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The Weights Detection of Multi-Criteria by using Solver

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ABSTRACT

Multi criteria, which are generally used for decision analysis, have certain characteristics that relate to the purpose of the decision. Multi criteria have complex structures and have different weights depending upon the consideration of assessors and the purpose of the decision also. Expert's judgment will be used to detect the criteria weights that applied by assessors. The aim of this study is a model to detect the criteria weights and biases on the subcontractor selection and detecting the significant weights, as decisive criteria. A method, which is used to modeling the weights detection, is the Solver Application. Data, totaling 40 sets, has been collected that consist of the assessor's assessment and the expert's judgment. The result is a pattern of weights and biases detection. The proposed model have been able to detect of 20 criteria weights and biases, that consist of 4 criteria in the total weights of 60% (as decisive criteria) and 16 criteria in the total weights of 40%. A model has been built by training process performed by the Solver, which the result for MSE training is 9.73711e-08 and for MSE validation is 0.00900528. Novelty in the study is a model to detect pattern of weights criteria and biases on subcontractor selection by transferring the expert's judgment using Solver Application.

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1. INTRODUCTION

The main contractor as a company who is responsible for completing the construction work should be able to act effectively and efficiently. One of the actions to support the result is by partnering with the right subcontractor. Partnering with the subcontractor will provide good result if the partnering is started with the process of qualifying a subcontractor properly, by applying the decision-making procedure correctly [1]. The procedure is important, such as determining the weights and decision criteria.

The Assessors, as the persons are doing the evaluation process for the selection of subcontractors, often have differences in determining the criteria weights and sometimes involve subjectivity [1], [2]. The criteria and its weights are not transparent in the selection process [2], sometimes, will make stumped the subcontractor in a strategy to win the bidding proposal. Subcontractor as potential partners must perform the proper analysis for the weights of the criteria that most determine and affect the assessment of assessors. Incomplete data information about the weights of the criteria will cause a problem in analyzing.

Based on these background, the problems to be answered in this study are how the weights pattern of the criteria and biases in the decision hierarchy structures of the subcontractor selection that are made by the assessors and how to detect the significant weights as decisive criteria. Implementing of these objectives, it needs the assessment of expert's judgments that perceived will represent ideal conditions [2].

Various methods and techniques have been conducted to assess the criteria weights, such as Decision Support Systems (DSS) or Expert Systems (ES), generally do not succeed in transferring properly

the experts' judgment, mainly due to the not transparent logic of the decision process [2]. It is in line with opinion of Saif SM et.al stated that "An expert system should able to explain the solution, but presenting the reason for the results obtained with a neural network is difficult" [3]. The Artificial Neural Network (NN) [2], Fuzzy Logic (FL) [1] are able to solve problems unstructurable, uncertainty and ambiguity, subjectivity and also succeeds to transfer expert judgment [2]. NN model and FL models are not ideal for a structured problem, such as the problem of multi-criteria in the subcontractor selection. The two model are possible for a practical and pragmatic purposes, otherwise it is not possible for decisions that require a little bit formal and the availability of clear rules. NN model and FL model, which are in black box, could not answer about the fundamental questions or reasons to support the decision.

This research is proposed to anticipate the problem solving of weights detection for subcontractor selection. Data generating will conduct to pattern the criteria weights of the subcontractor selection decision and to visualize the pattern the criteria weights, as pattern in the structure hierarchy of the decision. The advantages of the methods are able to show the pattern of the criteria weights directly (not in the black box) in hierarchy structures of decision. The novelty in this study, as the modeling that using the Solver Application, is ability to detect the criteria weights and biases of assessments of assessors and transfer expert's judgment, like machine learning concept, and it can be visualized as the structured logical model of weighted criteria on subcontractor selection decisions.

2. RESEARCH METHOD

2.1. Method Characteristic

Decision with multi criteria represents the selection of alternatives that satisfies the objective stated in problem statement [4], [5]. The decision alternatives (i) are the number of subcontractors that will be evaluated by assessors. Multi criteria of the decision (j) are the assessed aspects regarding the purpose of the decision [6]. The criteria weights of decision (w) are the importance levels of criteria that are provide proportion on results [7]. Assessments of assessors (n) are the assessment of object that is judges based on the criteria of the decision. Biases of assessors (b) are the preferences that are the experiences, the view of life, subjectivity, etc, assumed as biases in this decision model. Expert's judgment (t) is the judgment from the expert who has experience in the fields of procurement process and has the expertise to do the assessments on the selection of subcontractors. Framework diagram used to analyze the criteria weights in serve in the Figure 1.

The concept describes adjustment of the criteria weights and biases to find patterns of expert's judgment, as the basis of the selection for assessors in deciding the best subcontractors. The discovery of a pattern known as the learning process that is done by adjusting the criteria weights and biases to generate output. Goal of the desired output is equal to the value of the target that is the expert judgment.

The concept can be applied the modelling pattern of identification in other fields. The advantage of this model is able to identify the pattern of the criteria weights and to detect assessors who have the different pattern based on assessment the expert's judgment. The Solver may perform the value of the criteria weights and the biases, which have further analysis. Analysis for system used is based on a Ms Excel worksheet.

The biases are used to analyze the pattern of input data that are deviate the available data in general. This condition indicates that the identification of the model will also be used on advanced statistical techniques [8].

2.2. Data Set

The 40 dataset for the assessor's assessments and expert's judgments of the subcontractor selection have collected from the lead firms of construction that is involved in project construction in Banda Aceh. The data are consists of the assessor's assessments as an input and the expert's judgments as the target for the model development. The data will be trained by using the Solver Application to adjust the criteria weights, biases and the output of this proposed model that is compared toward expert's judgment [2]. The result of this proposed model, namely the weights criteria and biases, will be presented in the form of a pairwise matrix of the criteria and alternatives. The data are divided into 2 groups, which consist of 25 dataset for learning of the proposed model as presented in Table 1 (attached in appendix) and 15 dataset for validation of the proposed model as presented in Table 2 (attached in appendix).

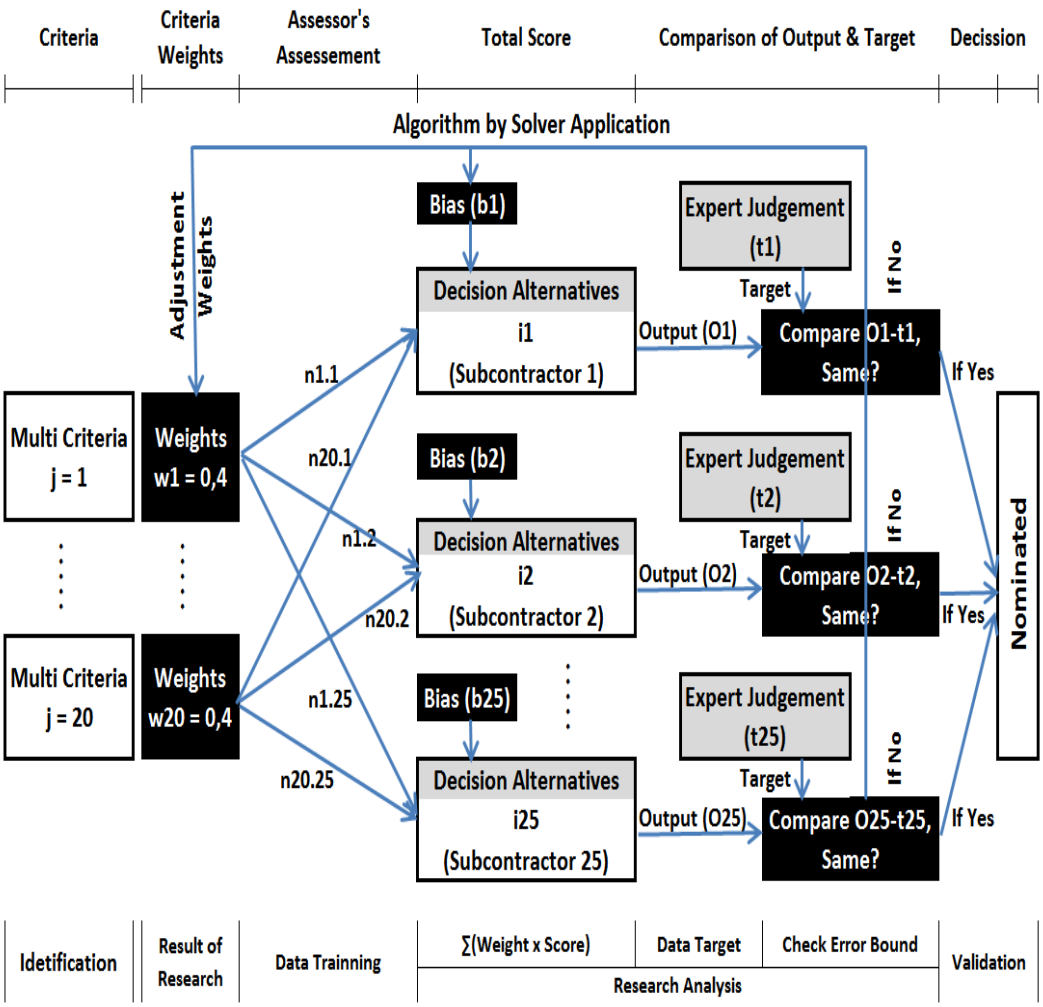

Figure 1. Framework of detecting the criteria weights of the decision

3. RESULTS

The weights of the criteria for the subcontractor selection in this research are obtained from the training process by using the Solver. Result of the criteria weights showed a uniform pattern for each alternative (prospective partner), as shown in Table 3 (attached in appendix). The best training the weights of criteria D (execution time) and E (type of project references) is shown as a zero value for the biases and standard deviation. It is possible in these training due to the sub criteria only one.

The biases, which are the value of the subjective factor, are difference between the assessor's assessments toward the expert's judgment. The biases are the parameter, which are a companion of the criteria, in understanding of expert's judgment. The result of the biases can be used as benchmarks to determine assessors who have high subjectivity level and a different pattern from the ideal conditions of the expert's judgment decision (the target). Standard deviations are variation of the weights criteria, which have been patterned of the assessor's assessments. The standard deviation shows a small the difference value, which indicates the uniform in weighting process for all alternatives (subcontractors).

4. DISCUSSION

4.1. Mean Square Error (MSE)

Training performance by the Solver is quite good with result of the MSE training of 9.73711e-08. Training curve of this model describe changes in error descending of -0.004 and the significant descending at the end of -0.02. The descending of MSE in training was occurring in constant manner and stable. This indicates that the training process to adapt the pattern was successful, as shown in Figure 2.

MSE of training on the main criteria, namely the subcontractor credibility (curve 1), quotation (curve 2), technical capability (curve 3), execution time (curve 4), kind of project references (curve 5) are successively 6.89903e-08, 1.3762e-07, 1.18952e-07, 9.722e-08, 7.90946e-08, as shown in Figure 2.

The error bound, which are reduction of output model to target, have two extreme data of 15 the error bound data, namely point 4 and 6, as shown in Figure 3. Overall error bound of the model provides results for MSE validation of 0.00900528 with a standard deviation for the square error is 0.13508, as shown in Figure 4.

The results of both MSE training and MSE validation is indicating the Solver has the ability to find patterns of the criteria weights and biases that is used by assessors in the subcontractor selection. Furthermore, the models can be used as a management's tool for the subcontractor selection as well.

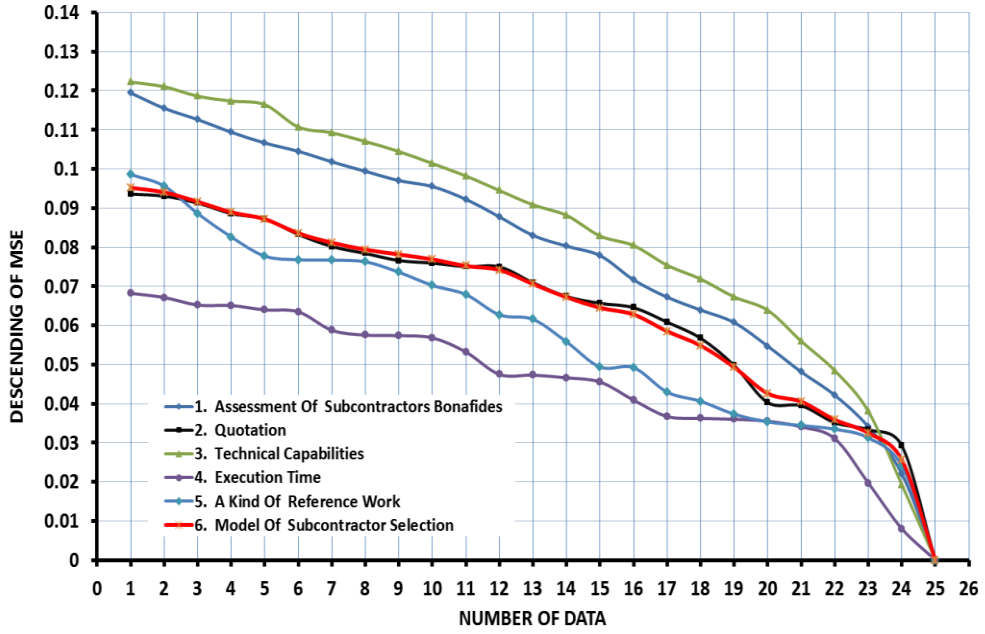

Figure 2. Training Curve for Model of Subcontractor Selection

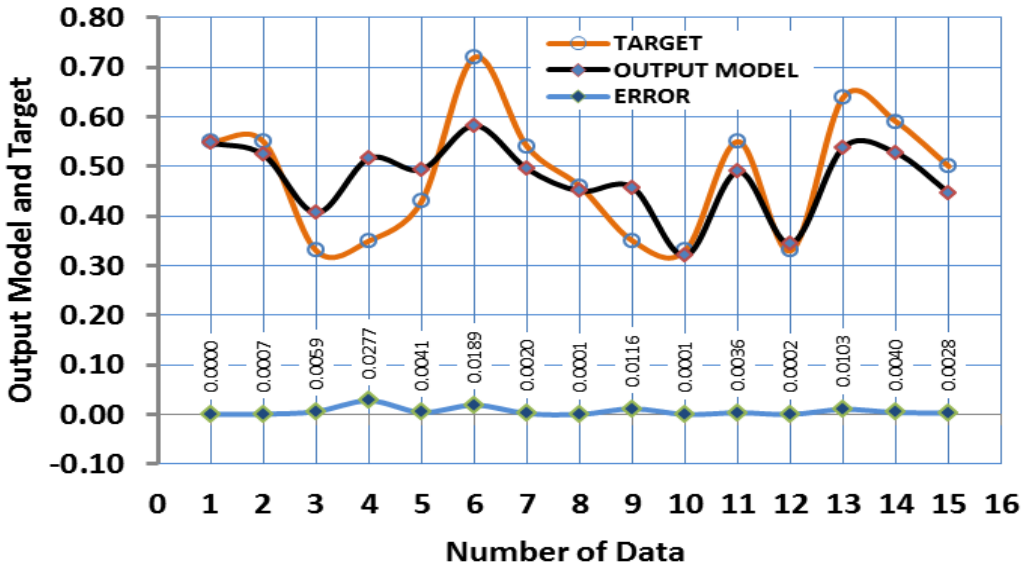

Figure 3. Error bound of Validation data

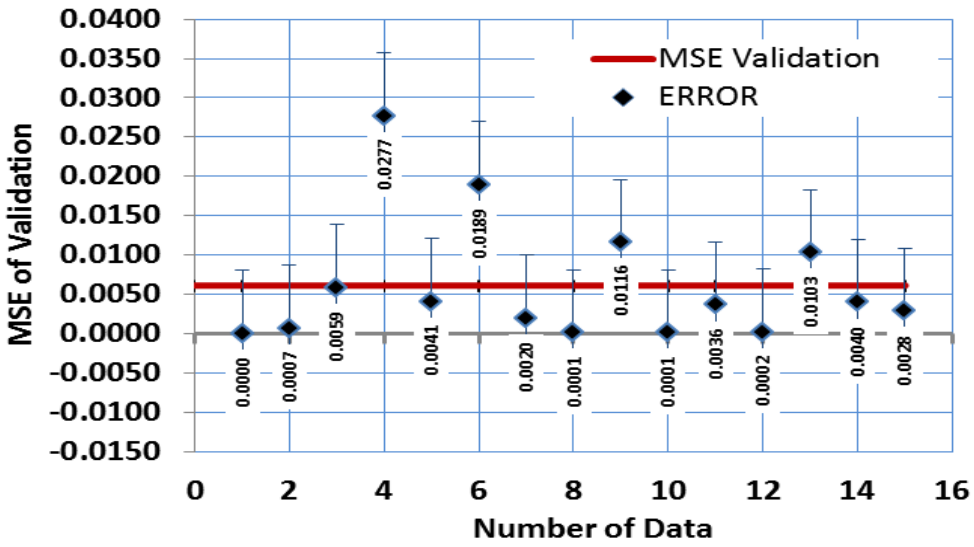

Figure 4. MSE Validation

4.2. The Criteria Weights with Major Impact

The results of the weights of the main criteria indicate uniformity for every the main criteria which are marked on the value of the small standard deviation. The weights for each the criteria are estimated at ± 20% with average of standard deviation about 0.0377. These weights show the same importance level in decision for the subcontractor selection, as shown in Table 4.

Structure of the proposed model are divided into five groups (main criteria) with the same weights is ± 20%. Each weighting on the main criteria will be distributed to the sub-criteria. The main criteria with many sub-criteria will lead to small weights of sub criteria. Weights at the sub criteria level, that consist of A1 to A13, B1 to B2, C1 to C3, D1, and E1, are produced successfully of 1.54%, 10%, 6.63%, 20% and 20% with a total of 100%, This results are illustrated at column of generally weights in Table 5.

Table 4. Weights Analysis for the Main Criteria of the Subcontractors Selection

Main Criteria of Subcontractor Selection	Weights Per Main Criteria			Estimate of Weights
	Decimal	Percentage	Standard Deviation	
A. Subcontractor Credibility	0.1947	19.47%	0.0049	20%
B. Quotation	0.2018	20.18%	0.0118	20%
C. Technical Capabilities	0.1946	19.46%	0.0067	20%
D. Execution Time	0.2080	20.80%	0.0054	20%
E. Kind of Project Reference	0.2009	20.09%	0.0089	20%
Grand Total	1.00	100%	0.0377	100

In this hierarchy structure, we will describe in detail the significant sub criteria as decisive criteria. The significant sub criteria are obtained the total weights 60% which is reached by 4 criteria (as decisive criteria), namely compression of schedule (D1) at 20%, number of similar project (E1) at 20%, quotation price (B1) at 10%, and method of payment (B2) at 10% respectively. Meanwhile others, 16 criteria as indecisive criteria, only reach the total weights 40%, as shown in Table 5. The criteria weights with major impact will give knowledge us about the strategic criteria to be a nominated subcontractor.

The proposed model by using the Solver has ability to detect the criteria weights in decision hierarchy structure. The proposed model was generated of the assessor's assessments by transferring the expert's judgments. This proposed model more advanced from study of Hatefi et.al and Gang et.al as well as, that has been done the discovery of the criteria weights through AHP (Analytic Hierarchy Process) method which is based on the respondent's perception about the importance criteria [6],[9].

The concept transferring the expert's judgment by using NN that built by Albino and Garavelli, they did not describe in detail about the pattern of the criteria weights [2], as well as Nguyen VU [1]. Therefore,

future research regarding the criteria weights will conduct, both the criteria weights of NN learning and Fuzzy Logic ambiguity, would be subject to being compared toward this proposed model research.

Table 5. Analysis for the Criteria Weights for Each Item

Criteria of Subcontractor Selection		Weights Per Main Criteria		In Generally Weights		Standard Deviation
		In Decimal	Estimate Percentage	In Decimal	Estimate Percentage	
A. Subcontractor Credibility						
1. Company Profile						
a. Management Capabilities						
• Quality system						
- ISO Certification, similar	A1	0.0765	7.70%	0.0154	1.54%	0.001
- Quality assurance	A2	0.0771	7.70%	0.0155	1.54%	0.001
- Company profile	A3	0.0766	7.70%	0.0154	1.54%	0.001
• Financial Stability						
- Balance Sheet	A4	0.0773	7.70%	0.0155	1.54%	0.002
- Bank guarantee	A5	0.0766	7.70%	0.0154	1.54%	0.001
b. Technology Capability						
• Facilities	A6	0.0771	7.70%	0.0155	1.54%	0.001
• Transport	A7	0.0771	7.70%	0.0155	1.54%	0.001
• Equipment	A8	0.0767	7.70%	0.0154	1.54%	0.001
2. Contract Trustworthy						
a. Project Experience	A9	0.0770	7.70%	0.0155	1.54%	0.002
b. Project achievement	A10	0.0772	7.70%	0.0155	1.54%	0.001
c. Type and amount of insurance	A11	0.0762	7.70%	0.0153	1.54%	0.001
d. Registered in associations	A12	0.0769	7.70%	0.0155	1.54%	0.001
e. Company legitimate	A13	0.0767	7.70%	0.0154	1.54%	0.001
Sub Total		1.00	100%			
B. Quotation						
1. Quotation Price	B1	0.5035	50%	0.1012	10.00%	0.096
2 Methods of payment	B2	0.4814	50%	0.0968	10.00%	0.044
Sub Total		1.00	100%			
C. Technical Capabilities						
1. Expertise of personnel	C1	0.3317	33.33%	0.0667	6.63%	0.029
2. Specializes in working methods	C2	0.3445	33.33%	0.0693	6.63%	0.025
3. Material specification	C3	0.3129	33.33%	0.0629	6.63%	0.023
Sub Total		1.00	100%			
D. Execution Time						
1. Compression of schedule	D1	1.0000	100.00%	0.2011	20.00%	0.00
Sub Total		1.00	100%			
E. Kind of Project Reference						
1. Number of similar project in last year	E1	1.0000	100.00%	0.2011	20.00%	0.00
Sub Total		1.00	100%			
Grand Total				1.00	100%	

4.3. Biases of the Criteria Weights

In addition to having the ability to detect the weights criteria, this proposed model can also detect the biases of the main criteria for each alternative decision (in this case as the subcontractor). Biases indicate the variation degree of assessors toward expert's judgments in giving weights to the main criteria. Based on the variation on determining the weights criteria, as shown in Table 6, shows the variation of the quotation that is quite large than the other main criteria.

The difference in determining the criteria weights between each assessor could be measured from the biases. The highest biases, which were resulted from the training process, indicate the assessor subjectivity in the aspect Quotation, as shown in Table 6. The assessors might have different perceptions about the importance level of the quotation. Using the proposed model, we could detect the subjectivity by preview it biases, thus, it could be immediately eliminated for improved performance of the subcontractor selection process. It is in line with the opinion of Albino V, Garavelli AC stated that "The complexity of subcontractor rating, due to the uncertainty and ambiguity involved in the decision making process, requires a formalization aimed to reduce the expert's subjectivity" [2].

The significant biases in alternative 7 and 20 of the quotation aspect (B) are successfully 0.139 and 0.231, as shown in table 3. These biases inform us that the proposed model by using the Solver could be used to detect the deviations of the assessor's assessments toward the expert's judgment. This scheme indicate the similarly to the advanced statistical techniques [10], [11]. The subjectivity in the subcontractor selection are reasonable things and it have tolerance spare more than decisions in high risk. Otherwise, biases are not allowed (or only very slightly loose) when faced with major decisions in high risk, as well as on the

issues [12], [13]. Furthermore, the proposed model can be applied in various fields with a higher degree of risk, where subjectivity and biases highly avoidable [14-16].

Table 6. Variation in Determined the Criteria Weights

Main Criteria of Subcontractor Selection	Biases of Weights Per Main Criteria		
	Decimal	Percentage	Variation
A. Subcontractor Credibility	0.001462	0.15%	Small
B. Quotation	0.056109	5.61%	moderate
C. Technical Capabilities	0.008135	0.85%	Small
D. Execution Time	0.000000	0.00%	Small
E. Kind of Project Reference	0.000000	0.00%	Small
In Final Decision	0.017044	1.17%	Small

4.4. Performance of the Solver to Weigh Detection

The Solver tool could detect patterns and hidden relationships in data. Modeling using Solver, we have developed a logic framework in excel sheet that can be used to predict behavior and make the subcontractor selection decisions. Zeljković and Gaćanović have stated that "what is more important, Solver is capable of handling non-linear problems by employing a generalized reduced gradient method*"* [17].

The performance of the Solver to detect the criteria weights, as in show in Table 3 (column of criteria weights) was demonstrated by using training curve with the parameter MSE and it declining, as shown in Figure 2. The proposed model will be validating with MSE of target data and output data, as shown in Figure 4. Solver, which is able to iterate the subcontractor data, can be used as a tool to identify the weights and biases of the subcontractor selection process. The success rate of the Solver can be measured from MSE training 9.73711e-08 and MSE validation of training 0.00900528.

The principle of data processing by the Solver to detect the weights of a multi-criteria and biases in the data selection is based on pattern in spreadsheet of excel base. It is in line with Fone, et.al stated that "designed the algorithms used within a NN become generic and they are trained using empirical example data. It has proved beneficial to demonstrate the mechanics of a neuron and simple NN, prior to, or alongside the introduction of the mathematical notations and this was achieved using the model implemented using an Excel spreadsheet" [18].

5. CONCLUSION

A proposed model for solving the problems of subcontractor selection has been successfully built. Ability of the proposed model by using the Solver has been able mapping the assessor's assessments toward the expert's judgment. The success of mapping is depicted in the pattern of criteria weights and biases in the hierarchical structure of the model decision on the selection of subcontractors.

Training process performed by the Solver shows that the results are quite good at training MSE level of 9.73711e-08. Training curve for the subcontractor selection models describe changes error of -0.004 and MSE for validation of 0.00900528. Thus, it could be conclude that the modeling of decision support system for the subcontractor selection by using the method of the Solver Application has been well achieved.

Patterns are drawn from a subcontractor selection model is outlined criteria are divided into five groups (main criteria) with the same weights is ± 20%. Each weighting on the main criteria will be distributed to the sub-criteria. The only the main criteria which have many sub-criteria, will lead to small weights criteria value. The significant criteria for the subcontractor selection is Compression of Schedule, Number of similar project in last year, Quotation Price, and Methods of payment in the totals amount is 60%. They are the strategic sub criteria that should be considered by the subcontractors to outperform in the selection process.

The novelty in the study conducted using the Solver Application is the ability to detect the criteria weights and biases of the assessors assessments with machine learning concept, and weights and biases could be visualized as a logical model of weighted criteria.

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APPENDIX

Table 1. Learning Data for the Assessment of Subcontractors and Expert Judgment as Target

Criteria of the Decision		Data for Training Alternative (Number of Subcontractors)																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A. Subcontractor Credibility																										
1. Company profile																										
a. Management Capabilities																										
• Quality system																										
- ISO certification, similar	A1	0.8	1.0	0.8	0.5	0.9	0.6	0.6	0.9	0.6	0.6	0.5	1.0	0.8	0.5	0.2	0.5	0.6	0.5	0.8	0.9	0.5	0.5	0.8	0.7	1.0
- Quality assurance	A1	1.0	0.5	0.6	1.0	0.5	0.5	0.7	0.5	0.5	0.4	0.5	0.3	0.5	0.1	0.3	0.5	0.3	0.8	0.6	1.0	0.6	0.5	0.6	0.9	1.0
- Company profile	A3	0.5	1.0	0.6	1.0	0.8	0.4	0.8	0.6	0.5	0.7	0.6	0.5	0.2	0.5	0.2	0.8	0.8	0.6	0.2	1.0	0.7	1.0	0.8	0.7	1.0
• Financial Stability																										
- Balance Sheet	A4	0.9	0.6	0.3	0.9	0.5	0.6	0.6	0.6	0.6	0.3	0.6	0.7	0.2	0.5	0.8	0.9	0.3	0.5	0.2	0.5	0.3	0.2	0.8	0.8	1.0
- Bank guarantee	A5	0.4	0.9	0.3	1.0	0.8	0.7	0.7	0.2	0.8	0.3	0.3	0.7	0.8	0.7	0.6	1.0	0.8	0.9	0.3	0.6	0.9	0.9	0.3	0.9	1.0
b. Technology capability																										
• Facilities	A6	1.0	0.7	0.5	0.6	0.9	0.3	0.6	0.8	0.5	0.2	0.7	0.9	0.6	0.4	0.6	0.5	0.5	0.3	0.1	0.8	0.7	0.5	0.5	0.6	0.5
• Transport	A7	0.5	0.6	0.6	0.7	0.5	0.1	0.8	0.2	0.4	0.5	0.6	0.2	0.5	0.9	0.7	1.0	0.4	0.4	0.7	0.3	0.9	0.6	0.8	0.6	0.6
• Equipment	A8	0.5	0.7	0.6	0.8	0.7	0.1	0.5	0.8	0.4	0.5	1.0	0.4	0.9	0.7	0.2	1.0	0.8	0.2	0.9	0.3	0.8	0.9	0.6	0.5	0.7
2. Contract Trustworthy																										
a. Project Experience	A9	0.4	1.0	0.5	0.9	0.4	0.9	0.3	0.3	0.6	0.3	0.5	0.3	1.0	0.8	0.6	0.3	0.8	0.1	0.3	0.5	0.6	0.7	0.9	0.6	1.0
b. Project achievement	A10	0.5	1.0	0.9	0.2	0.2	0.3	0.7	0.7	0.3	0.5	1.0	0.8	1.0	0.5	0.4	0.5	0.5	0.5	0.3	0.4	0.4	0.8	0.5	0.3	1.0
c. Type, amount of insurance	A11	1.0	0.6	0.9	0.3	0.5	0.8	0.5	0.6	0.5	0.4	1.0	1.0	1.0	0.3	0.5	1.0	1.0	0.6	0.9	0.9	0.9	0.4	0.6	0.5	1.0
d. Registered in associations	A12	0.8	0.2	0.9	0.5	0.2	0.6	0.4	0.5	0.5	0.2	0.5	1.0	1.0	0.7	0.6	1.0	0.8	0.8	0.1	0.3	0.8	0.6	0.5	0.8	0.9
e. Company legitimate	A13	0.6	0.9	1.0	0.5	0.5	1.0	0.6	0.2	0.5	0.8	0.4	1.0	1.0	0.2	0.5	0.8	0.8	0.4	0.8	0.2	0.4	0.9	0.3	0.6	1.0
B. Quotation																										
1. Quotation Price	B1	0.6	0.3	0.5	0.6	0.4	0.7	0.7	0.4	0.3	0.1	0.2	0.1	0.7	0.6	0.4	0.3	0.6	0.5	0.7	0.3	0.2	0.5	0.3	0.4	0.2

2 Methods of Payment	B2	0.6	0.3	0.2	0.3	0.6	0.4	0.1	0.5	1.0	1.0	1.0	0.2	0.4	0.6	0.3	0.3	0.3	0.8	0.6	0.4	0.2	0.2	0.2	0.4	0.4
C. Technical Capabilities																										
1. Expertise of personnel	C1	0.4	0.1	0.5	0.3	0.5	1.0	0.1	0.2	0.7	0.8	0.9	0.3	0.7	0.5	0.9	0.6	0.7	0.6	0.8	0.9	1.0	0.5	0.6	0.8	0.6
2. Specializes in working methods	C2	0.8	0.6	0.4	0.1	0.1	0.8	0.4	0.7	0.5	0.2	0.3	0.8	0.5	0.3	0.8	0.4	0.7	0.3	0.3	0.2	0.6	0.7	0.5	1.0	0.4
3. Material specification	C3	0.7	0.6	0.9	0.9	0.5	0.9	0.9	0.8	0.6	0.9	0.7	0.9	0.6	0.9	0.6	0.5	0.7	0.8	0.8	0.5	0.7	0.9	0.6	0.7	0.8
D. Execution Time																										
1. Compression of schedule	D1	0.3	0.3	0.4	0.1	0.3	0.2	0.6	0.3	0.1	0.2	0.5	0.6	0.1	0.2	0.3	0.5	0.5	0.2	0.1	0.2	0.3	0.4	0.6	0.5	0.6
E. Kind of Project Reference																										
1. Number of similar projects	E1	0.8	0.6	0.9	0.8	0.7	0.3	0.1	0.2	0.5	0.6	0.5	0.7	0.3	0.7	0.7	0.1	0.6	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.6
MAIN CRITERIA OF DECISION																										
A. Subcontractor Credibility	A	0.7	0.8	0.6	0.7	0.6	0.5	0.6	0.6	0.5	0.4	0.6	0.7	0.7	0.5	0.5	0.8	0.6	0.5	0.5	0.7	0.7	0.6	0.6	0.7	0.9
B. Quotation	B	0.6	0.3	0.5	0.6	0.4	0.7	0.6	0.4	0.4	0.3	0.3	0.1	0.6	0.6	0.4	0.3	0.5	0.6	0.7	0.7	0.2	0.5	0.3	0.4	0.2
C. Technical Capabilities	C	0.6	0.4	0.6	0.4	0.4	0.9	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.8	0.5	0.7	0.6	0.6	0.5	0.8	0.7	0.8	0.8	0.6
D. Execution Time	D	0.3	0.3	0.4	0.1	0.3	0.2	0.6	0.3	0.1	0.2	0.5	0.6	0.1	0.2	0.3	0.5	0.5	0.2	0.1	0.2	0.3	0.4	0.6	0.5	0.6
E. Kind of Project Reference	E	0.8	0.6	0.9	0.8	0.7	0.3	0.1	0.2	0.5	0.6	0.5	0.7	0.3	0.7	0.7	0.1	0.6	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.6
EXPERT JUDGMENT																										
A. Subcontractor Credibility	A	0.7	0.8	0.6	0.7	0.6	0.5	0.6	0.6	0.5	0.4	0.6	0.7	0.7	0.5	0.5	0.8	0.6	0.5	0.5	0.7	0.7	0.6	0.6	0.7	0.9
B. Quotation	B	0.6	0.3	0.5	0.6	0.4	0.7	0.6	0.4	0.4	0.3	0.3	0.1	0.6	0.6	0.4	0.3	0.5	0.6	0.7	0.7	0.2	0.5	0.3	0.4	0.2
C. Technical Capabilities	C	0.6	0.4	0.6	0.4	0.4	0.9	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.8	0.5	0.7	0.6	0.6	0.5	0.8	0.7	0.8	0.8	0.6
D. Execution Time	D	0.3	0.3	0.4	0.1	0.3	0.2	0.6	0.3	0.1	0.2	0.5	0.6	0.1	0.2	0.3	0.5	0.5	0.2	0.1	0.2	0.3	0.4	0.6	0.5	0.6
E. Kind of Project Reference	E	0.8	0.6	0.9	0.8	0.7	0.3	0.1	0.2	0.5	0.6	0.5	0.7	0.3	0.7	0.7	0.1	0.6	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.6
Total Expert Judgment of each Alternatives		0.6	0.4	0.5	0.6	0.4	0.6	0.5	0.4	0.4	0.4	0.4	0.3	0.6	0.5	0.5	0.4	0.6	0.5	0.6	0.6	0.3	0.5	0.4	0.5	0.4

Table 2. Validation Data for the Assessment of Subcontractors and Expert Judgment as Target

Criteria of the Decision		Data for Validation Alternative (Number of Subcontractors)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A. Subcontractor Credibility																
1. Company profile																
a. Management Capabilities																
• Quality system																
- ISO certification, similar	A1	1.0	1.0	0.0	0.8	0.6	0.6	0.0	1.0	0.5	0.2	1.0	0.1	0.5	0.9	0.4
- Quality assurance	A1	1.0	1.0	1.0	0.6	0.3	0.9	0.9	0.0	0.0	0.3	1.0	0.6	0.3	0.4	0.5
- Company profile	A3	0.6	0.7	0.3	1.0	0.2	0.4	0.6	0.5	0.5	0.5	1.0	0.2	0.5	0.8	0.8
• Financial Stability																
- Balance Sheet	A4	0.7	0.5	0.8	0.7	0.8	0.6	0.1	0.1	0.6	0.5	1.0	0.8	0.2	0.5	0.6
- Bank guarantee	A5	1.0	1.0	1.0	0.5	0.8	0.5	0.9	0.5	0.2	0.3	1.0	0.4	0.3	0.3	0.8
b. Technology capability																
• Facilities	A6	0.2	0.5	0.6	0.5	0.8	0.8	0.9	0.6	0.7	0.8	0.8	0.3	0.4	0.8	0.5
• Transport	A7	1.0	1.0	0.3	1.0	0.8	0.5	0.5	0.3	0.8	0.6	0.7	0.2	0.8	0.6	0.5
• Equipment	A8	0.8	0.5	0.3	0.6	0.8	0.5	0.7	0.5	0.1	0.3	0.5	0.5	0.9	0.3	0.5
2. Contract Trustworthy																
a. Project Experience	A9	1.0	0.5	0.7	1.0	0.6	0.3	0.8	0.5	0.5	0.4	0.9	0.6	1.0	0.5	0.7
b. Project achievement	A10	0.5	0.1	0.4	0.2	0.4	0.3	0.7	0.6	0.8	0.5	0.8	0.2	0.5	0.7	0.5
c. Type, amount of insurance	A11	0.5	1.0	0.6	1.0	0.9	0.5	0.9	0.7	0.3	0.2	1.0	0.7	0.9	0.6	0.6
d. Registered in associations	A12	1.0	1.0	0.3	1.0	1.0	0.5	0.8	0.5	0.1	0.9	1.0	0.2	0.4	0.8	0.6
e. Company legitimate	A13	0.7	1.0	0.5	1.0	0.5	0.8	0.5	0.4	0.8	0.5	1.0	0.5	0.6	0.6	0.3
B. Quotation																
1. Quotation Price	B1	0.6	0.6	0.2	0.1	0.4	0.8	0.6	0.5	0.3	0.4	0.6	0.2	0.7	0.6	0.6
2 Methods of Payment	B2	0.0	0.0	0.0	0.2	0.0	0.8	0.5	0.0	0.0	0.0	0.5	0.7	0.9	1.0	0.0
C. Technical Capabilities																
1. Expertise of personnel	C1	0.9	0.8	0.5	0.6	0.8	0.9	0.9	0.8	0.5	0.3	0.2	0.6	0.4	0.6	0.5
2. Specializes in working methods	C2	0.5	0.6	0.9	0.6	0.5	0.6	0.7	0.6	0.6	0.5	0.8	0.6	0.5	0.8	0.5
3. Material specification	C3	0.8	0.9	0.6	0.8	0.7	0.9	0.6	0.8	0.7	0.6	0.9	0.5	0.6	0.9	0.8
D. Execution Time																
1. Compression of schedule	D1	0.1	0.2	0.3	0.3	0.2	0.0	0.5	0.4	0.6	0.4	0.3	0.2	0.2	0.4	0.3
E. Kind of Project Reference																
1. Number of similar projects	E1	0.8	0.5	0.6	0.9	0.8	0.7	0.0	0.4	0.6	0.0	0.0	0.3	0.6	0.2	0.4
MAIN CRITERIA OF DECISION																
A. Subcontractor Credibility	A	0.8	0.8	0.6	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.9	0.4	0.6	0.6	0.6
B. Quotation	B	0.5	0.5	0.2	0.1	0.3	0.8	0.6	0.4	0.2	0.3	0.6	0.2	0.7	0.6	0.5
C. Technical Capabilities	C	0.7	0.8	0.7	0.7	0.7	0.8	0.7	0.7	0.6	0.5	0.6	0.6	0.5	0.8	0.6
D. Execution Time	D	0.1	0.2	0.3	0.3	0.2	0.0	0.5	0.4	0.6	0.4	0.3	0.2	0.2	0.4	0.3
E. Kind of Project Reference	E	0.8	0.5	0.6	0.9	0.8	0.7	0.0	0.4	0.6	0.0	0.0	0.3	0.6	0.2	0.4
EXPERT JUDGMENT																

A. Subcontractor Credibility	A	0.8	0.8	0.6	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.9	0.4	0.6	0.6	0.6
B. Quotation	B	0.5	0.5	0.2	0.1	0.3	0.8	0.6	0.4	0.2	0.3	0.7	0.3	0.7	0.6	0.5
C. Technical Capabilities	C	0.7	0.8	0.7	0.7	0.7	0.8	0.7	0.7	0.6	0.5	0.6	0.6	0.5	0.8	0.6
D. Execution Time	D	0.1	0.2	0.3	0.3	0.2	0.0	0.5	0.4	0.6	0.4	0.3	0.2	0.2	0.4	0.3
E. Kind of Project Reference	E	0.8	0.5	0.6	0.9	0.8	0.7	0.0	0.4	0.6	0.0	0.0	0.3	0.6	0.2	0.4
Total Expert Judgment of each Alternative		0.6	0.6	0.3	0.4	0.4	0.7	0.5	0.5	0.4	0.3	0.6	0.3	0.6	0.6	0.5

Table 3. The Criteria Weights and Biases for the Subcontractors Selection

Alternatives	Bias of Criteria					Weights Criteria																				Main Criteria					Bias of Main Criteria
	Bias A	Bias B	Bias C	Bias D	Bias E	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	B1	B2	C1	C2	C3	D1	E1	A	B	C	D	E	
1	0.003	0.011	0.004	0.0	0.0	0.076	0.075	0.078	0.076	0.078	0.075	0.078	0.078	0.078	0.078	0.075	0.076	0.077	0.486	0.503	0.365	0.309	0.323	1.0	1.0	0.194	0.200	0.198	0.213	0.190	0.005
2	0.002	0.000	0.007	0.0	0.0	0.075	0.078	0.075	0.078	0.076	0.077	0.078	0.077	0.075	0.075	0.078	0.080	0.076	0.500	0.500	0.374	0.309	0.309	1.0	1.0	0.191	0.214	0.206	0.212	0.198	-0.020
3	-0.001	0.068	0.008	0.0	0.0	0.076	0.077	0.077	0.079	0.079	0.078	0.077	0.077	0.078	0.075	0.075	0.075	0.075	0.423	0.508	0.344	0.358	0.289	1.0	1.0	0.201	0.210	0.203	0.212	0.189	-0.014
4	-0.001	0.073	0.016	0.0	0.0	0.078	0.075	0.075	0.076	0.075	0.078	0.077	0.076	0.076	0.080	0.079	0.078	0.078	0.419	0.508	0.345	0.371	0.268	1.0	1.0	0.191	0.196	0.201	0.216	0.185	0.012
5	0.005	-0.049	0.006	0.0	0.0	0.074	0.077	0.075	0.077	0.075	0.074	0.077	0.076	0.078	0.079	0.077	0.079	0.077	0.567	0.481	0.314	0.365	0.314	1.0	1.0	0.195	0.205	0.206	0.209	0.191	-0.006
6	0.000	0.079	0.002	0.0	0.0	0.076	0.077	0.078	0.076	0.076	0.078	0.080	0.080	0.075	0.078	0.075	0.076	0.074	0.413	0.508	0.317	0.349	0.333	1.0	1.0	0.194	0.189	0.178	0.208	0.204	0.026
7	0.001	0.139	0.017	0.0	0.0	0.077	0.076	0.075	0.077	0.076	0.077	0.075	0.077	0.079	0.076	0.077	0.078	0.077	0.358	0.504	0.373	0.341	0.270	1.0	1.0	0.192	0.194	0.198	0.192	0.214	0.011
8	0.002	-0.018	0.011	0.0	0.0	0.074	0.077	0.077	0.076	0.079	0.075	0.079	0.075	0.078	0.076	0.076	0.077	0.079	0.526	0.493	0.377	0.316	0.296	1.0	1.0	0.193	0.198	0.193	0.204	0.208	0.004
9	0.002	-0.097	0.000	0.0	0.0	0.076	0.077	0.077	0.076	0.075	0.077	0.077	0.077	0.076	0.078	0.077	0.077	0.077	0.690	0.406	0.317	0.352	0.331	1.0	1.0	0.198	0.203	0.196	0.218	0.200	-0.016
10	0.000	-0.101	0.015	0.0	0.0	0.076	0.077	0.075	0.078	0.078	0.078	0.077	0.077	0.078	0.077	0.077	0.078	0.075	0.721	0.380	0.305	0.388	0.291	1.0	1.0	0.202	0.210	0.193	0.212	0.196	-0.012
11	0.000	-0.102	0.010	0.0	0.0	0.078	0.078	0.077	0.077	0.079	0.076	0.077	0.075	0.078	0.075	0.075	0.078	0.078	0.715	0.387	0.293	0.377	0.321	1.0	1.0	0.199	0.214	0.198	0.204	0.206	-0.021
12	0.004	-0.022	0.014	0.0	0.0	0.075	0.079	0.078	0.077	0.076	0.076	0.080	0.078	0.079	0.076	0.075	0.075	0.075	0.532	0.491	0.380	0.310	0.296	1.0	1.0	0.202	0.232	0.204	0.207	0.205	-0.049
13	-0.001	0.064	0.028	0.0	0.0	0.077	0.078	0.080	0.080	0.077	0.078	0.078	0.076	0.075	0.075	0.075	0.075	0.075	0.428	0.507	0.315	0.335	0.322	1.0	1.0	0.185	0.189	0.188	0.211	0.203	0.024
14	0.001	0.000	0.011	0.0	0.0	0.077	0.079	0.077	0.077	0.076	0.078	0.075	0.076	0.075	0.077	0.078	0.076	0.079	0.500	0.500	0.343	0.363	0.283	1.0	1.0	0.196	0.195	0.195	0.211	0.191	0.011
15	0.001	0.019	0.002	0.0	0.0	0.079	0.078	0.079	0.075	0.076	0.076	0.075	0.079	0.076	0.077	0.077	0.076	0.077	0.476	0.505	0.318	0.325	0.355	1.0	1.0	0.202	0.207	0.190	0.213	0.195	-0.006
16	0.001	0.000	0.001	0.0	0.0	0.078	0.078	0.077	0.076	0.075	0.078	0.075	0.075	0.080	0.078	0.075	0.075	0.077	0.500	0.500	0.320	0.346	0.333	1.0	1.0	0.188	0.208	0.199	0.199	0.217	-0.011
17	-0.001	0.084	0.000	0.0	0.0	0.077	0.079	0.076	0.079	0.076	0.078	0.079	0.076	0.076	0.078	0.075	0.076	0.076	0.407	0.509	0.333	0.333	0.333	1.0	1.0	0.199	0.202	0.195	0.206	0.200	-0.002
18	0.001	-0.061	0.008	0.0	0.0	0.077	0.075	0.076	0.077	0.074	0.078	0.077	0.079	0.079	0.077	0.076	0.075	0.077	0.589	0.472	0.326	0.367	0.299	1.0	1.0	0.192	0.191	0.190	0.208	0.200	0.019
19	0.002	0.024	0.008	0.0	0.0	0.075	0.076	0.078	0.078	0.078	0.079	0.075	0.074	0.078	0.078	0.074	0.079	0.075	0.470	0.506	0.307	0.377	0.307	1.0	1.0	0.192	0.184	0.186	0.209	0.196	0.032
20	0.006	0.231	0.012	0.0	0.0	0.075	0.074	0.074	0.077	0.076	0.075	0.078	0.078	0.077	0.078	0.075	0.078	0.079	0.396	0.373	0.280	0.374	0.334	1.0	1.0	0.185	0.182	0.191	0.207	0.201	0.035
21	0.001	0.000	0.007	0.0	0.0	0.078	0.077	0.077	0.079	0.075	0.077	0.075	0.076	0.077	0.078	0.075	0.076	0.078	0.500	0.500	0.296	0.356	0.341	1.0	1.0	0.193	0.213	0.187	0.210	0.213	-0.015
22	-0.004	0.068	0.005	0.0	0.0	0.078	0.078	0.075	0.080	0.076	0.078	0.078	0.076	0.077	0.076	0.079	0.077	0.076	0.423	0.508	0.361	0.332	0.303	1.0	1.0	0.194	0.199	0.188	0.204	0.210	0.005
23	0.002	0.018	0.076	0.0	0.0	0.076	0.077	0.076	0.076	0.079	0.078	0.076	0.077	0.075	0.077	0.077	0.078	0.079	0.477	0.505	0.304	0.317	0.304	1.0	1.0	0.200	0.216	0.194	0.201	0.215	-0.027
24	0.001	0.000	0.004	0.0	0.0	0.077	0.075	0.077	0.076	0.075	0.077	0.077	0.078	0.077	0.079	0.078	0.076	0.077	0.500	0.500	0.335	0.312	0.350	1.0	1.0	0.199	0.210	0.191	0.208	0.206	-0.013
25	-0.001	-0.051	0.000	0.0	0.0	0.077	0.079	0.077	0.079	0.079	0.078	0.075	0.075	0.074	0.077	0.075	0.078	0.077	0.569	0.482	0.351	0.331	0.318	1.0	1.0	0.192	0.185	0.195	0.207	0.190	0.030
Total (Sum of Data)						1.911	1.928	1.915	1.933	1.915	1.927	1.926	1.917	1.925	1.930	1.905	1.923	1.918	12.59	12.04	8.294	8.611	7.822	25	25	4.868	5.045	4.865	5.201	5.021	
Data Count						25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	
Average of The Criteria Weights						0.076	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.076	0.077	0.077	0.503	0.481	0.332	0.344	0.313	1.0	1.0	0.195	0.202	0.195	0.208	0.201	
Standard Deviation						0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.096	0.044	0.029	0.025	0.023	0.0	0.0	0.005	0.012	0.007	0.005	0.009	
Percentage per Category (in %)						7.65	7.72	7.67	7.74	7.67	7.72	7.71	7.68	7.71	7.73	7.63	7.70	7.68	51.12	48.88	33.54	34.83	31.63	1.0	1.0	19.47	20.18	19.46	20.80	20.08	
Percentage of General (in %)						1.54	1.55	1.54	1.55	1.54	1.55	1.55	1.54	1.55	1.55	1.53	1.55	1.54	10.12	9.68	6.67	6.93	6.29	20.1	20.1	19.47	20.18	19.46	20.80	20.08	