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Original Article

Selection of the Use of Formwork in the Holiday Inn Bukit Randu Hotel Project Using the Fuzzy AHP Method

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Abstract. Along with the development of the construction world, formwork has also progressed from being assembled on site to being assembled first at the factory. In Indonesia, many types of formworks have been used, which each have their own advantages and disadvantages. In selecting the type of formwork used, many factors or criteria need to be considered. The purpose of this study is to determine the type of formwork that is relatively best for use in the Holiday Inn Bukit Randu Hotel Project by calculating the weight of the criteria, sub criteria, and also the alternatives used using the Fuzzy AHP Method. Based on the criteria and alternatives that have been compiled by the researcher, as well as the analysis carried out using the Fuzzy AHP method, it is known that metal (system) formwork is the relatively best formwork with the largest final weight of 43.6%, while semi-system formwork with a final weight of 24, 6% and conventional formwork by 31.8%. However, after being reviewed based on the cost aspect, the semi-system formwork is the relatively best formwork to be used in the Holiday Inn Bukit Randu Hotel Project.

Keywords: formwork, conventional, semi-systems, metal (systems), fuzzy analytic hierarchy

1. Introduction

Formwork is one of the important elements in a construction project, be it buildings, dams, roads, or other construction projects. In Indonesia formwork or concrete molds have many types and alternatives, including conventional formwork, semi-systems, and metal (systems) where each type of formwork has advantages and disadvantages. To determine the type of formwork used, many factors or criteria must be considered. The method that can be used to determine the type of formwork is the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). Fuzzy AHP is a method developed and created from the AHP method to cover the shortcomings of the Analytic Hierarchy Process AHP method which cannot take into account ambiguous or unclear factors [1].

There are several studies that have been carried out using the AHP and fuzzy AHP methods related to formwork. Among them are Basu and Jha [2] who conducted research on the selection of horizontal formwork systems in residential construction in India using the AHP method. In this study, an analysis of the factors or criteria used in the selection of the formwork system was also carried out, in order to obtain 6 factors that influence the determination of the formwork system with the most decisive factors, namely the available capital factor and site characteristics.

Another study conducted by Hansel et al. [3] in Indonesia regarding the decision-making framework for the selection of formwork systems by contractors. In this study, there are 2 alternative types of formwork (conventional and aluminum) and also 8 factors as selection criteria, with the results of the study being that aluminum formwork is a type of formwork that Indonesian contractors tend to use compared to conventional formwork. Jin and Gambatese [4] also conducted research on the selection of technology in monitoring concrete formwork using the Fuzzy AHP method. In this study there are 3 alternative technologies, 4 criteria, and 10 sub-criteria in the selection. After conducting an online survey with experts, it was found that the sensor network is the best technology for monitoring concrete formwork.

This research was conducted at the Holiday Inn Bukit Randu Hotel Project in Bandar Lampung City, Lampung, Indonesia. In this study, the selection of the relatively best type of formwork to be applied to research case studies using the fuzzy AHP method will be carried out, where analysis will be carried out on three types of formwork, namely conventional formwork, semi-systems formwork, and metal or systems formwork.

2. Materials and Methods

Data analysis in this study used the Fuzzy Analytic Hierarchy Process method as a decision-making method, using 9 sub-criteria which were grouped into 4 criteria as a factor in determining the type of formwork to be used.

Determination of criteria is done through literature study and also discussions with research respondents which can be seen in Table 1 and Table 2 for the alternatives used.

Table 1. Hyperparameters

Criteria	Sub Criteria	Reference	
		Researcher name	Industry
(C1) Quality	(C1-1) Accuracy and Precision	Hansel et al. (2020)	Building construction
	(C1-2) Surface Smoothness of the Resulting Concrete	Saputra (2013)	
	(C1-3) Result of Beam-Column Connection	Hansel et al. (2020)	
(C2) Cost	(C2-1) Material Cost/Rental Fee	Primary et al. (2017)	
	(C2-2) Labor Cost	Primary et al. (2017)	
(C3) Security	(C3-1) Safety in Work	Jin and Gambate (2020)	
(C4) Working Process	(C4-1) Job Completion Time	Hansel et al. (2020)	
	(C4-2) Ease of Work	Saputra (2013)	
	(C4-3) Skilled Worker Required	Hansel et al. (2020)	

Table 2. Alternative Types of Formworks

Criteria	Reference	
	Researcher name	Industry
(A1) Conventional Formwork	Mashur (2020), Pratama et al. (2017), Yazid et al. (2019), Wijaya et al. (2012)	Building construction
(A2) Semi System Formwork	Mashur (2020), Muis and Trijeti (2013), Pratama et al. (2017), Yazid et al. (2019), Wijaya et al. (2012), Suprabowo et al. (2017)	
(A3) *Metal* or System Formwork	Mashur (2020), Pratama et al. (2017), Yazid et al. (2019)	

The data used in determining the weight of each criterion, sub-criteria and also alternatives were obtained through a questionnaire with the respondent being a person who was considered an expert. In this study there are several criteria used to determine that the respondent is a person who is considered an expert, these criteria include:

1. Have an educational background in construction.
2. Have been involved in a building construction project and have a minimum of 5 years work experience in the construction field.
3. Knowing and understanding the three types of formworks used as an alternative.
4. Have a certificate of expertise or a certificate of skills.

2.1. Weighting and Assessment Techniques Quantitative Decision Making Based on Provisions

This weighting and scoring technique involve identifying attributes that can influence decisions. Where this weighting approach allows to build a weighted score which can be expressed as [5, 6] :

$$S = w_1S_1 + w_2S_2 + \cdots + w_nS_n = \sum_{i=1}^{n} w_iS_i \qquad (1)$$

Where w_i is the weight of the importance of each attribute used to make decisions and S_i is a score of the performance level of each attribute.

2.2. Fuzzy Analytic Hierarchy Process

Fuzzy AHP is a combination of the fuzzy concept approach and the AHP method, which in Fuzzy AHP the pairwise comparison matrix does not use the AHP scale but uses a triangular fuzzy number (TFN).

Table 3. Triangular Fuzzy Number

AHP Scale	Triangular Fuzzy Number			Description
	l	m	u	
1	1	1	3	Elements are equally important
2	1	2	4	in the middle

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3	1	3	5	1 (one) element is quite important compared to other elements
4	2	4	6	in the middle
5	3	5	7	1 (one) strong element is important compared to other elements
6	4	6	8	in the middle
7	5	7	9	1 (one) element is more important than the other elements
8	6	8	10	in the middle
9	7	9	11	1 (one) element is absolutely more important than the other elements

Sources: Emrouznejad and Ho, 2018; Puspitasari, 2009

Geometric mean operation is widely applied in research for group decision making. The geometric mean for each component can be calculated using the following equations [7, 8, 9]:

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk}\right)^{\frac{1}{k}}, m_{ij} = \left(\prod_{k=1}^{k} m_{ijk}\right)^{\frac{1}{k}}, u_{ij} = \left(\prod_{k=1}^{k} u_{ijk}\right)^{\frac{1}{k}} \quad (2)$$

The completion steps in the fuzzy AHP method are as follows [7, 10, 11]:

1. Fuzzy synthetic
   Fuzzy value synthetic (Si) against a criterion i can be calculated using the following equation:

$$Si = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} \quad (3)$$

2. Degree of possibility M 2 M 1

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{If } \boldsymbol{m_2} \geq \boldsymbol{m_1} \\ 0 & \text{If } \boldsymbol{l_1} \geq \boldsymbol{u_2} \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{Other} \end{cases} \quad (4)$$

3. Vector weight
   The vector weights can be defined as follows:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (5)$$

Where:

$$d'(A_i) = \min V(S_i \geq S_k) \quad (6)$$

4. Normalization

By normalizing (defuzzification) the normalized vector weight (W) is not a fuzzy number as follows:

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (7)$$

It is necessary to check the consistency of Fuzzy AHP. Consistency ratio checks (CR) were carried out to monitor the validity of paired comparisons, with pairwise comparisons being said to be valid if the CR value 0.1 [7]. The consistency index (CI) and consistency ratio (CR) can be calculated as follows [11]:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (8)$$

$$CR = \frac{CI}{RI} \quad (9)$$

Table 4. Random Index Value

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51

Sources: Saaty, 1977; Emrouznejad and Ho, 2018

3. Results and Discussions

3.1. Hierarchical Structure Analysis

In the Fuzzy AHP method, it is necessary to have a hierarchical structure to represent the problem to be solved by breaking down the problem into smaller and simpler parts, where there are several levels in the hierarchical structure. The hierarchical structure of the problems in this study can be seen in Figure 1 below.

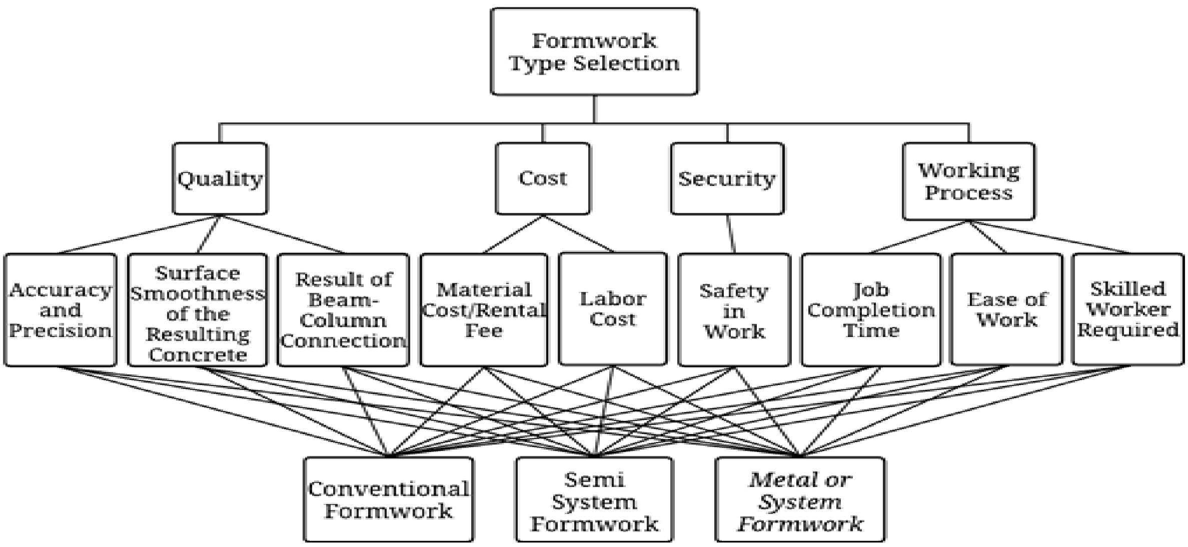

Figure 1. Hierarchical Structure

3.2. Research Respondent Analysis

Based on the research respondents' criteria used, this study uses the assessment of four respondents who are considered experts, with the following identities. The data is presented on Table 5 below.

Table 5. Identity of Respondents

Respondent	Recent Education	Work Experience (Years)	Certificate of Expertise/Certificate of Skills
1	S1 (Civil Engineering)	17	Have Certificate of Expertise
2	High school/ equivalent	12	Have Certificate of Expertise
3	High school/ equivalent	12	Do not have Certificate of Expertise and Certificate of Skills
4	High school/ equivalent	12	Do not have Certificate of Expertise and Certificate of Skills

From the table above, it is known that there are several respondents in this study who do not meet the criteria. However, the respondent's assessment is still used by weighting each respondent. The weighting of the respondents using equation 1 and the provisions in Table 6.

Table 6. Scoring Terms

Attribute	Weight (w_i)	Provision	Scoring (S_i)	$w_i S_i$
Last education	30%	High School/Equivalent	20	6
		D3	40	12
		S1	60	18
		S2	80	24
		S3	100	30
Work experience	40%	6-10 yrs	20	8
		11-15 yrs	40	16
		16-20 yrs	60	24
		21-25 yrs	80	32
		26-30 yrs	100	40
Certificate of Expertise/	30%	Do not have SKA/SKT	20	6
		SKT	40	12
		SKA	60	18

Certificate of Skills		(Young Expert)		
		SKA (Intermediate Expert)	80	24
		SKA (Principal Expert)	100	30

Table 7. Weight of Respondents

Respondent	SCORE ($w_i S_i$)			TOTAL (S)	Respondent's Weight (W)
	Work experience	Last education	SKA/ SKT		
1	18	24	24	66	0.423
2	6	16	12	34	0.217
3	6	16	6	28	0.18
4	6	16	6	28	0.18
TOTAL				156	1

3.3. Pairwise Comparison Matrix Analysis

From the results of the expert assessment questionnaire, the assessment was compiled into a pairwise comparison matrix. The scale used in the pairwise comparison matrix from the questionnaire results is the Analytic Hierarchy Process (AHP) importance level scale. In the Fuzzy AHP method, the scale used for the pairwise comparison matrix is no longer the AHP importance level scale, but the Triangular Fuzzy Number (TFN), so needed a scale change from the AHP scale to TFN. Based on the assessments of the four respondents, the assessments were combined into one pairwise comparison matrix. The combined assessment is done by applying the weights of each respondent into the geometric average calculation, so that the equation used becomes:

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk} \times W_i\right)^{\frac{1}{k}},$$

$$m_{ij} = \left(\prod_{k=1}^{k} m_{ijk} \times W_i\right)^{\frac{1}{k}} \qquad (10)$$

$$u_{ij} = \left(\prod_{k=1}^{k} u_{ijk} \times W_i\right)^{1/k}$$

3.4. Consistency Ratio (CR) Analysis

The calculation of the consistency ratio was carried out to determine the validity of the pairwise comparison values given by the experts. Where pairwise comparisons are valid if the value of the consistency ratio (CR) is less than or equal to 0,1. To determine the consistency ratio, the pairwise comparison matrix used is a pairwise comparison matrix using the AHP scale. Before calculating the consistency ratio, it is necessary to combine the pairwise comparison assessment of the questionnaire results (AHP scale) using equation 2.

By using equations 8 and 9 to calculate the CI and CR values, the results of the CR values at the level of criteria, sub-criteria and also alternatives to the criteria in Table 8 have met the requirements, namely having a value less than or equal to 0,1. This shows that the expert's assessment is consistent and can be continued to calculate the weights on the criteria, sub-criteria and alternatives.

Table 8. Consistency Ratio

Variable	**CR**
Criteria	0.004
Sub Criteria Quality	0.001
Sub Criteria Cost	0
Sub Criteria Working Process	0.007
Alternative to Accuracy and Precision Sub-Criteria	0.004
Alternatives to Smoothness of the Resulting Concrete Surface Sub-Criteria	0.004
Alternative to Beam-Column Connection Sub Criteria	0.0004
Alternatives to Material Cost/Rental Cost Sub Criteria	0.013
Alternative to Labor Cost Sub Criteria	0.0005
Alternative to Safety in Work Sub Criteria	0.004
Alternatives to Work Completion Time Sub-Criteria	0.007
Alternatives to the Ease of Work Sub-criteria	0.006
Alternative to Skilled Worker Required Sub Criteria	0.013

3.5. Criteria Weight Analysis

Criteria used were grouped into quality criteria (C1), cost (C2), safety (C3), and workmanship as (C4).

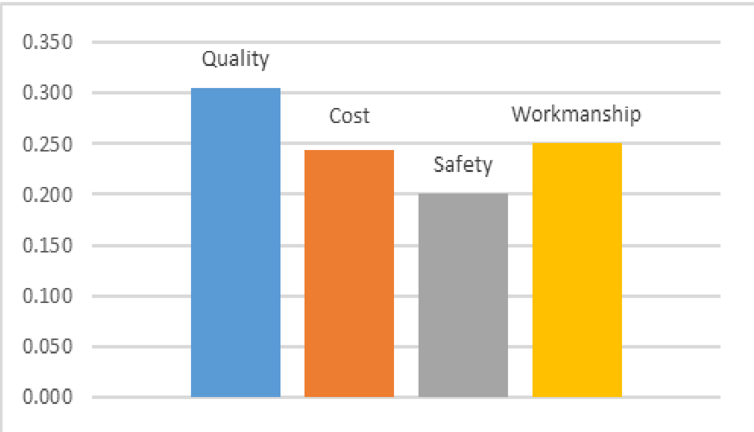

Figure 2. Weight of Criteria

From the graph in the figure, it is known that the quality criterion is the criterion with the highest weight, which indicates that the quality criterion is the most influential criterion in the selection of the formwork system.

3.6. Sub Criteria Weight Analysis

In some criteria there are sub-criteria which are elaborations or details of these criteria. In the calculations carried out in determining the sub-criteria weights, the weights obtained are local weights. The local weights are the sub-criteria weights that apply only to those criteria. The weights of the sub-criteria in each of the criteria obtained are:

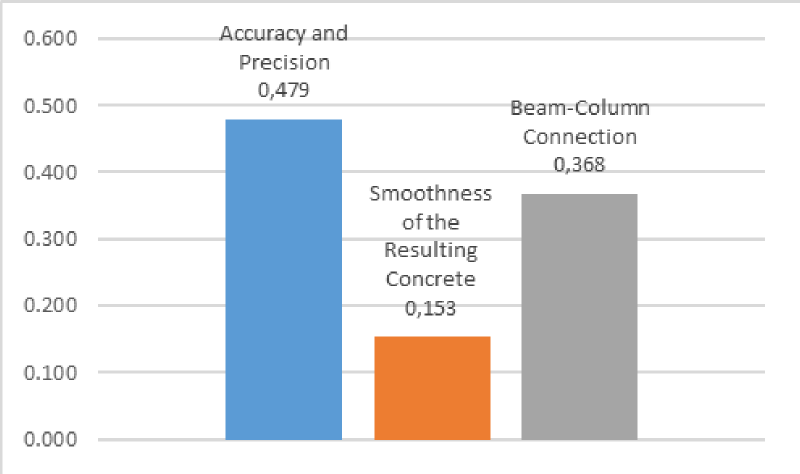

Figure 3. Weight of Quality Sub Criteria

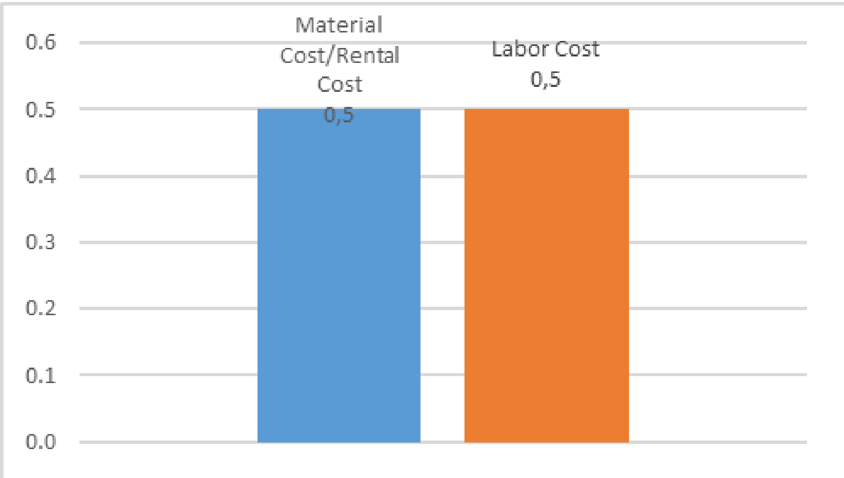

Figure 4. Weight of Cost Sub Criteria

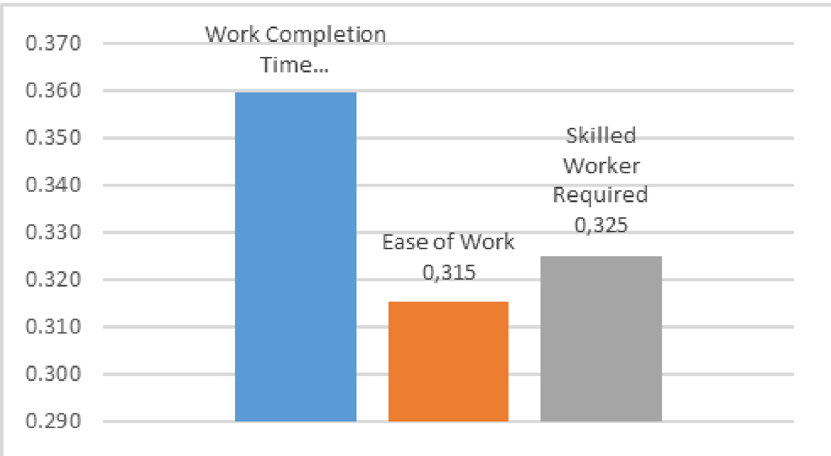

Figure 5. Weight of Work Process Sub Criteria

3.7. Analysis of Alternative Weights to Sub Criteria

In this alternative weight analysis, calculations are carried out to determine the weight of each alternative, namely conventional formwork, semi-system formwork, and metal or system formwork against each sub-criterion. So that it is known which type of formwork is the most superior based on each sub-criteria, as on Table 9.

Table 9. Alternative Weights

Sub Criteria	Alternative (Formwork)		
	Conventional	Semi System	*Metal* (System)
Accuracy and Precision	0.328	0.196	0.476
Produced Concrete Surface	0.328	0.196	0.476
Beam-Column Connection	0.237	0.166	0.597
Material Cost/Rental Fee	0.330	0.430	0.240
Labor costs	0.333	0.329	0.338
Safety in Work	0.2	0.238	0.228
Work Completion Time	0.373	0.208	0.419
Ease of Work	0.363	0.167	0.470
Skilled Worker Needed	0.465	0.227	0.308

3.8. Global Weight and Final Weight

The global weight is the weight that applies to all criteria. The global weight is obtained by multiplying the local weight that has been obtained by the weight of the criteria. After obtaining the global weight, to get the final weight, it is done by multiplying the global weight by the alternative weight, then to get the best decision, the average is done for each alternative, as in Table 10.

Table 10. Global Weight and Final Weight

<table>
<tr><th rowspan="2" colspan="2"></th><th rowspan="2">Criteria Weight</th><th rowspan="2">Local Weight</th><th rowspan="2">Global Weight</th><th colspan="3">Alternative Weight</th><th colspan="3">Final Weight</th></tr>
<tr><th>A1</th><th>A2</th><th>A3</th><th>A1</th><th>A2</th><th>A3</th></tr>
<tr><td rowspan="3">C1</td><td>C1-1</td><td rowspan="3">0.306</td><td>0.479</td><td>0.146</td><td>0.328</td><td>0.196</td><td>0.476</td><td>0.048</td><td>0.029</td><td>0.070</td></tr>
<tr><td>C1-2</td><td>0.153</td><td>0.047</td><td>0.328</td><td>0.196</td><td>0.476</td><td>0.015</td><td>0.009</td><td>0.022</td></tr>
<tr><td>C1-2</td><td>0.368</td><td>0.113</td><td>0.237</td><td>0.166</td><td>0.597</td><td>0.027</td><td>0.019</td><td>0.067</td></tr>
<tr><td rowspan="2">C2</td><td>C2-1</td><td rowspan="2">0.244</td><td>0.5</td><td>0.122</td><td>0.330</td><td>0.430</td><td>0.240</td><td>0.040</td><td>0.053</td><td>0.029</td></tr>
<tr><td>C2-2</td><td>0.5</td><td>0.122</td><td>0.333</td><td>0.329</td><td>0.338</td><td>0.041</td><td>0.040</td><td>0.041</td></tr>
<tr><td colspan="2">C3</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.238</td><td>0.228</td><td>0.533</td><td>0.048</td><td>0.046</td></tr>
<tr><td rowspan="3">C4</td><td>C4-1</td><td rowspan="3">0.25</td><td>0.36</td><td>0.09</td><td>0.373</td><td>0.208</td><td>0.419</td><td>0.034</td><td>0.019</td><td>0.038</td></tr>
<tr><td>C4-2</td><td>0.315</td><td>0.079</td><td>0.363</td><td>0.167</td><td>0.470</td><td>0.029</td><td>0.013</td><td>0.037</td></tr>
<tr><td>C4-3</td><td>0.325</td><td>0.081</td><td>0.465</td><td>0.227</td><td>0.308</td><td>0.038</td><td>0.018</td><td>0.025</td></tr>
<tr><td colspan="8">Total</td><td>0.035</td><td>0.027</td><td>0.048</td></tr>
<tr><td colspan="8">Percentage (%)</td><td>31.8</td><td>24.6</td><td>43.6</td></tr>
</table>

From table 10, it can be seen in the table above if the lowest final weight is found in alternative 2 (semi system formwork) of 24.6%, then after that alternative 1 (conventional formwork) is above it with a weight of 31.8%, and the highest weight is found in alternative 3 (metal formwork) with a weight of 43.6%. So that the best decision can be taken from the highest final weight, namely the metal formwork or system. With the most decisive sub-criteria, namely the sub-criteria for safety in workmanship, the sub-criteria for accuracy and precision, and the sub-criteria for material costs/rental costs and also sub-criteria for labor costs.

From the results of the analysis using fuzzy AHP above, it is found that the metal formwork or system is the best formwork. However, in the Holiday Inn Bukit Randu Hotel Project, the formwork used is semi-system formwork, with plywood molded board material and a scaffolding system . The choice of semi-system formwork in the Holiday Inn Bukit Randu Hotel Project could be due to the very large cost difference between semi-system formwork and metal or system formwork. Where metal formwork or systems require much more expensive costs when compared to semi system formwork. In addition, taking into account the availability of existing materials in the area around the project, where there is sufficient wood material in the Lampung area so that semi-system formwork is the choice taken in the use of formwork in the Holiday Inn Bukit Randu Hotel Project.

4. Conclusions

After analyzing using the fuzzy AHP method, it can be concluded that the sub-criteria for safety in workmanship, accuracy and precision, as well as the sub-criteria for material costs/rental costs and also labor costs are the most decisive sub-criteria in the selection of types. Alternative weights are 31.8% for conventional formwork, 24.6% for semi-system formwork, and 43.6% for metal or system formwork. Technically, by using the fuzzy AHP analysis method, the relatively best formwork is metal formwork or systems, but in terms of cost and accommodation, semi-system formwork is considered better to be applied to the Holiday Inn Bukit Randu Hotel Project.

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