	0.001	0.251	2nd
a3 (32x32; 9.0; 1.07)	0.081	0.043	0.009	0.033	0.005	0.007	0.004	0.004	0.049	0.004	0.239	3rd
a4 (36dia; 9.0; 0.99)	0.026	0.030	0.039	0.070	0.007	0.010	0.010	0.002	0.031	0.014	0.237	4th
Programmer	Weighting factor for each alternative in each criteria for design engineer (λ=8.853712, CI=0.121959, CR=0.086496)											
	C1 (0.010)	C2 (0.007)	C3 (0.032)	C4 (0.022)	C5 (0.019)	C6 (0.016)	C7 (0.012)	C8 (0.007)	C9 (0.583)	C10 (0.292)	Σ	Ranking
a1 (36x36; 6.0; 1.92)	0.005	0.002	0.005	0.004	0.004	0.004	0.002	0.002	0.051	0.026	0.104	4th
a2 (40x40; 6.0; 0.92)	0.002	0.003	0.008	0.003	0.009	0.007	0.003	0.004	0.083	0.015	0.136	3rd
a3 (32x32; 9.0; 1.07)	0.003	0.001	0.004	0.005	0.002	0.002	0.002	0.001	0.276	0.062	0.358	2nd
a4 (36dia; 9.0; 0.99)	0.001	0.001	0.016	0.011	0.003	0.003	0.005	0.001	0.174	0.189	0.402	1st
Construction manager	Weighting factor for each alternative in each criteria for construction manager (λ= 8.793054, CI=0.113293, CR=0.08035)											
	C1 (0.078)	C2 (0.029)	C3 (0.139)	C4 (0.031)	C5 (0.030)	C6 (0.050)	C7 (0.155)	C8 (0.238)	C9 (0.031)	C10 (0.219)	Σ	Ranking
a1 (36x36; 6.0; 1.92)	0.035	0.008	0.023	0.005	0.007	0.013	0.031	0.057	0.003	0.019	0.202	3rd
a2 (40x40; 6.0; 0.92)	0.014	0.011	0.032	0.004	0.014	0.022	0.043	0.123	0.005	0.011	0.280	2nd
a3 (32x32; 9.0; 1.07)	0.022	0.006	0.016	0.007	0.004	0.006	0.022	0.037	0.015	0.046	0.180	4th
a4 (36dia; 9.0; 0.99)	0.007	0.004	0.067	0.015	0.005	0.009	0.060	0.020	0.009	0.142	0.339	1st
Aggregation	C1 (0.126)	C2 (0.084)	C3 (0.084)	C4 (0.066)	C5 (0.029)	C6 (0.041)	C7 (0.064)	C8 (0.089)	C9 (0.240)	C10 (0.177)	Σ	Ranking
a1 (36x36; 6.0; 1.92)	0.057	0.023	0.014	0.011	0.007	0.011	0.013	0.022	0.021	0.016	0.193	4th
a2 (40x40; 6.0; 0.92)	0.023	0.033	0.019	0.008	0.014	0.018	0.018	0.046	0.034	0.009	0.222	3rd
a3 (32x32; 9.0; 1.07)	0.035	0.017	0.010	0.015	0.003	0.005	0.009	0.014	0.113	0.037	0.259	2nd
a4 (36dia; 9.0; 0.99)	0.011	0.012	0.041	0.032	0.005	0.007	0.025	0.008	0.071	0.115	0.326	1st

In this case there were three decision makers. Decision before coalition revealed the result of weighting each alternative for each decision maker. The design architect chose 36x36 columns as the best solution, meanwhile design engineer and construction manager chose a cylinder column.

1.5 Satisfying Option on Value Criteria

One way of categorizing the options of technical solution for high-rise building column is to identify material cost and construction method cost as ‘Cost’, and to identify all functions as 'Function'. Table A-3 show the selectability (Ps) and rejectability (Pr) that represent function and cost of technical solution of high-rise building column respectively.

Table A-3 Cost and Function of High-rise Building Column Options

	Cost				Function								Normalization	
	c1	c2	∑	Loss	f1	f2	f3	f4	F5	f6	f7	f8	Cost (Pr)	Function (Ps)
a1	0.09	0.09	0.18	0.95	0.45	0.27	0.17	0.17	0.23	0.26	0.20	0.09	0.381	0.229
a2	0.14	0.05	0.19	0.93	0.18	0.39	0.23	0.12	0.48	0.45	0.27	0.14	0.373	0.283
a3	0.47	0.21	0.68	0.44	0.28	0.20	0.12	0.23	0.12	0.12	0.14	0.47	0.176	0.210
a4	0.30	0.65	0.95	0.18	0.09	0.14	0.48	0.48	0.17	0.17	0.39	0.30	0.071	0.278

Based on the result presented on Table 3, Figure 3 provides a cross plot of function of the technical solution options. Observe that although a2 has the highest function, it also has high cost which is resulted its value below F/C=1. In this case, the highest basic value is a4 since it gives the highest satisfaction due to its high function and low cost.

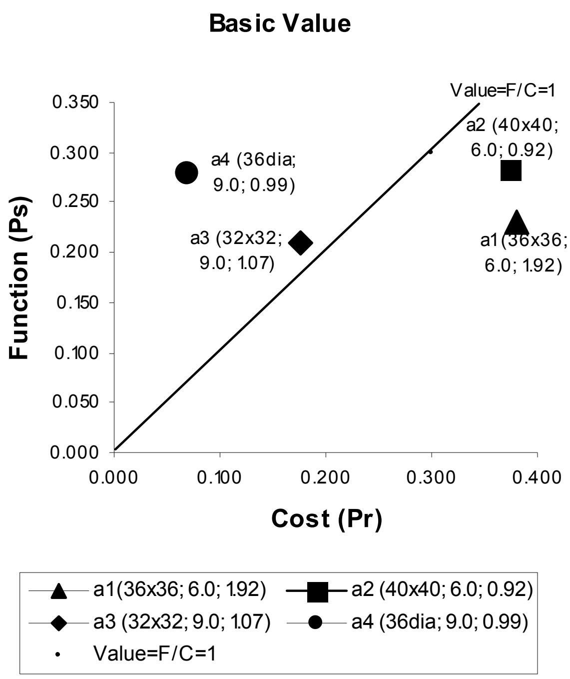

Figure A-3 Basic Value of High-rise Building Column Options

Figures A-4, A-5, and A-6 provide a cross plot of function and cost of design architect, design engineer, and construction manager respectively. It means that the value of technical solution depends on the preference of stakeholder. Observe that the construction manager's preference has influence on a3. Basically a3 has value more than F/C=1 or this option has selectability options. The construction manager's preference has changed it to a value below F/C=1 or rejectability options.

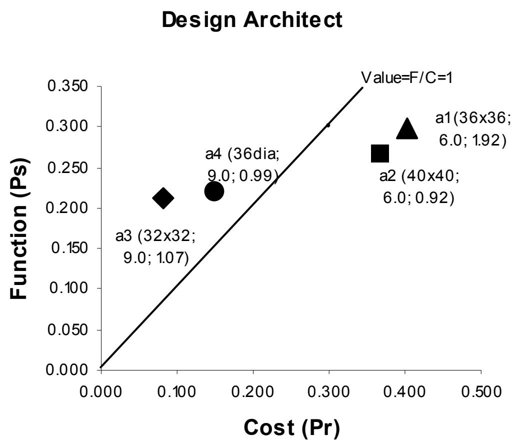

Figure A-4 Value of High-rise Building Column Options for Design Architect

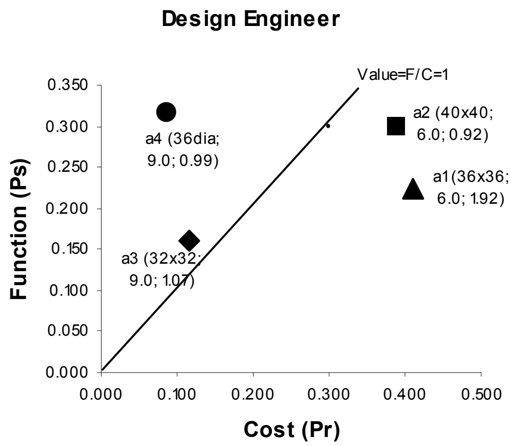

Figure A-5 Value of High-rise Building Column Options for Design Engineer

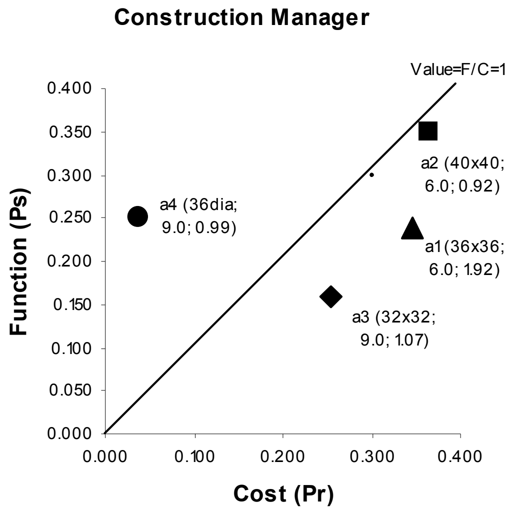

Figure A-6 Value of High-rise Building Column Options for Construction Manager

1.6 Agreement Options and Coalition

(1) *Determining the weighting factor (weight of preferences) of each criteria for individual decision maker.*

Figures A-7 and A-8 reveal different preferences between the decision makers. In contrast to the programmer who put most weight on material cost, the designer put satisfying decor as the most preferred criteria; meanwhile the construction manager put most preference on minimizing errors. The difference presents rationality amongst the decision makers.

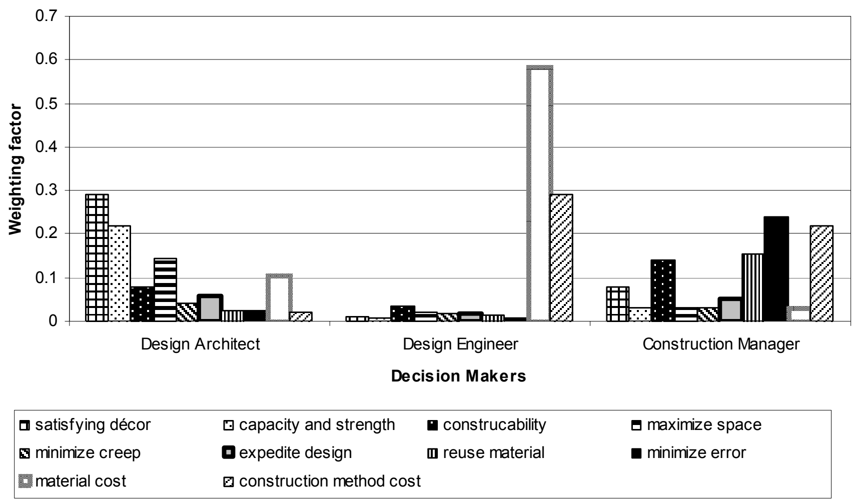

Figure A-7 Weighting Factor for Each Stakeholder on Criteria

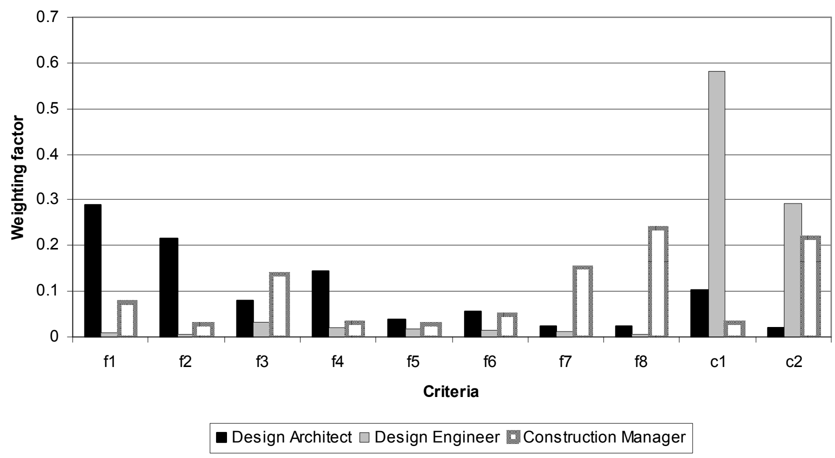

Figure A-8 Weighting Factor of Criteria for Each Stakeholder

(2) *Grading alternative for each evaluation criteria.*

Figure A-9 presents that a2 is the 'best fit' for f2, f5, f6, and f8. The 'best fit' solution for f1 is a1; a3 is best fit for criteria c1 that is material cost; meanwhile a4 is the 'best fit' for f3, f4, f7 and c2.

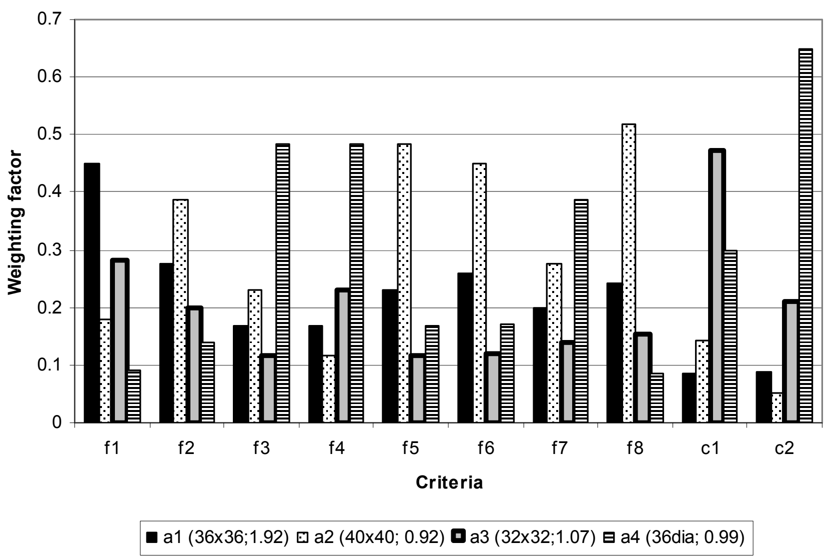

Figure A-9 Weighting Factor of Alternatives for Each Criteria

(3) *Scoring every alternative for every stakeholder.*

Figure A-10 shows that stakeholders have different best option as a solution alternative. Before coalition, the design architect chose 36x36 columns as the best solution, while the design engineer and the construction manager chose a cylinder column.

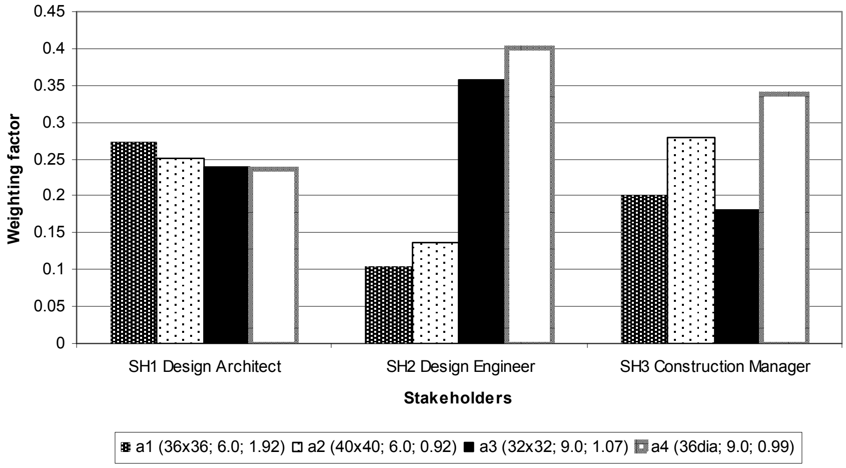

Figure A-10 Weighting Factor of Alternative for Each Stakeholder

(4) *Determining payoff optimum.*

Determination of the payoff optimum follows the algorithm in Equations 6.1, 6.2, 6.3, and 6.4 presented in Chapter Six. The process and result are presented on Tables A-4 and A-5 for Cost and Function respectively.

Table A-4 Cost Payoff Optimum for Each Coalition on Building Column Selection

Coalition		Alternatives				Payoff Optimum	
SH1+2+3		a1	a2	a3	a4	Max-min	Optimum
	SH1	0.403	0.365	0.082	0.150	0.321	0.403
	SH2	0.412	0.387	0.115	0.087	0.325	0.397
	SH3	0.347	0.362	0.254	0.038	0.324	0.362
		1.161	1.113	0.450	0.275		
SH1+2		a1	a2	a3	a4		
	SH1	0.403	0.365	0.082	0.150	0.321	0.403
	SH2	0.412	0.387	0.115	0.087	0.325	0.412
		0.815	0.752	0.197	0.237		
SH1+3		a1	a2	a3	a4		
	SH1	0.403	0.365	0.082	0.150	0.321	0.403
	SH3	0.347	0.362	0.254	0.038	0.324	0.347
		0.750	0.727	0.335	0.188		
SH2+3		a1	a2	a3	a4		
	SH2	0.412	0.387	0.115	0.087	0.325	0.397
	SH3	0.347	0.362	0.254	0.038	0.324	0.362
		0.758	0.748	0.369	0.125		

Table A-5 Function Payoff Optimum for Each Coalition on Building Column Selection

Coalition		Alternatives				Payoff Optimum	
SH1+2+3		a1	a2	a3	a4	Max-min	Optimum
	SH1	0.299	0.269	0.212	0.220	0.087	0.299
	SH2	0.224	0.301	0.160	0.315	0.155	0.315
	SH3	0.239	0.352	0.159	0.250	0.193	0.307
		0.763	0.921	0.531	0.786		
SH1+2		a1	a2	a3	a4		
	SH1	0.299	0.269	0.212	0.220	0.087	0.299
	SH2	0.224	0.301	0.160	0.315	0.155	0.271
		0.523	0.570	0.372	0.535		
SH1+3		a1	a2	a3	a4		
	SH1	0.299	0.269	0.212	0.220	0.087	0.299
	SH3	0.239	0.352	0.159	0.250	0.193	0.321
		0.538	0.620	0.371	0.470		
SH2+3		a1	a2	a3	a4		
	SH2	0.224	0.301	0.160	0.315	0.155	0.315
	SH3	0.239	0.352	0.159	0.250	0.193	0.337
		0.464	0.652	0.319	0.565		

Payoff optimum for cost and function become the data for the best fit options algorithm. The result of the process is presented at stage (5) below.

(5) *Analyzing the best fit option for every coalition and grand coalition.*

The result is presented on Table A-6. It shows the priorities that followed the best fit option process and algorithm in Equation 6.5 in Chapter Six. It also presents the result of priorities of the technical solution for high-rise building column in first negotiation round. In this case, the a4 (36 dim; 0.99) is the best fit option.

Table A-6 Ranking of Building Column Options for each Coalition

Alternative ranking and coalition	Priorities			
	a1	a2	a3	a4
SH 1 (Design Architect)	1st	2nd	3rd	4th
SH 2 (Design Engineer)	4th	3rd	2nd	1st
SH 3 (Construction Manager)	3rd	2nd	4th	1st
Coalition SH1 and SH2	4th	3rd	2nd	1st
Coalition SH1 and SH3	3rd	1st	2nd	4th
Coalition SH2 and SH3	2nd	3rd	4th	1st
Grand coalition SH1,2,3	4th	3rd	2nd	1st
RESULT	3rd	2nd	-	1st

1.7 Similarity Index

Similarity index of three models of group decision are presented on Table A-7. The table shows that model 3 proposed on this research is the only model giving satisfaction to all stakeholders. The closer the value of individual stakeholder to the best fit group, the more satisfying the model is to every stakeholder.

Table A-7 Similarity Index Result for High-rise Building Column Selection

	Model 1: Single weighting	Model 2: Aggregation	Model 3: Coalition algorithm
Stakeholder 1	>1 =1	>1 =1	0.0857
Stakeholder 2	>1 =1	0.74496644	0.4564
Stakeholder 3	>1 =1	>1 =1	0.4110

1.8 Conclusion of the Case Study

The coalition table (Table A-6) reveals the start of the first negotiation round. Some of the solutions will not be an option if no individual stakeholder or coalition of stakeholders desires to select it. In this case, alternative solution a3 is not an option. Table A-6 also indicates the alternative solution that will be determined to be the best fit solution. As the the 'best fit' solution, a4 is contrary to the best option selected by the design architect, who chose a1. On the process of trade off in the next negotiation round, the design architect can propose a new preference if he or she did not accept a4 as the best option. The process of validation using similarity index revealed the best group decision model that satisfied all stakeholders. That came from the algorithm of the proposed negotiation support model.

Case study 2: Wall System Selection

2.1 Background

This case study involved the selection of wall system (Utomo, et al., 2008c). Five decision makers were involved: Property Manager, Project Manager, Architect, QS, and Engineer. As one of the most important system in a building, wall system selection can be part of the building design. The selection process is difficult because of the large number of factors, many of which are unrelated or conflicting with one another, and the lack of key data (such as realistic design service life). Like in high-rise building column selection, a computer integrated knowledge based system would also greatly benefit to wall system selection process.

Based on value criteria which are function and cost, there are seven attributes of wall functions that need to be considered in decision making, namely work function, environmental support, security assurance, user need, image, property management support, building economics. It is critical that the selected system sufficiently satisfies all of the criteria. Wall system selection criteria depend on the perspective of the individual decision makers. For example, an architect might be more interested in the image of building that will be influenced by the wall system and user satisfaction, whereas a project manager is more interested in domain issues related to owner and constraints such as budget that reflected on initial cost. This makes it difficult for decision makers to agree on the evaluation criteria.

In this case study, there are five possible solutions of wall system to be evaluated according to six criteria of function and cost, involving five decision makers. The possible solutions are:

1. Reinforced brick wall.
2. Precast wall concrete.
3. Metal frame wall.
4. Timber wall panel.
5. Glass wall

2.2 Function Analysis of Wall System

The function of building wall system can be identified using the function analysis system technique (FAST). Figure A-11 shows the FAST diagram. The diagram is determined by Focus Group research. In this case, there are eight functions identified on the wall system which are structural stability; exclusion of rain and water; thermal properties; acoustics properties; protection to occupant's asset; fire safety; satisfy and user convenience; image and aesthetic. Further the identified function will become the attributes for decision.

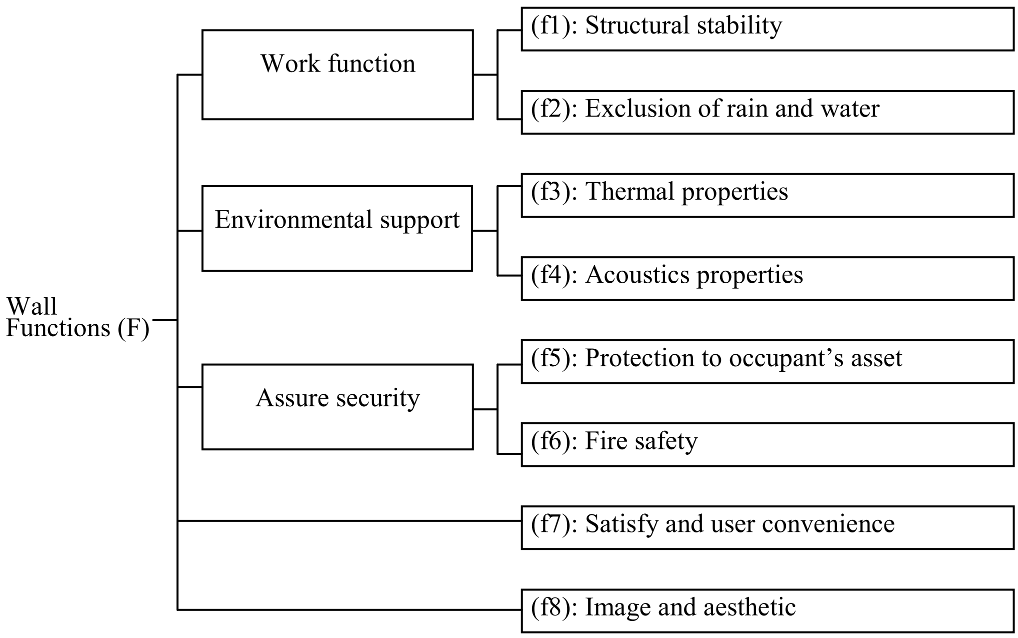

Figure A-11 FAST Diagram of the Building Wall System

2.3 Life Cycle Cost of Wall System

Cost drivers of the wall system which are initial cost and operation maintenance cost are identified. Since operation and maintenance (O&M) costs have annual basis, Equation (2.3) in Chapter Two was used to calculate the O&M costs. Table A-8 below presents the cost of the wall system for each technical solution which are a1 (reinforced brick wall), a2 (Precast wall concrete), a3 (Metal frame wall), a4 (Timber wall panel), and a5 (Glass wall). The cost drivers namely c1 (initial cost) and c2 (operation and maintenance cost) become evaluation criteria in the selection of wall system solution.

Table A-8 Cost of Wall System

Cost category	Present Worth (1000USD)				
	a1	a2	a3	a4	a5
(c1) Initial	250	1600	800	1600	1200
(c2) Operation and maintenance	800	200	400	2000	800

2.4 Wall System Selection

In order to obtain a good representation of the problem, it has to be structured into different components called activities. Figure A-12 shows that the goal of the problem (G ="To select wall system") is addressed by some alternatives (A = a1; a2; a3, a4, a5) which are metal frame wall, precast wall concrete, glass wall, timber wall panel, and reinforced brick wall respectively. The problem is split into value criteria namely function and cost and subproblem (f1, f2, f3, f4, f5, f6, f7, f8, c1, c2) which are the evaluation criteria.

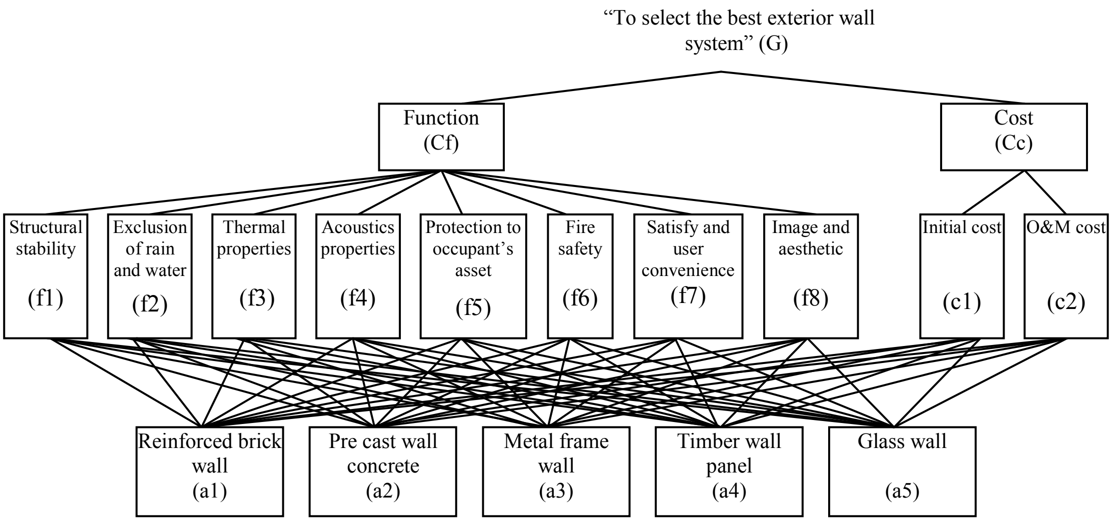

Figure A-12 Decision Hierarchy to Select the Best Wall System

The weighting factor of each alternative in wall system for each decision maker is presented on Table A-9. It represents the ranking of the solutions. The process to determine the ranking is followed to AHP calculation presented on Appendix B. Aggregation value that represents the group value is also presented in the table. Later the aggregation value will be compared with the result from coalition by similarity index in the next section.

Table A-9 Judgment Synthesis of Every Stakeholder on Each Wall System Solutions

Property Manager											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.022	0.117	0.053	0.040	0.190	0.264	0.093	0.097	0.013	0.113	
a1	0.022	0.117	0.053	0.040	0.190	0.264	0.093	0.097	0.013	0.113	0.2734
a2	0.001	0.012	0.022	0.017	0.044	0.109	0.024	0.020	0.007	0.018	0.2890
a3	0.002	0.015	0.016	0.012	0.088	0.082	0.006	0.014	0.001	0.055	0.1619
a4	0.003	0.029	0.007	0.006	0.031	0.043	0.007	0.007	0.003	0.026	0.0879
a5	0.006	0.004	0.006	0.002	0.017	0.008	0.037	0.004	0.000	0.004	0.1878
Project Manager											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.038	0.021	0.013	0.007	0.009	0.054	0.074	0.034	0.675	0.075	
a1	0.002	0.002	0.005	0.003	0.002	0.022	0.019	0.007	0.374	0.012	0.4487
a2	0.003	0.003	0.004	0.002	0.004	0.017	0.004	0.005	0.035	0.036	0.1129
a3	0.005	0.005	0.002	0.001	0.002	0.009	0.006	0.002	0.177	0.017	0.2252
a4	0.010	0.001	0.001	0.000	0.001	0.002	0.030	0.001	0.025	0.003	0.0732
a5	0.018	0.010	0.001	0.001	0.000	0.005	0.015	0.018	0.065	0.007	0.1399
Architect											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.123	0.043	0.040	0.057	0.040	0.083	0.183	0.307	0.083	0.042	
a1	0.007	0.004	0.017	0.025	0.009	0.034	0.047	0.062	0.046	0.007	0.2576
a2	0.008	0.006	0.013	0.016	0.018	0.026	0.011	0.043	0.004	0.020	0.1656
a3	0.016	0.011	0.005	0.008	0.007	0.014	0.014	0.023	0.022	0.009	0.1285
a4	0.031	0.002	0.004	0.003	0.004	0.002	0.073	0.011	0.003	0.001	0.1354
a5	0.060	0.021	0.002	0.005	0.002	0.007	0.037	0.168	0.008	0.004	0.3129
QS											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.143	0.022	0.034	0.025	0.130	0.176	0.099	0.038	0.250	0.083	
a1	0.008	0.002	0.014	0.011	0.030	0.073	0.025	0.008	0.139	0.013	0.3229
a2	0.010	0.003	0.011	0.007	0.060	0.055	0.006	0.005	0.013	0.040	0.2100
a3	0.019	0.005	0.005	0.003	0.021	0.029	0.008	0.003	0.065	0.019	0.1772
a4	0.036	0.001	0.004	0.001	0.012	0.005	0.040	0.001	0.009	0.003	0.1122
a5	0.069	0.011	0.001	0.002	0.006	0.015	0.020	0.021	0.024	0.008	0.1777
Engineer											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.070	0.185	0.122	0.043	0.065	0.126	0.027	0.029	0.067	0.267	
a1	0.004	0.019	0.050	0.019	0.015	0.052	0.007	0.006	0.037	0.042	0.2509
a2	0.005	0.024	0.038	0.012	0.030	0.039	0.002	0.004	0.003	0.130	0.2874
a3	0.009	0.046	0.016	0.006	0.011	0.021	0.002	0.002	0.017	0.060	0.1908
a4	0.018	0.007	0.013	0.002	0.006	0.004	0.011	0.001	0.002	0.009	0.0726
a5	0.034	0.089	0.005	0.003	0.003	0.011	0.005	0.016	0.006	0.026	0.1983
Aggregation											
	f1	f2	f3	f4	f5	f6	f7	f8	c1	c2	Weight
	0.079	0.078	0.053	0.034	0.087	0.141	0.095	0.101	0.218	0.116	
a1	0.005	0.008	0.022	0.015	0.020	0.058	0.024	0.020	0.121	0.018	0.3107
a2	0.005	0.010	0.016	0.010	0.040	0.044	0.006	0.014	0.011	0.056	0.2130
a3	0.010	0.019	0.007	0.005	0.014	0.023	0.007	0.007	0.057	0.026	0.1767
a4	0.020	0.003	0.006	0.002	0.008	0.004	0.038	0.004	0.008	0.004	0.0963
a5	0.038	0.037	0.002	0.003	0.004	0.012	0.019	0.055	0.021	0.011	0.2033

2.5 Satisfying Option on Value Criteria

In this case study, initial cost and O&M cost are identified as 'Cost' and the other eight functions which are structural stability; exclusion of rain and water; thermal properties; acoustics properties; protection to occupant's asset; fire safety; satisfy and user convenience; image and aesthetic are identified as 'Function'. Table A-10 shows the selectability (Ps) and rejectability (Pr) that represent function and cost of technical solution of wall system respectively.

Table A-10 Cost and Function of Wall System Options

	Cost		Function								Normalization	
	c1	c2	f1	f2	f3	f4	f5	f6	f7	f8	Cost (Pr)	Function (Ps)
a1	0.554	0.158	0.058	0.103	0.411	0.437	0.234	0.412	0.255	0.202	0.037	0.264
a2	0.051	0.486	0.069	0.132	0.311	0.288	0.463	0.310	0.059	0.140	0.128	0.222
a3	0.261	0.227	0.132	0.249	0.133	0.139	0.163	0.164	0.079	0.074	0.154	0.142
a4	0.037	0.034	0.253	0.037	0.105	0.056	0.091	0.030	0.402	0.037	0.372	0.126
a5	0.096	0.096	0.487	0.480	0.040	0.080	0.048	0.085	0.205	0.547	0.309	0.247

Based on the result presented on Table A-10, Figure A-13 provides a cross plot of function of the technical solution options. In this case the highest basic value is a1. It gives the highest satisfaction since it has high function and low cost.

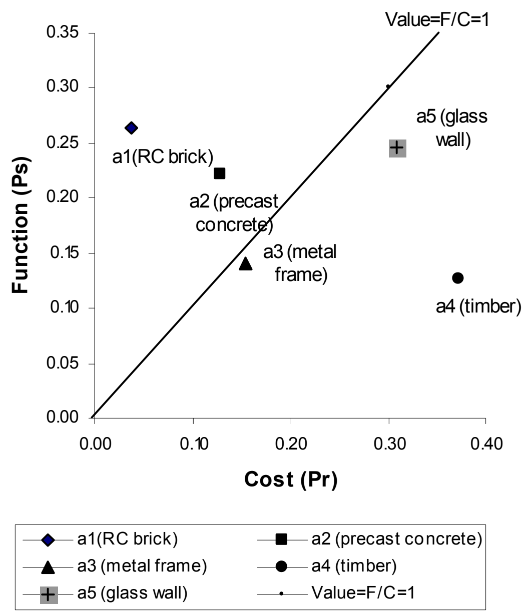

Figure A-13 Basic Value of Wall System Options

Figures A-14, A-15, A-16, A-17 and A-18 provide a cross plot of function and cost for property manager, project manager, architect, QS, and engineer respectively. It means that the value of technical solution depends on the preference of stakeholders. Observe the influence of the engineer's preference on a3. Basically a3 has a value below F/C=1, which is a rejected option. However, the engineer's preference changes it to a value greater than F/C=1, thus a3 becomes a selected option.

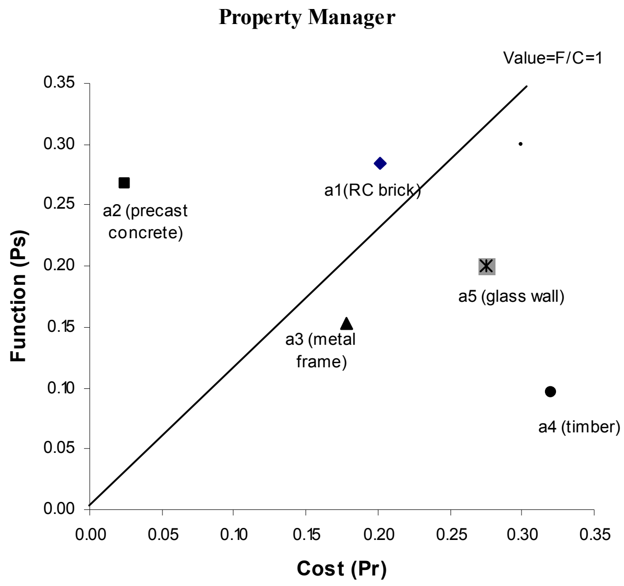

Figure A-14 Value of Wall System Options for Property Manager

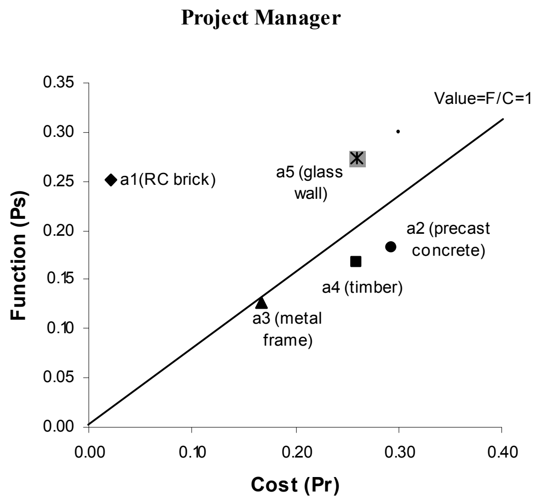

Figure A-15 Value of Wall System Options for Project Manager

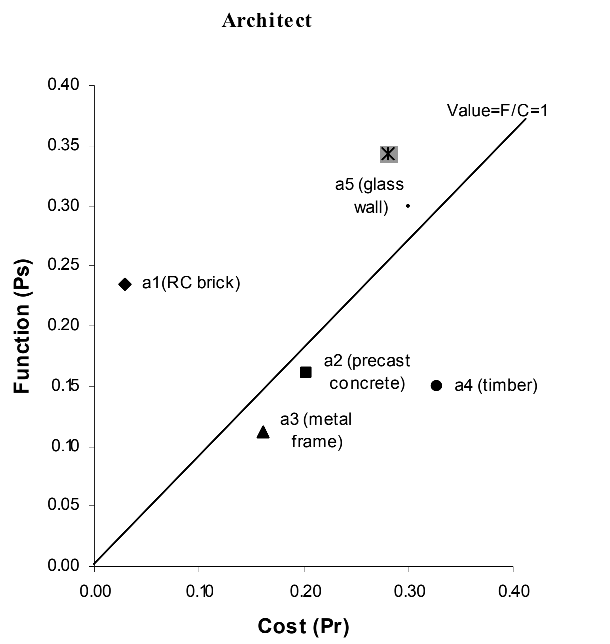

Figure A-16 Value of Wall System Options for Architect

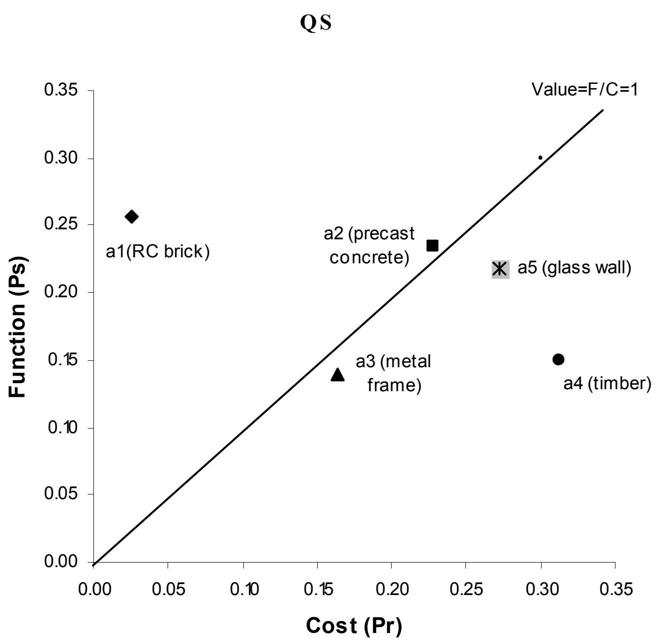

Figure A-17 Value of Wall System Options for QS

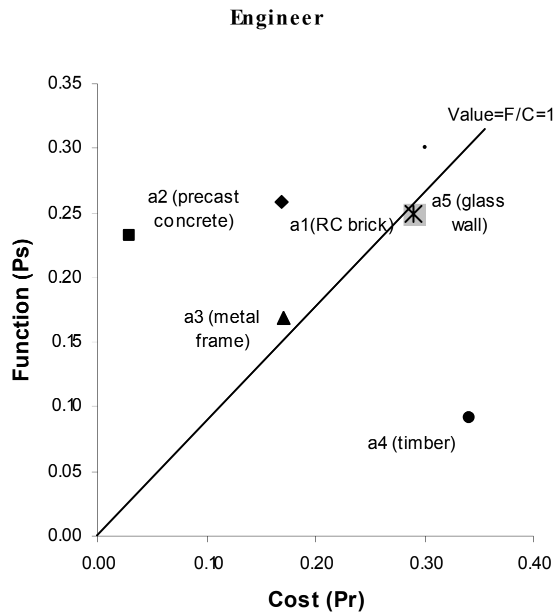

Figure A-18 Value of Wall System Options for Engineer

2.6 Agreement Options and Coalition

(1) *Determining the weighting factor (weight of preferences) of criteria for each stakeholder.*

Figure A-19 reveals different preferences between stakeholders.

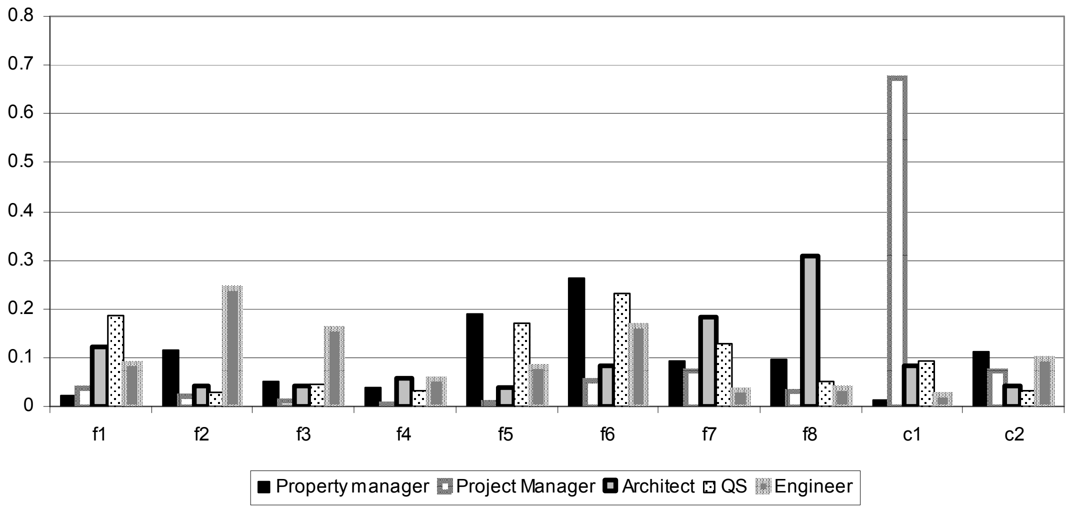

Figure A-19 Weight of Preferences of Wall System Criteria for Each Stakeholder

(2) *Grading alternative for each evaluation criteria.*

Figure A-20 presents that a5 is the 'best fit' for f1, f2, f8 whereas a1 is the 'best fit' for f3, f4, f6, and c1.

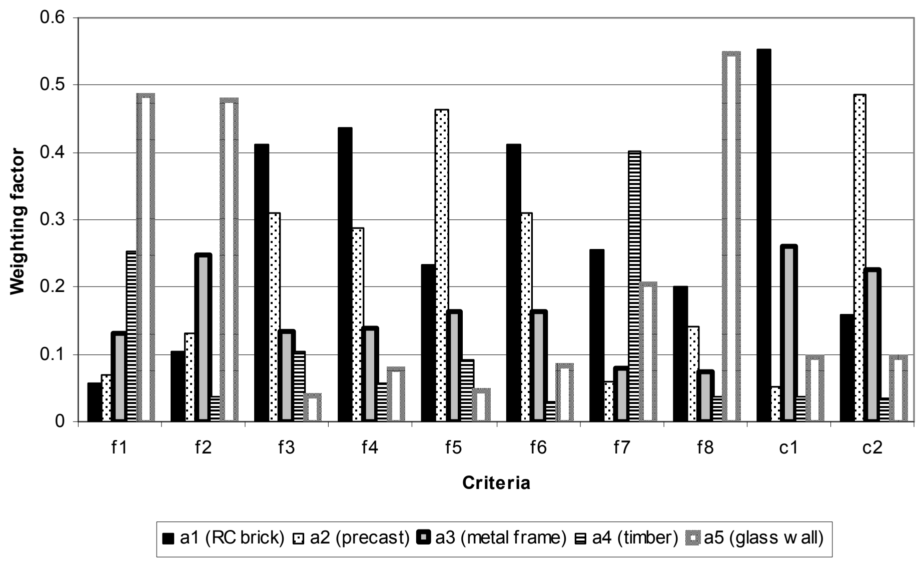

Figure A-20 Weighting Factor of Each Wall System Option for Each Criterion

(3) *Scoring every alternative for every stakeholder.*

Figure A-21 shows that stakeholders have different best option as solution alternative. In this case only Stakeholder 1 (Property Manager) chose precast (a2) as the best option, architect chose a5, engineer choose a2 and other two stakeholders choose a1 as the best solution for wall system.

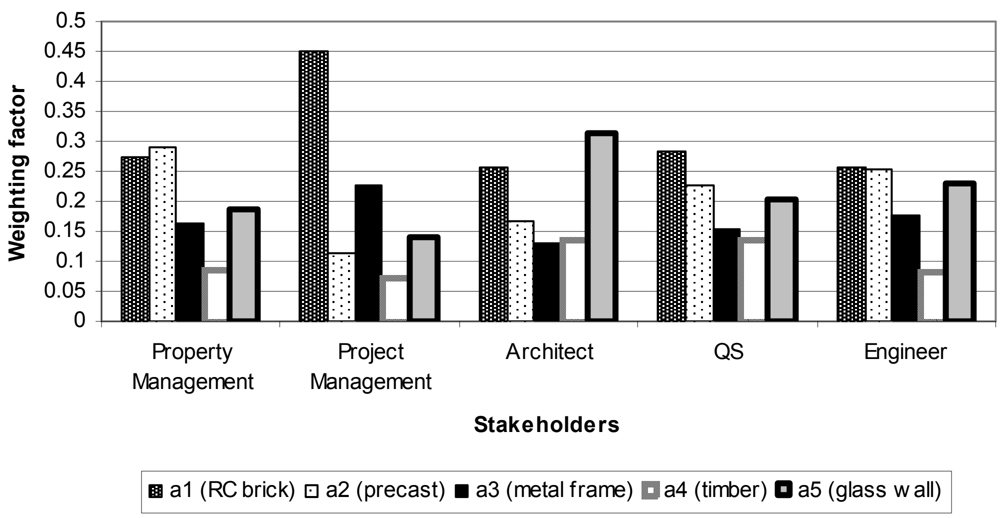

Figure A-21 Weighting Factor of Each Wall System Option for Each Stakeholder

(4) Determining payoff optimum

The process of determining payoff optimum and the result are presented on Tables A-11 and A-12 for cost and function respectively.

Table A-11 Cost Payoff Optimum for Each Coalition on Wall System Selection

Coalition		Alternatives					Payoff Optimum	
SH1+2+3+4+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.123
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		1.060	1.117	1.194	1.080	0.548		1.194
SH1+2		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.251
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
		0.313	0.365	0.533	0.451	0.337		0.533
SH1+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.172
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
		0.326	0.430	0.467	0.448	0.329		0.467
SH1+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.270
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.234	0.362	0.513	0.464	0.427		0.513
SH1+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.239
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.280	0.396	0.490	0.456	0.378		0.490
SH2+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
		0.577	0.505	0.461	0.407	0.051		0.577
SH2+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.263
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.485	0.437	0.507	0.423	0.149		0.507
SH2+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.077	0.282
	SH5	0.249	0.251	0.220	0.210	0.070	0.041	0.249
		0.531	0.471	0.484	0.415	0.100		
SH3+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.258
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.498	0.502	0.441	0.419	0.141		0.502
SH3+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.293

	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.544	0.536	0.418	0.411	0.092		
SH4+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.224
		0.452	0.467	0.464	0.427	0.190		0.467
SH1+2+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.154
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
		0.608	0.650	0.730	0.653	0.359		0.730
SH1+2+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.251
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.516	0.582	0.776	0.669	0.457		0.776
SH1+2+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.221
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.562	0.616	0.753	0.661	0.408		0.753
SH1+3+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.172
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.529	0.647	0.711	0.666	0.449		0.711
SH1+3+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.142
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.575	0.681	0.688	0.658	0.399		
SH1+4+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.239
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.483	0.612	0.734	0.674	0.498		0.734
SH2+3+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.254
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
		0.780	0.722	0.704	0.624	0.170		0.780
SH2+3+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
	SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.293
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.826	0.756	0.681	0.616	0.121		0.826
SH2+4+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.239
	SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
	SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
		0.734	0.687	0.727	0.632	0.219		0.734

SH3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.258
SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
	0.746	0.752	0.661	0.629	0.211		0.752
SH1+2+3+4	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.154
SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
	0.811	0.867	0.974	0.871	0.478		0.974
SH1+2+3+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.123
SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
	0.857	0.901	0.951	0.863	0.429		0.951
SH1+2+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.221
SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
	0.765	0.832	0.997	0.879	0.527		0.997
SH1+3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.031	0.145	0.270	0.246	0.308	0.276	0.142
SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.295
SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
	0.778	0.897	0.931	0.875	0.519		0.931
SH2+3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH2	0.282	0.220	0.263	0.205	0.030	0.253	0.282
SH3	0.295	0.285	0.197	0.202	0.021	0.274	0.252
SH4	0.203	0.217	0.243	0.218	0.120	0.124	0.243
SH5	0.249	0.251	0.220	0.210	0.070	0.180	0.251
	1.028	0.972	0.925	0.834	0.241		1.028

Table A-12 Function Payoff Optimum for Each Coalition on Wall System Selection

Coalition			Alternatives			Payoff Optimum	
SH1+2+3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.811	1.001	0.915	0.789	1.485		1.485
SH1+2	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	0.401	0.416	0.425	0.306	0.452		0.452

SH1+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.278
	SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.189
		0.358	0.409	0.440	0.326	0.467		0.467
SH1+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.204
	SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
		0.422	0.421	0.489	0.319	0.349		0.489
SH1+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.270
	SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.195
		0.390	0.415	0.464	0.322	0.408		0.464
SH2+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
		0.252	0.384	0.262	0.310	0.792		0.792
SH2+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
		0.316	0.397	0.311	0.302	0.674		0.674
SH2+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH2	0.147	0.196	0.123	0.145	0.389	0.072	0.196
	SH5	0.137	0.195	0.163	0.161	0.344	0.058	0.195
		0.284	0.391	0.287	0.306	0.733		
SH3+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.189
	SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.201
		0.273	0.390	0.327	0.322	0.688		0.390
SH3+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
	SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
		0.241	0.384	0.302	0.326	0.747		
SH4+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
	SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
		0.305	0.396	0.351	0.318	0.629		0.629
SH1+2+3		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
	SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
		0.506	0.604	0.563	0.471	0.855		0.855
SH1+2+4		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
	SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
		0.570	0.617	0.612	0.463	0.737		0.737
SH1+2+5		a1	a2	a3	a4	a5	Max-min	Optimum
	SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
	SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
	SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
		0.538	0.611	0.588	0.467	0.796		0.796

SH1+3+4	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH1+3+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.495	0.604	0.603	0.487	0.811		
SH1+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.559	0.616	0.652	0.480	0.693		0.693
SH2+3+4	a1	a2	a3	a4	a5	Max-min	Optimum
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
	0.421	0.586	0.450	0.467	1.077		1.077
SH2+3+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.389	0.579	0.426	0.470	1.136		1.136
SH2+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.453	0.592	0.475	0.463	1.018		1.018
SH3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.410	0.585	0.490	0.483	1.032		1.032
SH1+2+3+4	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
	0.675	0.806	0.751	0.628	1.140		1.140
SH1+2+3+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.643	0.799	0.727	0.632	1.199		1.199
SH1+2+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344

	0.707	0.812	0.776	0.624	1.081		1.081
SH1+3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH1	0.254	0.220	0.301	0.162	0.063	0.238	0.063
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.664	0.805	0.791	0.644	1.096		1.096
SH2+3+4+5	a1	a2	a3	a4	a5	Max-min	Optimum
SH2	0.147	0.196	0.123	0.145	0.389	0.265	0.389
SH3	0.105	0.189	0.139	0.165	0.403	0.299	0.403
SH4	0.169	0.201	0.188	0.157	0.285	0.128	0.285
SH5	0.137	0.195	0.163	0.161	0.344	0.208	0.344
	0.557	0.781	0.613	0.627	1.421		1.421

Payoff optimum for cost and function become the data for the best fit options algorithm. The result of the process is presented at stage (5) below.

(5) *Analyzing the best fit option for every coalition and grand coalition.*

The result is presented on Table A-13. It shows the priorities that followed the best fit options process and algorithm in Equation 6.5 in Chapter Six. It also presents the result of priorities of the technical solution for wall system in the first negotiation round.

Table A-13 Ranking of Wall System Options for each Coalition

No	Alternative ranking and coalition	Alternatives				
		a1	a2	a3	a4	a5
1	0	0	0	0	0	0
2	SH 1 (Property Manager)	2nd	1st	4th	5th	3rd
3	SH 2 (Project Manager)	1st	4th	2nd	5th	3rd
4	SH 3 (Architect)	2nd	3rd	5th	4th	1st
5	SH 4 (QS)	1st	2nd	4th	5th	3rd
6	SH 5 (Engineer)	2nd	1st	4th	5th	3rd
7	Coalition SH1,2	4th	2nd	3rd	1st	5th
8	Coalition SH1,3	4th	2nd	3rd	1st	5th
9	Coalition SH1,4	4th	2nd	3rd	1st	5th
10	Coalition SH1,5	4th	2nd	3rd	1st	5th
11	Coalition SH2,3	5th	3rd	4th	2nd	1st
12	Coalition SH2,4	4th	2nd	3rd	1st	5th
13	Coalition SH2,5	1st	3rd	4th	2nd	5th
14	Coalition SH3,4	5th	3rd	2nd	1st	4th
15	Coalition SH3,5	5th	4th	3rd	2nd	1st
16	Coalition SH4,5	5th	4th	3rd	1st	2nd
17	Coalition SH1,2,3	4th	5th	3rd	2nd	1st

No	Alternative ranking and coalition	Alternatives				
		a1	a2	a3	a4	a5
18	Coalition SH1,2,4	3rd	5th	2nd	1st	4th
19	Coalition SH1,2,5	2nd	3rd	4th	1st	5th
20	Coalition SH1,3,4	2nd	4th	3rd	1st	5th
21	Coalition SH1,3,5	4th	3rd	2nd	1st	5th
22	Coalition SH1,4,5	4th	3rd	2nd	1st	5th
23	Coalition SH2,3,4	3rd	2nd	4th	1st	5th
24	Coalition SH2,3,5	5th	2nd	4th	1st	3rd
25	Coalition SH2,4,5	4th	2nd	3rd	1st	5th
26	Coalition SH3,4,5	4th	2nd	3rd	1st	5th
27	Coalition SH1,2,3,4	4th	3rd	2nd	1st	5th
28	Coalition SH1,2,3,5	4th	3rd	2nd	1st	5th
29	Coalition SH1,2,4,5	4th	2nd	3rd	1st	5th
30	Coalition SH1,3,4,5	4th	2nd	3rd	1st	5th
31	Coalition SH2,3,4,5	5th	3rd	2nd	1st	4th
32	Coalition SH1,2,3,4,5	3rd	2nd	4th	1st	5th
Result		3rd	4th	-	1st	2nd

2.7 Similarity Index

The result of similarity index is presented on Table A-14. The similarity index shows that the coalition algorithm model gives satisfaction to all stakeholders.

Table A-14 Similarity Index Result for Wall System Selection

	Model 1: Single weighting	Model 2: Aggregation	Model 3: Coalition algorithm
Stakeholder 1	>1=1	>1=1	0.466823
Stakeholder 2	>1=1	0.660666	0.151679
Stakeholder 3	1	0.664501	0.199419
Stakeholder 4	>1=1	>1=1	0.008331
Stakeholder 5	>1=1	0.79176	0.142212

2.8 Conclusion of the Case Study

In this case study, solutions a3 is not options for wall system. Table A-13 also indicates the alternative solution that will be determined to be the best fit solution. In the first negotiation round a4 was the ‘best fit’ solution for the group. It means that timber wall panel is the best technical solution for wall system. This result is very interesting because on the individual stakeholder preferences, no one choose a4.

Case study 3: Highway Guardrail Selection

3.1 Background

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 ASTM 2004. In this case, a highway guardrail was selected (Utomo, et al., 2009c). 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 then 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".

3.2 Function Analysis of Highway Guardrail

Function analysis of highway guardrail is presented in Figure A-22. It consists of four sequential steps in a function analysis. Figure A-22 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'.

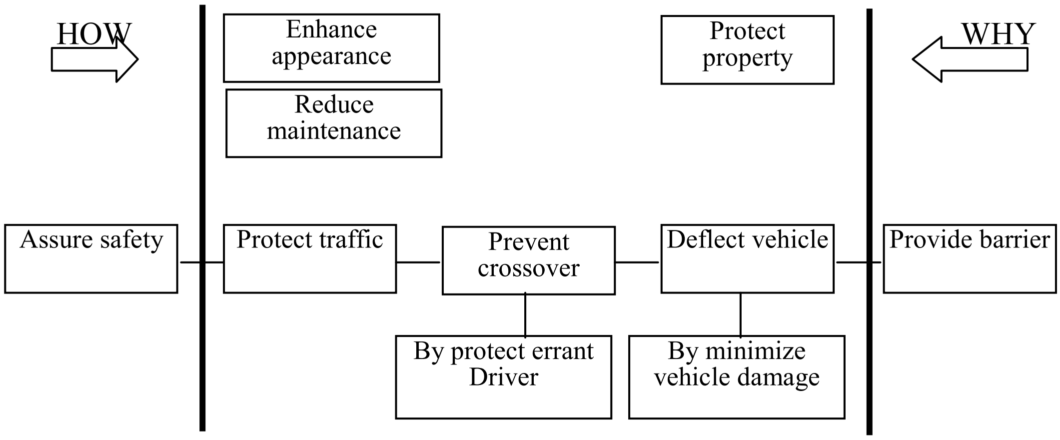

Figure A-22 FAST Diagram of Highway Guardrail

3.3 Life Cycle Cost of Highway Guardrail

Based on Equation (2.1) in Chapter Two, a cost driver of highway guardrail was calculated. Table A-15 presents LCC and the initial cost.

Table A-15 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

3.4 Highway Guardrail Selection

Figure A- 23 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.

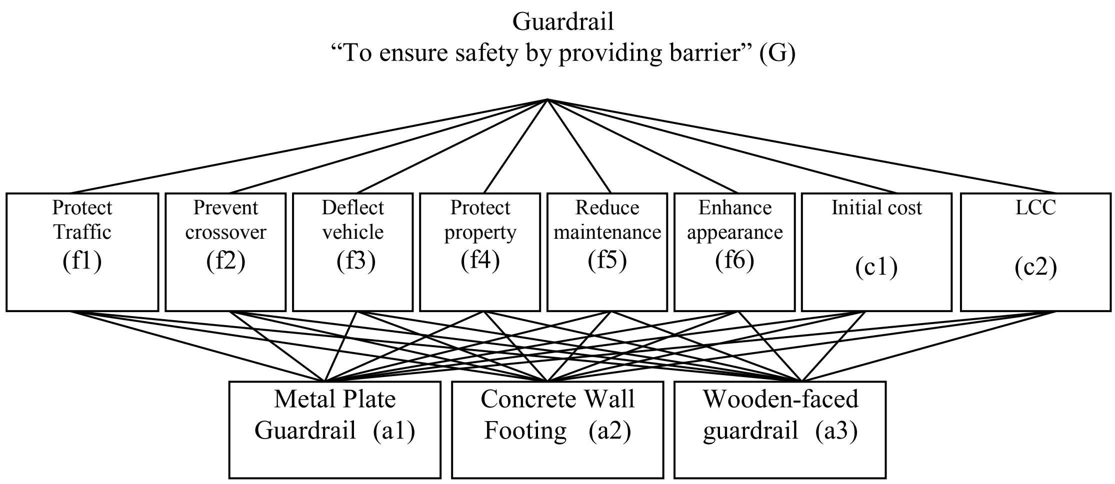

Figure A-23 Decision Hierarchy to Choose Highway Guardrail

Table A-16 Weighting Factor of Each Guardrail Solutions for Individual Stakeholder

	Estate Manager									
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.100	0.095	0.076	0.072	0.347	0.022	0.029	0.259		
a1	0.028	0.060	0.023	0.009	0.220	0.003	0.007	0.150	0.4988	1st
a2	0.059	0.025	0.012	0.017	0.090	0.005	0.019	0.080	0.3076	2nd
a3	0.013	0.010	0.041	0.047	0.037	0.015	0.004	0.028	0.1935	3rd
	Project Manager									
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.134	0.080	0.051	0.026	0.037	0.188	0.353	0.130		
a1	0.037	0.051	0.015	0.003	0.023	0.023	0.081	0.076	0.3095	2nd
a2	0.079	0.021	0.008	0.006	0.010	0.043	0.229	0.040	0.4369	1st
a3	0.017	0.009	0.028	0.017	0.004	0.122	0.043	0.014	0.2536	3rd

QS										
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.133	0.051	0.046	0.070	0.047	0.098	0.199	0.356		
a1	0.037	0.032	0.014	0.009	0.030	0.012	0.046	0.207	0.3859	2nd
a2	0.079	0.013	0.008	0.016	0.012	0.022	0.129	0.110	0.3899	1st
a3	0.017	0.005	0.025	0.045	0.005	0.063	0.024	0.039	0.2243	3rd
In-house Designer										
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.186	0.029	0.049	0.036	0.182	0.334	0.129	0.056		
a1	0.051	0.018	0.015	0.004	0.115	0.041	0.030	0.032	0.3067	3rd
a2	0.110	0.008	0.008	0.008	0.047	0.077	0.083	0.017	0.3589	1st
a3	0.024	0.003	0.027	0.023	0.019	0.216	0.016	0.006	0.3343	2nd
Engineer										
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.107	0.272	0.176	0.069	0.100	0.187	0.042	0.047		
a1	0.030	0.173	0.052	0.008	0.063	0.023	0.010	0.028	0.3860	1st
a2	0.064	0.071	0.029	0.016	0.026	0.043	0.027	0.015	0.2900	3rd
a3	0.014	0.029	0.095	0.045	0.011	0.121	0.005	0.005	0.3241	2nd
Aggregation										
	f1	f2	f3	f4	f5	f6	c1	c2	Weight	Ranking
	0.107	0.272	0.176	0.069	0.100	0.187	0.042	0.047		
a1	0.036	0.067	0.024	0.007	0.090	0.020	0.035	0.099	0.3774	1st
a2	0.078	0.028	0.013	0.013	0.037	0.038	0.098	0.052	0.3567	2nd
a3	0.017	0.011	0.043	0.035	0.015	0.107	0.018	0.019	0.2660	3rd

3.5 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 A-17 shows the selectability (Ps) and rejectability (Pr) that represent function and cost of technical solution of highway guardrail respectively.

Table A-17 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

Based on the result presented on Table A-17, Figure A-24 provides a cross plot of function of the technical solution options. In this case the highest basic value is a2.

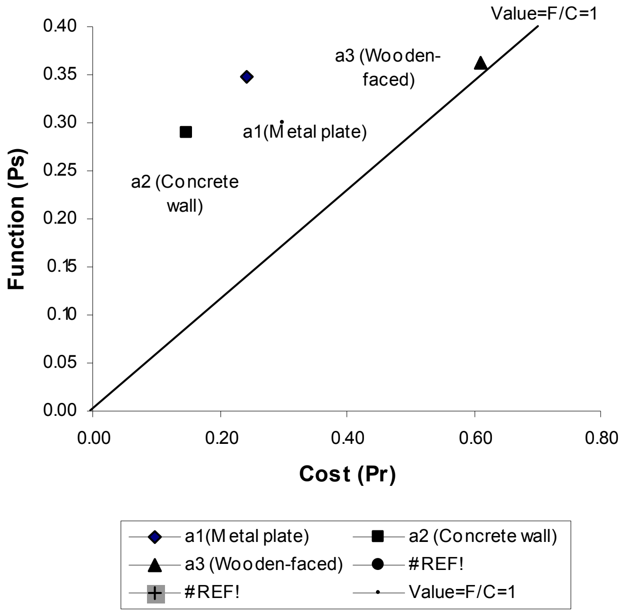

Figure A-24 Basic Value of Highway Guardrail Options

Figures A-25, A-26, A-27, A-28 and A-29 provide cross plots of function and cost for five stakeholders. It means that the basic value of technical solution presented in Figure A-24 will be changed by preferences of stakeholders.

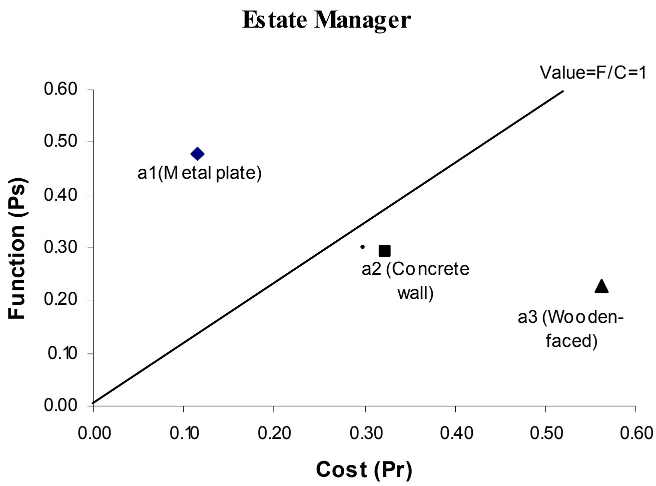

Figure A-25 Value of Highway Guardrail Options for Estate Manager

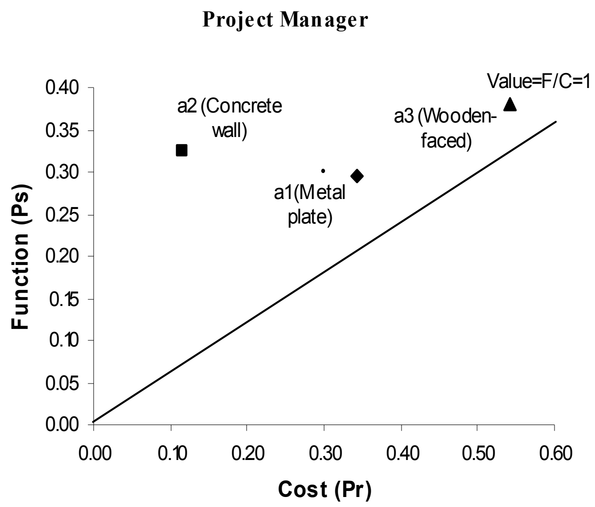

Figure A-26 Value of Highway Guardrail Options for Project Manager

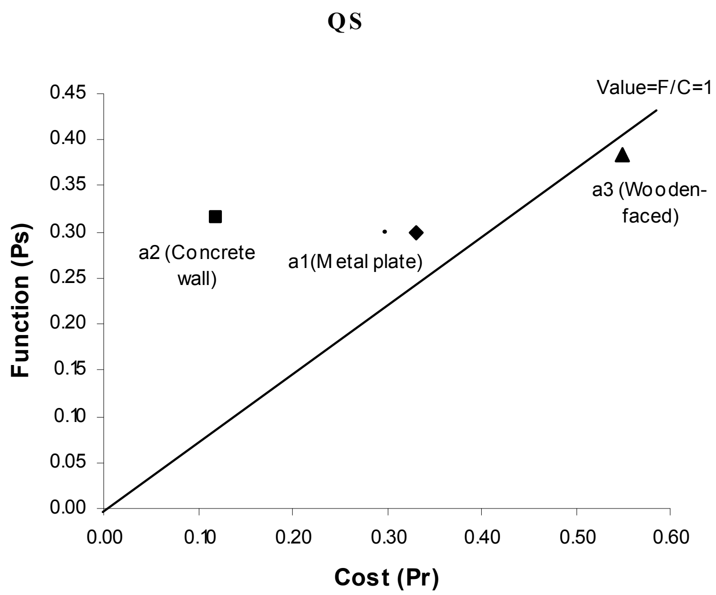

Figure A-27 Value of Highway Guardrail Options for QS

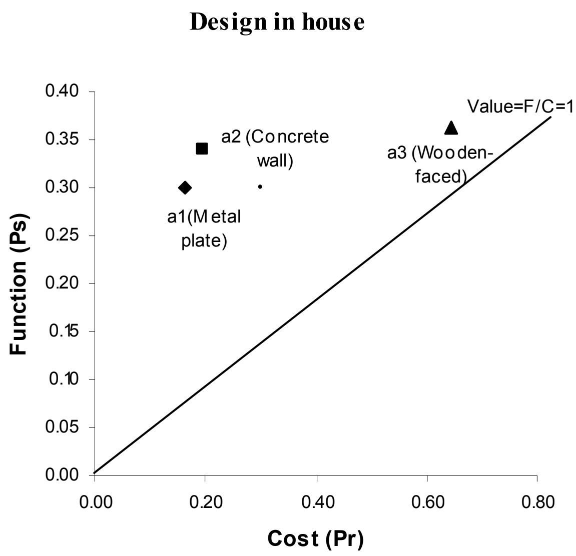

Figure A-28 Value of Highway Guardrail Options for In-house Designer

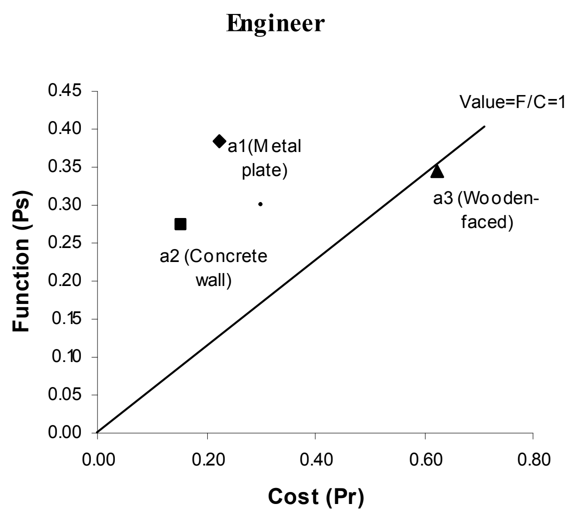

Figure A-29 Value of Highway Guardrail Options for Engineer

3.6 Agreement Options and Coalition

(1) *Determining the weighting factor (weight of preferences) of criteria for each stakeholder.*

Figure A-30 reveals different preferences among stakeholders.

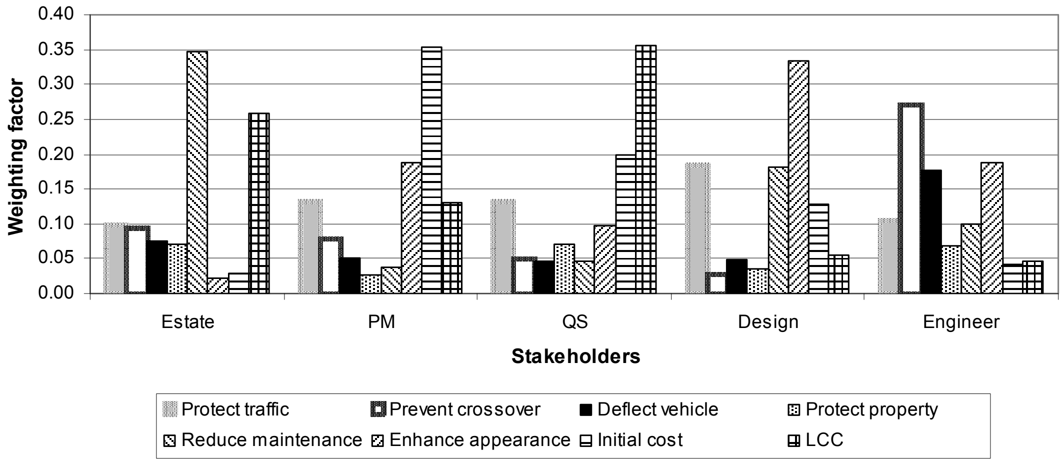

Figure A-30 Weight of Preferences for Each Stakeholder

(2) *Grading alternative for each evaluation criteria.*

Figure A-31 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.

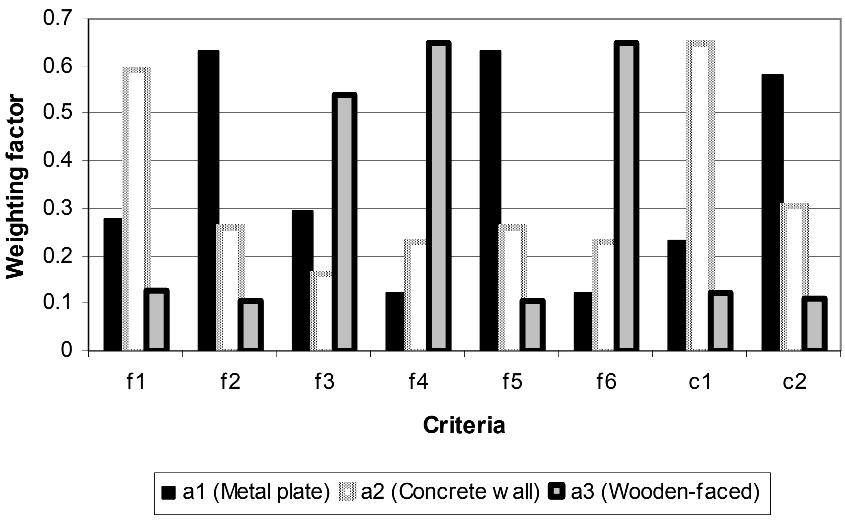

Figure A-31 Weighting Factor of Every Alternative for Each Criteria

(3) *Scoring every alternative for each stakeholder.*

Figure A-32 shows that each stakeholder has different best option as a solution alternative.

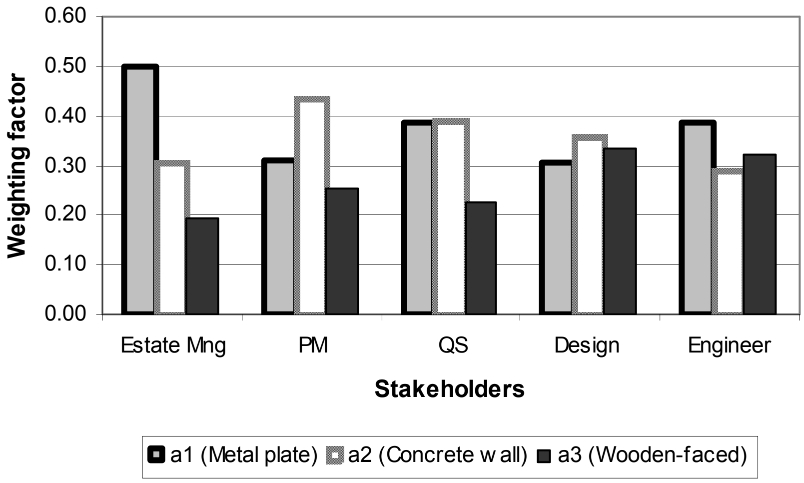

Figure A-32 Weighting Factor of Every Alternative for Each Stakeholder

(4) Determining payoff optimum

Table A-18 and A-19 show process and result for Cost and Function payoff optimum.

Table A-18 Cost Payoff Optimum for Each Coalition on Highway Guardrail Selection

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
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH3	0.503	0.152	0.345	0.351	0.503
		0.945	0.377	0.678		0.945
SH1+4		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH4	0.491	0.085	0.423	0.406	0.491
		0.933	0.310	0.757		0.933
SH1+5		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH5	0.567	0.137	0.297	0.430	0.567
		1.009	0.362	0.630		1.009

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
SH2+4		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
		0.851	0.351	0.797		0.851
SH2+5		a1	a2	a3	Max-min	Optimum
	SH2	0.360	0.266	0.374	0.108	0.374
	SH5	0.567	0.137	0.297	0.430	0.553
		0.927	0.403	0.670		
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
SH3+5		a1	a2	a3	Max-min	Optimum
	SH3	0.503	0.152	0.345	0.351	0.503
	SH5	0.567	0.137	0.297	0.430	0.567
		1.070	0.288	0.642		
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
SH1+2+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
	SH4	0.491	0.085	0.423	0.406	0.491
		1.293	0.576	1.130		1.293
SH1+2+5		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
	SH5	0.567	0.137	0.297	0.430	0.567
		1.369	0.628	1.004		1.369
SH1+3+4		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH3	0.503	0.152	0.345	0.351	0.503
	SH4	0.491	0.085	0.423	0.406	0.491
		1.436	0.462	1.102		1.436
SH1+3+5		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH3	0.503	0.152	0.345	0.351	0.503
	SH5	0.567	0.137	0.297	0.430	0.567
		1.512	0.513	0.975		

SH1+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	SH4	0.491	0.085	0.423	0.406	0.491
	SH5	0.567	0.137	0.297	0.430	0.567
		1.500	0.447	1.053		1.500
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
SH1+2+3+5		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
	SH5	0.567	0.137	0.297	0.430	0.567
		1.872	0.779	1.349		1.872
SH1+2+4+5		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
	SH4	0.491	0.085	0.423	0.406	0.491
	SH5	0.567	0.137	0.297	0.430	0.567
		1.860	0.713	1.427		1.860
SH1+3+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.442	0.225	0.333	0.217	0.442
	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
		2.003	0.599	1.399		2.003

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

Table A-19 Function Payoff Optimum for Each Coalition on Highway Guardrail

Coalition		Alternatives			Payoff Optimum	
SH1+2+3+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		2.780	1.302	0.918		2.780
SH1+2		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
		1.125	0.517	0.358		1.125
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH3	0.544	0.266	0.190	0.354	0.544
		1.101	0.526	0.373		1.101
SH1+4		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH4	0.556	0.259	0.185	0.371	0.556
		1.113	0.519	0.368		1.113
SH1+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH5	0.556	0.259	0.185	0.371	0.556
		1.113	0.519	0.368		1.113
SH2+3		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
		1.111	0.523	0.365		1.111
SH2+4		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH4	0.556	0.259	0.185	0.371	0.556
		1.124	0.516	0.360		1.124
SH2+5		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH5	0.556	0.259	0.185	0.371	0.556
		1.124	0.516	0.360		
SH3+4		a1	a2	a3	Max-min	Optimum
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
		1.100	0.526	0.375		1.100

SH3+5		a1	a2	a3	Max-min	Optimum
	SH3	0.544	0.266	0.190	0.354	0.544
	SH5	0.556	0.259	0.185	0.371	0.556
		1.100	0.526	0.375		

SH4+5		a1	a2	a3	Max-min	Optimum
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		1.112	0.519	0.369		1.112

SH1+2+3		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
		1.668	0.783	0.548		1.668

SH1+2+4		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH4	0.556	0.259	0.185	0.371	0.556
		1.681	0.776	0.543		1.681

SH1+2+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH5	0.556	0.259	0.185	0.371	0.556
		1.681	0.776	0.543		1.681

SH1+3+4		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
		1.657	0.786	0.558		1.657

SH1+3+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH3	0.544	0.266	0.190	0.354	0.544
	SH5	0.556	0.259	0.185	0.371	0.556
		1.657	0.786	0.558		

SH1+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		1.669	0.779	0.552		1.669

SH2+3+4		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
		1.667	0.783	0.550		1.667

SH2+3+5		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH5	0.556	0.259	0.185	0.371	0.556
		1.667	0.783	0.550		1.667

SH2+4+5		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		1.680	0.776	0.545		1.680
SH3+4+5		a1	a2	a3	Max-min	Optimum
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		1.656	0.785	0.559		1.656
SH1+2+3+4		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
		2.224	1.043	0.733		2.224
SH1+2+3+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH5	0.556	0.259	0.185	0.371	0.556
		2.224	1.043	0.733		2.224
SH1+2+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH2	0.568	0.257	0.175	0.393	0.568
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		2.237	1.036	0.728		2.237
SH1+3+4+5		a1	a2	a3	Max-min	Optimum
	SH1	0.557	0.260	0.183	0.374	0.557
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		2.213	1.045	0.742		2.213
SH2+3+4+5		a1	a2	a3	Max-min	Optimum
	SH2	0.568	0.257	0.175	0.393	0.568
	SH3	0.544	0.266	0.190	0.354	0.544
	SH4	0.556	0.259	0.185	0.371	0.556
	SH5	0.556	0.259	0.185	0.371	0.556
		2.223	1.042	0.735		2.223

(5) *Analyzing the best fit options for every coalition and grand coalition.*

The results of analyzing the best fit option using coalition algorithm in Chapter 6 are presented on Table A-20. 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 A-20 Ranking of Highway Guardrail 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

3.7 Similarity Index

The result of similarity index is presented on Table A-21. The table shows that the coalition algorithm model gives satisfaction to all stakeholders.

Table A-21 Similarity Index Result for Highway Guardrail Selection

	Model 1: Single weighting	Model 2: Aggregation	Model 3: Coalition algorithm
Stakeholder 1	>1 = 1	0.934065	0.772583
Stakeholder 2	1	0.643977	0.55980
Stakeholder 3	>1 = 1	>1 = 1	0.840685
Stakeholder 4	>1 = 1	0.927939	0.80472
Stakeholder 5	>1 = 1	>1 = 1	0.996691

3.8 Conclusion of the Case Study

In this case study, 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 is presented in Table A-20. The table 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.

Case study 4: Support Bridge Selection

4.1 Background

This case study was on the selection of suitable material for a support bridge structure (Utomo, et al., 2009e) involving three decision makers, who are an Estate Manager, Project Manager, and Engineer. There are three alternative solutions for the material of the support bridge structure, which are (a1) steel, (a2) reinforced concrete and (a3) wood.

4.2 Function Analysis of Support Bridge

The functions of Support Bridge are identified by performing FAST analysis on the problem. Fig. 2 shows the FAST diagram; the identified function will become the attributes for decision.

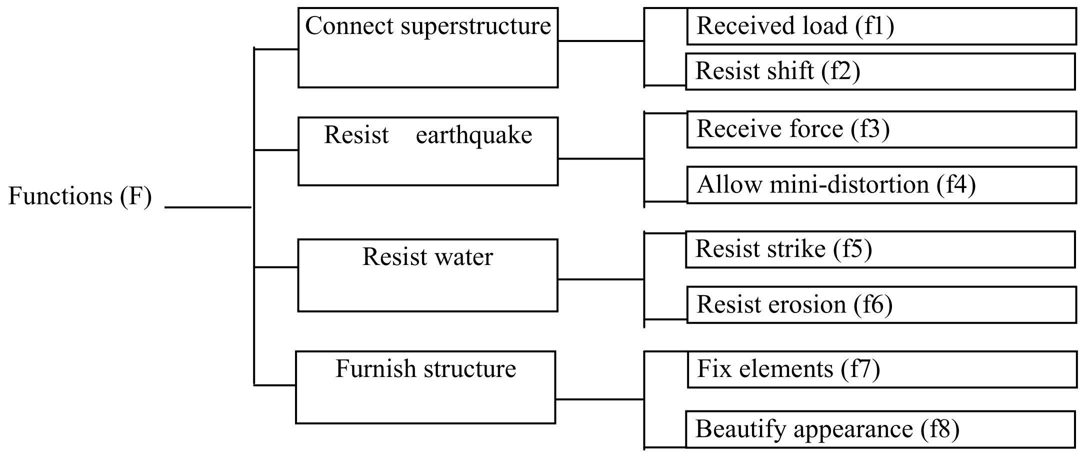

Figure A-33 FAST Diagram of the Support Bridge

4.3 Life Cycle Cost of the Support Bridge

The cost of the support bridge was calculated; here the energy cost was not calculated because its cost is not involved in a support bridge. Table A-22 presents LCC and initial cost (including investment cost). Similar to the other three case studies, Equation (2.3) was used to calculate the O&M cost since these costs have annual basis. Equation (2.2) was used for replacement cost since this cost has variability in period.

Table A-22 Cost of the Support Bridge

Cost category	Present Worth (1000USD)		
	a1	a2	a3
Initial	8102	5600	3720
LCC	40135	22625	55320

4.4 Support Bridge Selection

Figure A-34 shows four levels of decision hierarchy. The goal (G) of the problem is "To select the best choice for Support Bridge”. The goal is addressed by some alternatives (A = a1; a2; a3) which are steel bridge structure, reinforced bridge structure, and wooden bridge structure respectively. The problem is split into two value criteria namely Function (Cf) and Cost (Cc), which are divided further into respective sub-criteria f1, f2, f3, f4, f5, f6, f7, f8, and c1and c2.

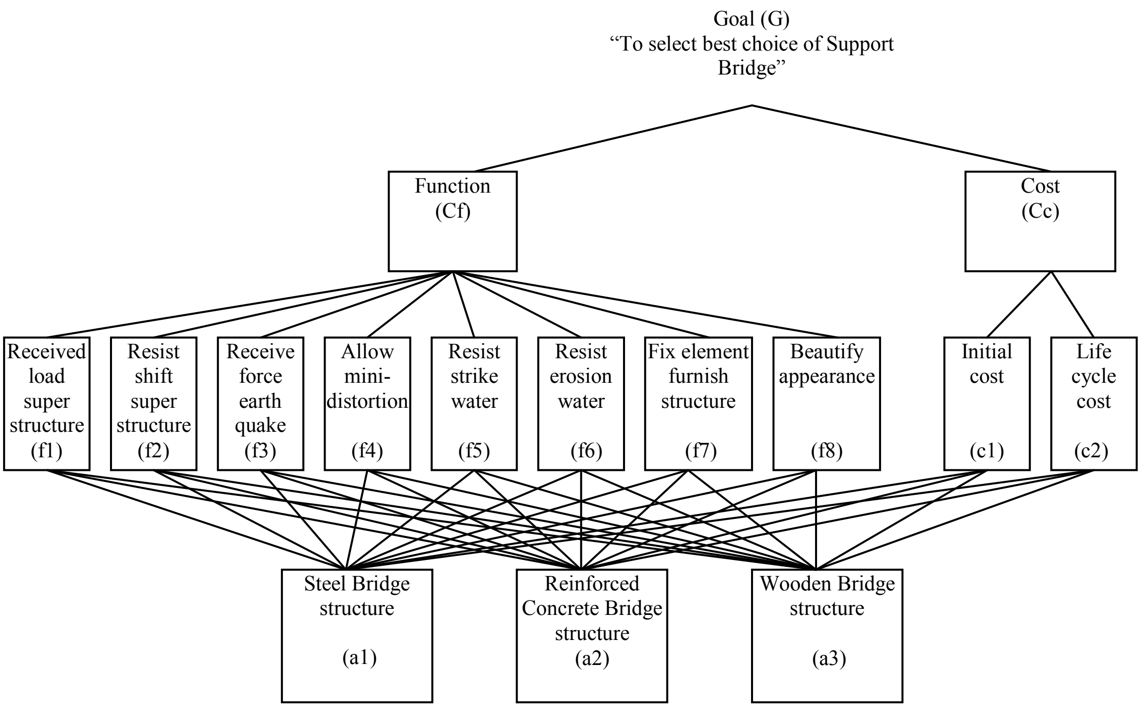

Figure A-34 Decision Hierarchy to Choose Support Bridge

Table A-23 Weighting Factor of Each Alternative to Each Stakeholder

	Synthesis from AHP judgment and calculation on 3 Stakeholders										
	(f1)	(f2)	(f3)	(f4)	(f5)	(f6)	(f7)	(f8)	(c1)	(c2)	Weight
Stakeholder 1 (Estate Manager)											
a1 (steel bridge)	0.045	0.024	0.027	0.086	0.114	0.046	0.006	0.023	0.004	0.038	0.414
a2 (reinforced concrete)	0.023	0.009	0.007	0.037	0.025	0.016	0.049	0.013	0.009	0.146	0.334
a3 (wooden)	0.008	0.005	0.014	0.023	0.053	0.010	0.028	0.059	0.029	0.024	0.252
Stakeholder 2 (Project Manager)											
a1 (steel bridge)	0.020	0.016	0.013	0.021	0.003	0.011	0.008	0.026	0.093	0.021	0.232
a2 (reinforced concrete)	0.012	0.006	0.005	0.012	0.015	0.035	0.040	0.021	0.410	0.080	0.634
a3 (wooden)	0.004	0.004	0.006	0.006	0.002	0.005	0.021	0.023	0.053	0.011	0.134
Stakeholder 3 (Engineer)											
a1 (steel bridge)	0.046	0.031	0.034	0.051	0.030	0.065	0.012	0.045	0.002	0.020	0.335
a2 (reinforced concrete)	0.027	0.014	0.008	0.025	0.005	0.030	0.079	0.023	0.010	0.096	0.317
a3 (wooden)	0.008	0.009	0.013	0.013	0.010	0.020	0.044	0.217	0.004	0.012	0.349

4.5 Satisfying Option on Value Criteria

In this case study, initial cost and LCC are identified as 'Cost' and all 6 other functions which are 'received load', 'resist shift', 'receive forced'. Allow mini distortion', 'resist strike', 'resist erosion', 'fix elements', and 'beauty appearance' are identified as 'Function'. Table A-24 shows the selectability (Ps) and rejectability (Pr) that represent function and cost of support bridge solutions. An option will be a rejectability options if the value of the options is below F/C=1 or the cost is higher than the function. In other word it can be said that there is unnecessary cost in the technical solution option.

Table A-24 Cost and Function of Support Bridge Options

	Cost				Function								Normalization	
	c1	c2	∑	Loss	f1	f2	f3	f4	f5	f6	f7	f8	Cost (Pr)	Function (Ps)
a1	0.10	0.18	0.28	0.91	0.60	0.62	0.57	0.59	0.59	0.64	0.08	0.24	0.57	0.49
a2	0.21	0.70	0.91	0.28	0.30	0.24	0.14	0.25	0.13	0.23	0.59	0.14	0.18	0.25
a3	0.69	0.11	0.80	0.40	0.10	0.14	0.29	0.16	0.28	0.14	0.33	0.62	0.25	0.26

Figure A-35 provides a cross plot of function of the technical solution options. The figure is based on the result from Table A-24. Observe that although a1 has the highest function, it also has the high cost which resulted in its value below F/C=1. In this case study, the highest value is a2 since it gives the highest satisfaction due to its low function and low cost.

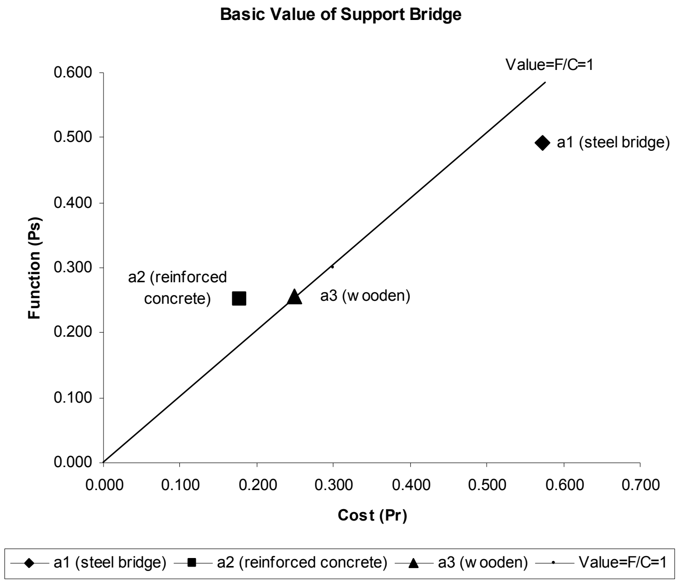

Figure A-35 Basic Value of Support Bridge Options

Figures A-36, A-37, and A-38 provide cross plots of function and cost of the estate manager, project manager, and engineer respectively. Observe the influence of the estate manager's preference on a1. Basically that a1 is a rejected option since it has a value less than F/C=1. The estate manager's preference changes it to a value more than F/C=1, which made it to fall into selectability options.

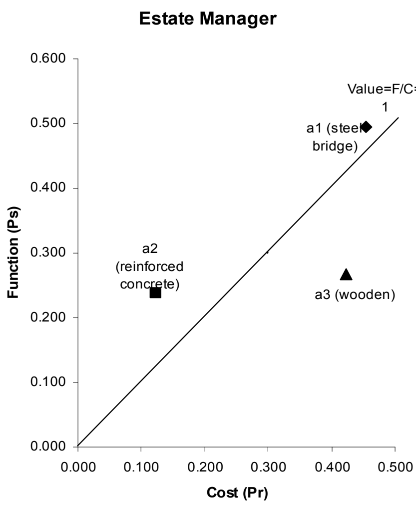

Figure A-36 Value of Support Bridge Options for Estate Manager

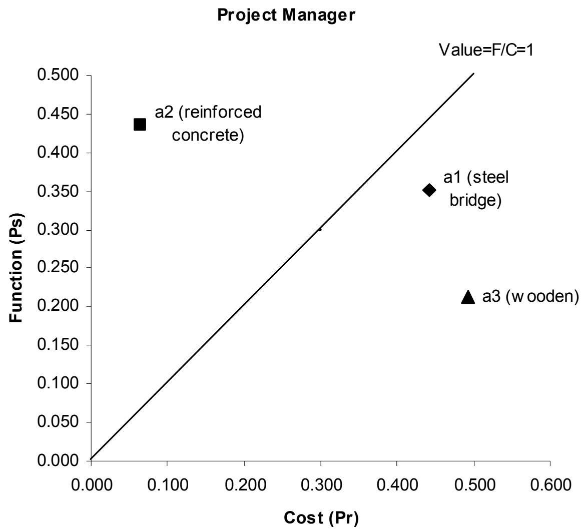

Figure A-37 Value of Support Bridge Options for Project Manager

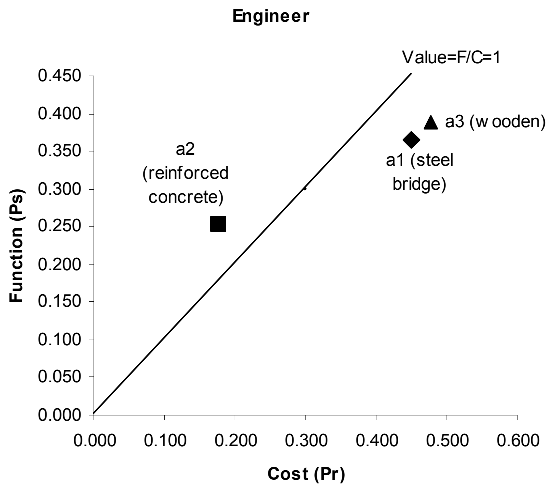

Figure A-38 Value of Support Bridge Options for Engineer

4.6 Agreement Options and Coalition

(1) *Determining the weighting factor (weight of preferences) of each criteria for each stakeholder and the aggregation.*

Based on the pair wise comparison of each criterion, Figure A-39 reveals the different preferences among the three stakeholders.

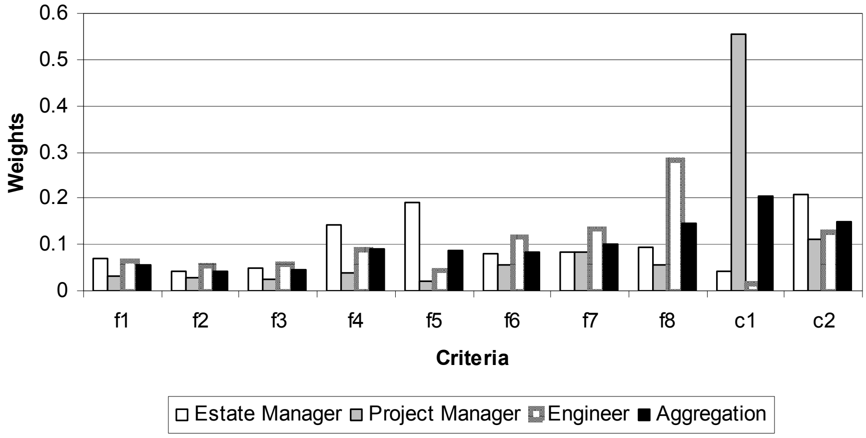

Figure A-39 Weight of Preferences for Each Stakeholder

(2) *Grading alternative for each evaluation criteria.*

Figure A-40 shows that a1 is the 'best fit' for f1, f2, f3, f4, f5, and f6. The 'best fit' solution for c1 and f8 is a3, and a2 for c2 and f7.

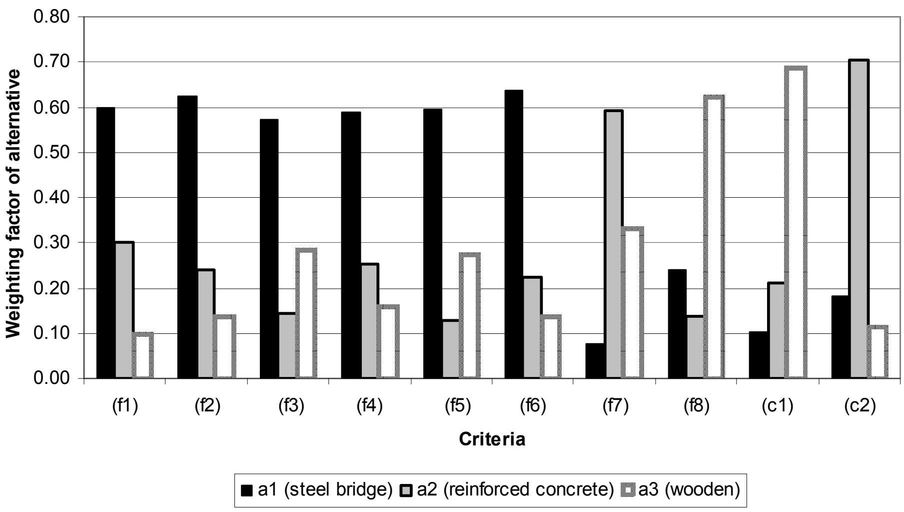

Figure A-40 Weighting Factor of Every Alternative for Each Criteria

(3) *Scoring every alternative for every stakeholder.*

Figure A-41 shows that each stakeholder has different best option as the solution alternative. Here, before conducting negotiation, the estate manager chose steel structure as the best choice; the project manager chose reinforced concrete structure, while the engineer chose wooden bridge structure as the best choice.

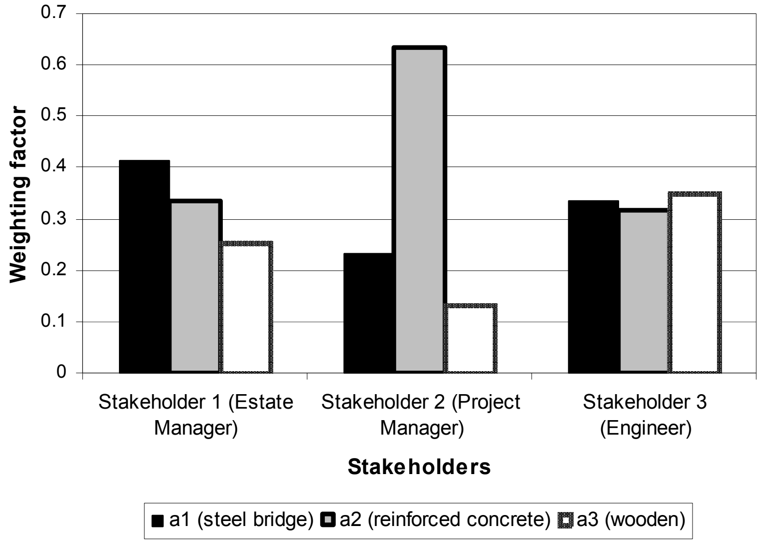

Figure A-41 Weighting Factor of Every Alternative for Each Stakeholder

(4) Determining payoff optimum

The payoff optimum for every stakeholder and every alternative was determined by using Equations 6.1-6.4, and the values are tabulated on Tables A-25 and A-26 for Cost and Function respectively.

Table A-25 Cost Payoff Optimum for Each Coalition on Support Bridge Selection

Coalition		Alternatives			Payoff Optimum	
SH1+2+3		a1	a2	a3	Max-min	Optimum
	SH1	0.455	0.123	0.422	0.331	0.455
	SH2	0.443	0.064	0.493	0.429	0.461
	SH3	0.450	0.072	0.477	0.405	0.477
		1.348	0.260	1.393		
SH1+2		a1	a2	a3	Max-min	Optimum
	SH1	0.455	0.123	0.422	0.331	0.455
	SH2	0.443	0.064	0.493	0.429	0.461
		0.897	0.188	0.915		
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.455	0.123	0.422	0.331	0.455
	SH3	0.450	0.072	0.477	0.405	0.450
		0.905	0.195	0.900		
SH2+3		a1	a2	a3	Max-min	Optimum
	SH2	0.443	0.064	0.493	0.429	0.493
	SH3	0.450	0.072	0.477	0.405	0.477
		0.893	0.136	0.970		

Table A-26 Function Payoff Optimum for Each Coalition on Support Bridge Selection

Coalition		Alternatives			Payoff Optimum	
SH1+2+3		a1	a2	a3	Max-min	Optimum
	SH1	0.495	0.239	0.267	0.256	0.388
	SH2	0.352	0.436	0.212	0.224	0.436
	SH3	0.366	0.246	0.389	0.143	0.389
		1.212	0.920	0.867		
SH1+2		a1	a2	a3	Max-min	Optimum
	SH1	0.495	0.239	0.267	0.256	0.411
	SH2	0.352	0.436	0.212	0.224	0.436
		0.847	0.674	0.479		
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.495	0.239	0.267	0.256	0.471
	SH3	0.366	0.246	0.389	0.143	0.389
		0.860	0.484	0.655		
SH2+3		a1	a2	a3	Max-min	Optimum
	SH2	0.352	0.436	0.212	0.224	0.436
	SH3	0.366	0.246	0.389	0.143	0.282
		0.718	0.681	0.601		

(5) *Analyzing the best fit options for every coalition and grand coalition.*

The results are presented on Table A-27. It shows the best fit option process. It also presents the ranking of the technical solutions for Support Bridge.

Table A-27 Ranking of Support Bridge Solutions for Every Coalition

Alternative ranking and coalition	Priorities		
	a1	a2	a3
SH 1 (Estate Manager)	1^{st}	2^{nd}	3^{rd}
SH 2 (Project Manager)	2^{nd}	1^{st}	3^{rd}
SH 3 (Engineer)	2^{nd}	3^{rd}	1^{st}
Aggregation	2^{nd}	1^{st}	3^{rd}
Coalition SH1 and SH2	2^{nd}	3^{rd}	1^{st}
Coalition SH1 and SH3	2^{nd}	1^{st}	3^{rd}
Coalition SH2 and SH3	1^{st}	2^{nd}	3^{rd}
Grand coalition	1^{sd}	2^{nd}	3^{rd}
RESULT	1^{st}	2^{nd}	3^{rd}

4.7 Similarity Index

The result of similarity index is presented on Table A-28. The table shows that coalition algorithm model gives satisfaction to all stakeholders.

Table A-28 Similarity Index Result for Support Bridge Selection

	Model 1: Single weighting	Model 2: Aggregation	Model 3: Coalition algorithm
Stakeholder 1	>1 = 1	>1 = 1	0.45625
Stakeholder 2	1	0.588	0.384
Stakeholder 3	>1 = 1	>1 = 1	0.28125

4.8 Conclusion of the Case Study

Firstly, individually all stakeholder have their own best solution. Finally, as shown on Table A-27, steel structure (a1) is found to be the 'best fit' solution for all stakeholders after coalition. On this case, it can be observed that the best solution based on aggregation is different with the best solution after coalition formation. This finding is supported by the result in Figure A-40. This figure shows that a1 have the highest weighting factor on the six criteria from the ten criteria.

Case study 5: Building Energy System Selection

5.1 Background

The need to provide energy-efficient design is becoming more important. This is especially true in relationship to the design life of a project. A means of accounting for the energy uses for the construction and operation of a building is therefore needed. New building designs display an increasing awareness of sustainability but invariability assumed a certain level of technical sustainability, and concentrates more on economic and social sustainability. At times it is difficult to quantify and qualify the importance of value other than those relating to only cost. In this case study, decision must be made on the energy system for affordable housing (Utomo, et al., 2008b) involving three groups of decision makers namely Design Management, Facility Management and Project Management.

The available alternatives for a building energy system are:

1. Passive energy. This alternative utilizes an architectural concept of passive energy buildings; maximum opening wall for natural lighting and air conditioning.
2. Electrical equipment. It utilizes electrical equipments for example, lighting and air conditioners.

'User processes'. The utilization of energy for a building depends on the 'user processes'. It processes through out life cycle of buildings; a building is equipped with electrical wiring but no electrical equipments are provided.

5.2 Function Analysis of Building Energy System

Based on the process of FAST, there are three sustainability functions that are technical, economic, and social sustainability. Figure A-42 presents the function together with the life cycle cost of technical solution. For some functions it may be decided that a set of generic process is needed to perform the function, each of which will give rise to an associated set of possible specific processes. A number of processes may be identified as being probable candidates for performing the function.

In this case study there are three functions of sustainability, which are technical, economic, and social.

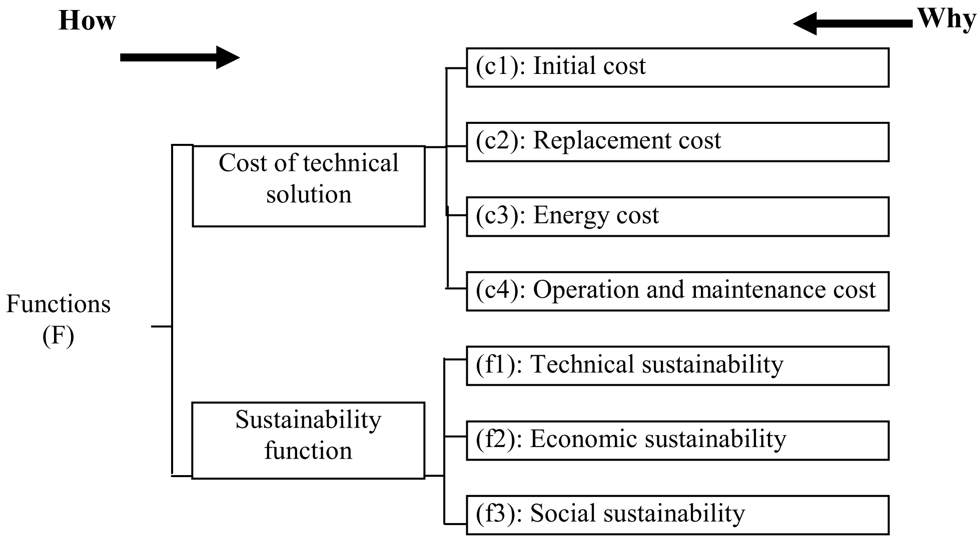

Figure A-42 FAST Diagram of Building Energy System

5.3 Life Cycle Cost of Building Energy System

In all of case studies, salvage value was not calculated because it was not a practice in Indonesia. Table A-29 presents LCC and the proportion for each category; initial cost (including investment cost), energy cost, operation and maintenance (O&M) cost, and replacement cost. It is difficult to separate energy system cost from the total cost of housing because some of the energy system is part of the housing system.

Table A-29 Life Cycle Cost of Building Energy System

Cost category	Present Worth of alternatives (USD1000)		
	Passive energy	Electrical equipment	User Process
Initial	2102	1600	1720
Energy	135	625	320
Operation & Maintenance	1115	3200	1600
Replacement	83	316	236
Total Cost	3437	5741	3876

5.4 Building Energy System Selection

Figure A-43 shows a model of decision hierarchy based on LCC and sustainable function for an affordable public housing and infrastructure in Indonesia. Each of the objects in this model contains attribute representing their various properties and different preferences. The goal of the problem (G ="to select energy system of a building in sustainability function") is addressed by some alternatives (A = a1; a2; a3). The problem is split into subproblems (c1, c2, c3, c4, f1, f2, f3) which are the evaluation criteria. Three stakeholders were involved and each has their own preference. The result based on individual judgment is presented on Table A-30.

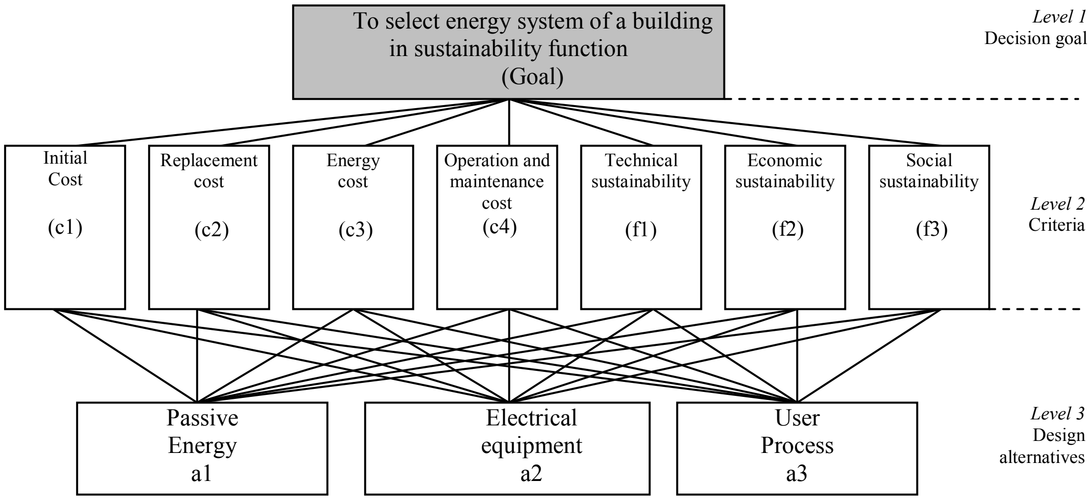

Figure A-43 Decision Hierarchy of Building Energy System Selection

Table A-30 Weighting Factor of Each Alternative for Individual Stakeholder

	c1	c2	c3	c4	f1	f2	f3	WEIGTH
				Stakeholder 1 (Facility Management)				
a1	0.0020	0.0286	0.0642	0.2499	0.0136	0.0496	0.0335	0.4415
a2	0.0075	0.0054	0.0054	0.0471	0.0504	0.0202	0.0145	0.1506
a3	0.0172	0.0152	0.0192	0.0887	0.0216	0.1206	0.1256	0.4079
				Stakeholder 2 (Design Management)				
a1	0.0030	0.0293	0.2182	0.0575	0.0292	0.0578	0.0219	0.4168
a2	0.0114	0.0055	0.0185	0.0108	0.1080	0.0235	0.0095	0.1872
a3	0.0260	0.0156	0.0651	0.0204	0.0462	0.1405	0.0822	0.3959
				Stakeholder 3 (Project Management)				
a1	0.0255	0.0135	0.0532	0.0259	0.0436	0.0410	0.0168	0.2194
a2	0.0977	0.0026	0.0045	0.0049	0.1611	0.0167	0.0072	0.2946
a3	0.2223	0.0072	0.0159	0.0092	0.0689	0.0997	0.0629	0.4860

5.5 Satisfying Option on Value Criteria

The technical solution options for building energy system were categorized into ‘Cost’ identified by initial cost, replacement cost, energy cost, and operation and maintenance cost; and 'Function' by all three functions. Table A-31 shows the selectability (Ps) and rejectability (Pr) that represent function and cost of technical solution of building energy system respectively.

Table A-31 Cost and Function of Building Energy Options

	Cost						Function			Normalization	
	c1	c2	c3	c4	∑	Loss	F1	F2	F3	Cost (Pr)	Function (Ps)
a1 (passive)	0.07	0.58	0.72	0.65	2.03	0.58	0.16	0.26	0.19	0.151	0.204
a2 (electric)	0.28	0.11	0.06	0.12	0.58	2.03	0.59	0.11	0.08	0.532	0.259
a3 (user)	0.64	0.31	0.22	0.23	1.40	1.20	0.25	0.63	0.72	0.316	0.536

Based on the result presented on Table A-31, Figure A-44 provides a cross plots of function of the technical solution options. In this case the highest value is a3. It gives highest satisfaction since it has the highest function and medium cost.

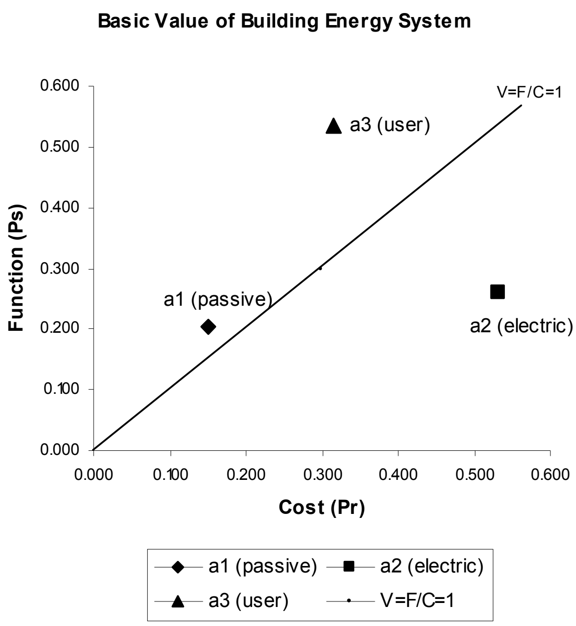

Figure A-44 Basic Value of Building Energy System

Figures A-45, A-46, and A-47 provide a cross plots of function and cost of facility management, design management, and project management respectively. Observe the influence of project management preference influence on a1. Basically a1 has value more than F/C=1. The project management's preference changed it to a value of less than F/C=1.

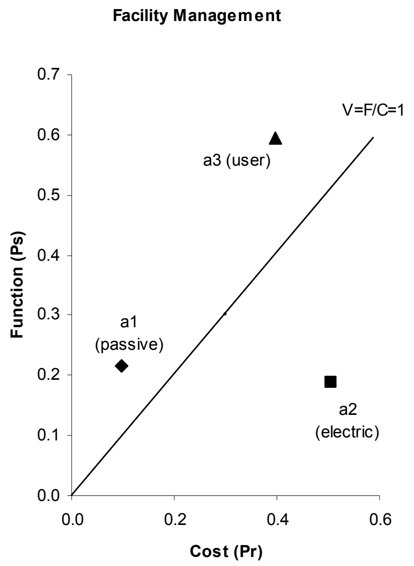

Figure A-45 Value of Building Energy System Options for Facility Management

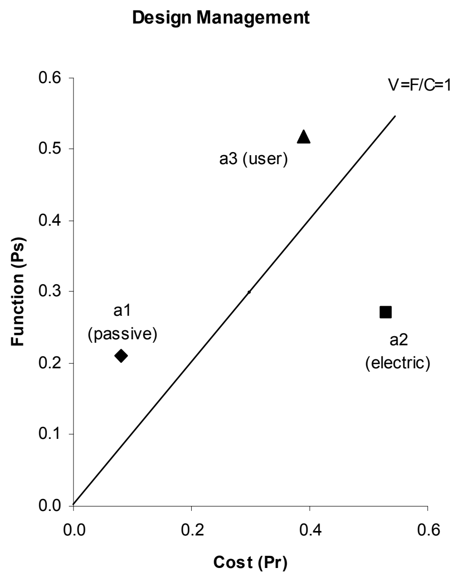

Figure A-46 Value of Building Energy System Options for Design Management

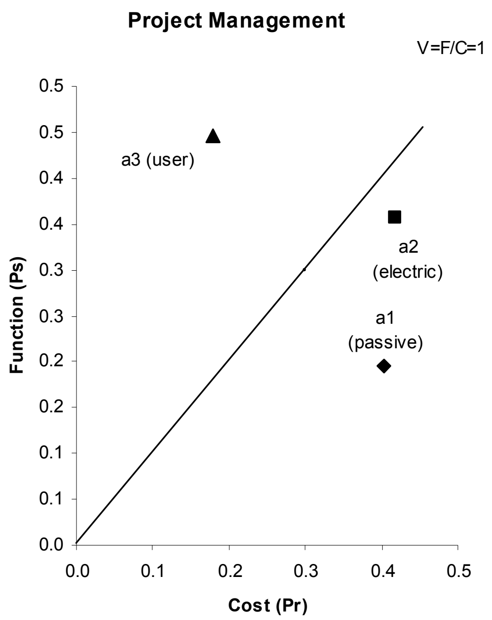

Figure A-47 Value of Building Energy System Options for Project Management

5.6 Agreement Options and Coalition

(1) *Determining the weighting factor (weight of preferences) of criteria for each decision-maker.*

Figure A-48 reveals different preferences among stakeholders.

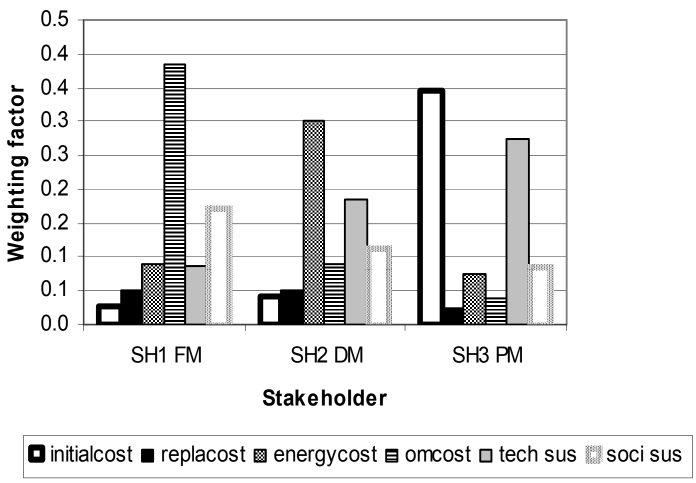

Figure A-48 Weight of Building Energy Criteria for Individual Stakeholder

(2) *Grading alternative for each evaluation criteria.*

Figure A-49 shows that every criteria has different priorities of options.

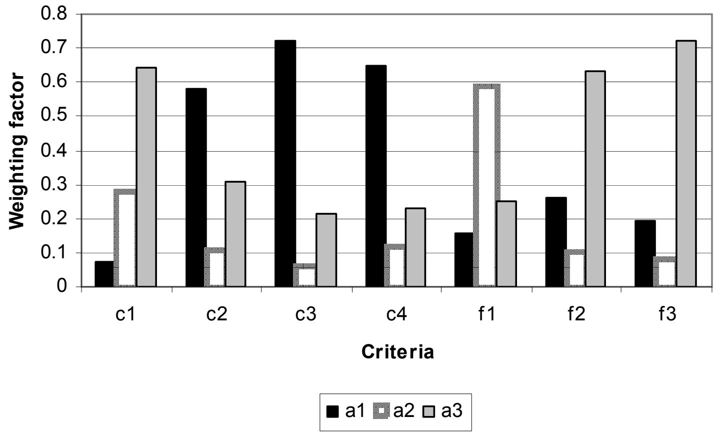

Figure A-49 Weighting Factor of Every Alternative for Each Criteria

(3) *Scoring every alternative for every decision-maker.*

Figure A-50 shows that every stakeholder has different alternative solutions. But only two alternatives are identified as the best options, which are a1and a3.

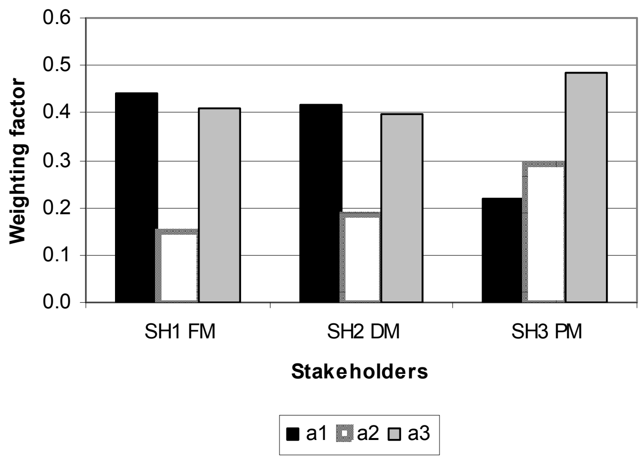

Figure A-50 Weighting Factor of Every Alternative for Each Stakeholder

(4) *Determining payoff optimum*

Table A-32 and A-33 present the process and result of payoff optimum for Cost and Function respectively.

Table A-32 Cost Payoff Optimum on Building Energy System Selection for Each Coalition

Coalition		Alternatives			Payoff Optimum	
SH1+2+3		a1	a2	a3	Max-min	Optimum
	SH1	0.096	0.507	0.397	0.410	0.507
	SH2	0.080	0.530	0.391	0.450	0.530
	SH3	0.403	0.417	0.180	0.237	0.417
		0.579	1.454	0.967		1.454
SH1+2		a1	a2	a3	Max-min	Optimum
	SH1	0.096	0.507	0.397	0.410	0.507
	SH2	0.080	0.530	0.391	0.450	0.530
		0.176	1.036	0.788		1.036
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.096	0.507	0.397	0.410	0.507
	SH3	0.403	0.417	0.180	0.237	0.417
		0.500	0.924	0.577		0.924
SH2+3		a1	a2	a3	Max-min	Optimum
	SH2	0.080	0.530	0.391	0.450	0.530
	SH3	0.403	0.417	0.180	0.237	0.417
		0.483	0.947	0.570		0.947

Table A-33 Function Payoff Optimum on Building Energy Selection for Each Coalition

Coalition		Alternatives			Payoff Optimum	
SH1+2+3		a1	a2	a3	Max-min	Optimum
	SH1	0.215	0.189	0.596	0.406	0.596
	SH2	0.210	0.272	0.518	0.308	0.518
	SH3	0.196	0.357	0.447	0.251	0.447
		0.621	0.818	1.561		1.561
SH1+2		a1	a2	a3	Max-min	Optimum
	SH1	0.215	0.189	0.596	0.406	0.596
	SH2	0.210	0.272	0.518	0.308	0.518
		0.425	0.461	1.114		1.114
SH1+3		a1	a2	a3	Max-min	Optimum
	SH1	0.215	0.189	0.596	0.406	0.596
	SH3	0.196	0.357	0.447	0.251	0.447
		0.411	0.547	1.042		1.042
SH2+3		a1	a2	a3	Max-min	Optimum
	SH2	0.210	0.272	0.518	0.308	0.518
	SH3	0.196	0.357	0.447	0.251	0.447
		0.406	0.629	0.965		0.965

(5) *Analyzing the best fit options for every coalition and grand coalition.*

The result is presented on Table A-34. It also presents the result of priorities of the technical solution for building energy system selection in the first negotiation round.

Table A-34 Ranking of Building Energy System Solution on Each Coalition

Alternatives ranking for each stakeholder and coalition	Ranking of alternatives		
	a1	a2	a3
SH1 (Facility Management)	1st	3rd	2nd
SH2 (Design Management)	1st	3rd	2nd
SH3 (Project Management)	3rd	2nd	1st
Coalition SH1 and SH2	2nd	3rd	1st
Coalition SH1 and SH3	2nd	3rd	1st
Coalition SH2 and SH3	3rd	2nd	1st
Grand Coalition	2nd	3rd	1st
RESULT	2nd	-	1st

5.7 Similarity Index

The result of similarity index is presented on Table A-35. The table shows that coalition algorithm model gives satisfaction to all stakeholders.

Table A-35 Similarity Index Result for Building Energy System Selection

	Model 1: Single weighting	Model 2: Aggregation	Model 3: Coalition algorithm
Stakeholder 1	>1 = 1	0.960261	0.884608
Stakeholder 2	>1 = 1	>1 = 1	0.961113
Stakeholder 3	1	0.789802	0.707244

5.8 Conclusion of the case study

In this case, electrical equipment (a2) is not an option because no one or coalition selects this solution as an option. Table A-34 indicates that ‘user process’ (a3) is the best solution. The results are supported by Figure A-49. This figure indicates that both a3 and a1 (passive energy) have the highest weighting factor on three criteria. Solution a2 has only one criteria with highest weighting factor which is technical sustainability.