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Application of fuzzy analytical hierarchy process for choosing the best project cost estimation in the Gresik district

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A B S T R A C T

The purpose of this research is to make an application for cost estimation of road construction projects in the Gresik district. This project is a collaboration with civil engineering and informatics to make an application using the fuzzy analytical hierarchy process (FAHP). Many times the project manager gets bids from many contractors to complete a single project. Cost estimation is a determinant element and becomes a guide to formulating policies that can be taken primarily in determining the number of investment costs or the budget that must be allocated annually and can be made the best suggestion to the project manager which contractor can provide the greatest benefit to the project manager. There are several studies that have developed applications for cost estimation, and some have even involved experts to validate the output of the application. However, this study combines five studies as FAHP calculations and two experts to assess the results of the application. FAHP in this research has five criteria, there are drainage, earthworks, grained pavement and cement pavement, paved pavement, and structure. The FAHP method can be implemented in selecting the best project that can provide the lowest raw material purchase price and give the best profit to the project manager, which can be shown by the Application FAHP with the lowest Total Score value. This process is carried out by the admin doing pairwise comparisons with the AHP scale, transforming the pairwise comparison matrix into the TFN scale, calculating the fuzzy synthesis value (Si), the vector value (V), and the defuzzification ordinate (d'), input the project budget that has been implemented (or last year), normalization, calculating the consistency ratio and calculating the best cost estimation as a total score FAHP.

1. Introduction

A construction project in general that requires a lot of budgets, and inaccuracy in carrying out "an earthquake" that results in the project work overload, and those could be the main cause of losses and sub-optimal results, even the construction project could be stopped. This condition has an unfavorable effect on the parties involved in it. Functionally, earthquake in costs is also used for the preparation of a payment system, scheduling, and predicting events in the process of implementing a construction project. Contractors with no experience in cost components, including indirect costs, and increase the risk might be happened (Mahamid, 2011). The cost estimate has a very significant effect and is one of the important benchmarks in evaluating the success of a construction project. In addition, cost estimation is also a determinant element and becomes a guide to formulating policies that can be taken primarily in determining the number of investment costs or the budget that must be allocated annually (Erdogan et al., 2019).

Therefore, making good decisions with the satisfaction of various criteria is one of the main conditions to achieve business objectives. All important decisions which are made in the construction project management and construction industry have multiple character criteria. The crucial decisions, which concern large projects, have long-term consequences on all aspects of the realization and exploitation of a project. Many times the project manager gets bids from many contractors to complete a single project. Cost estimation is a

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determinant element and becomes a guide to formulating policies that can be taken primarily in determining the number of investment costs or the budget that must be allocated annually and can be made the best suggestion to the project manager which contractor can provide the greatest benefit to the project manager.

In practice, contractor selection is normally a two-stage process whereby contractors are first pre-qualified (for example, to get onto a select list or be invited to tender for a given project). Subsequently, their tender submissions are evaluated in the second stage. This research describes the application for choosing the best project and gives the best suggestion using the Fuzzy Analytical Hierarchy Process (FAHP) to the project manager.

The analytic hierarchy process (AHP) was proposed by Saaty (1977, 1980) and found wide applications in many areas. The main advantage of AHP is its possibility to be combined with other methods, including linear programming, fuzzy logic, etc. (Vaidya and Kumar, 2006). In order to model the uncertainty of this human preference, the AHP method is combined with the paired comparison of fuzzy sets. The FAHP facilitates decision-making procedures with precise definitions. Abbasimehr and Tarokh (2017) was an early researcher of FAHP, who used the triangular membership function to represent pair fuzzy ratios to figure out the partial fuzzy priority through the method of least squares (later the geometric mean method).

FAHP has been used in the literature by researchers in many different fields including project selection by assigning weights to selected project characteristics or criteria based on importance (Kubler et al., 2016). Bilgen and Şen (2012) used a FAHP to develop a selection tool for six sigma projects. Their selection tool used resources, benefits, and effects as the major characteristics of their FAHP project selection tool. Nguyen and Tran (2017) studied the use of FAHP in construction projects for site selection, contractor selection, construction methods, risk assessment, and other areas related to construction projects. Other examples exist in the literature utilizing the FAHP methodology in project selection (Hatefi and Tamošaitienė, 2018).

2. Literature review

2.1. Fuzzy AHP

The triangular fuzzy numbers are used in studies of FAHP. The fuzzy triangular numbers are shown as (l/m, m/u) or (1, m, u). For a fuzzy case, l is the smallest possible value, m is the largest value that can be taken, and u is the widest possible value represented (Baslıgil, 2005). The linear representations of each triangular number can be defined as the left and right sides with the membership function in Eq. 1 (Kahraman et al., 2015).

$$\mu\left(\frac{x}{\tilde{M}}\right) = \left\{\begin{matrix} 0, x < 1, \\ \frac{x-l}{m-l}, \ l \le x \le m, \\ \frac{(u-x)}{(u-m)}, m \le x \le u, \\ 0, x > u, \end{matrix}\right\} \tag{1}$$

The geometric representation of the fuzzy number X from Eq. 1 is shown in Fig. 1.

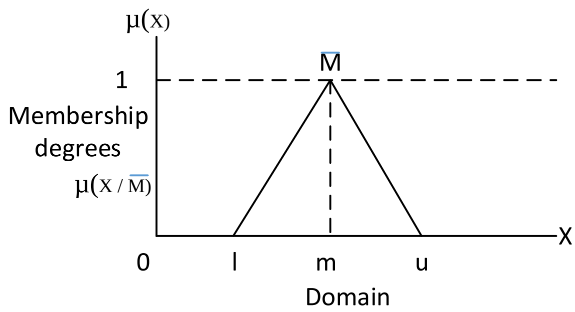


Fig. 1: A triangular fuzzy number (TFN) (Chang, 1996)

The definition value of the intensity of AHP into interest priority of fuzzy AHP can be seen in Table 1.

Table 1: Interest priority of fuzzy AHP

No	Interest priority of fuzzy AHP	Triangular fuzzy number (TFN)	Rhetoric (l, m, u)
1	Just Equal=1	(1, 1, 1)	(1, 1, 1)
2	First	(1/2, 1, 3/2)	(2/3, 1, 2)
3	Intermediate=2	(1, 3/2, 2)	(1/2, 3/2, 1)
4	Moderately Important=3	(3/2, 2, 5/2)	(2/5, 1/2, 3/2)
5	Second Intermediate=4	(2, 5/2, 3)	(1/3, 2/5, 1/2)
6	Strongly important=5	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
7	Third Intermediate=6	(3, 7/2, 4)	(1/4, 2/7, 1/3)

2.2. Project cost estimation

Several methods of cost estimation are as follows. The parameter method is a method that relates costs to certain physical characteristics of objects, for example, Area, length, weight, volume, and so on (Sayadi et al., 2015).

Using a list of price indexes and information on previous projects, namely by looking for a comparison between prices at one time (certain year) against prices at that time (year) which is used as a basis. Also, the use of data from manuals, handbooks, catalogs, and periodicals, is very helpful in estimating project costs (Enrica et al., 2021). The method of analyzing the elements (Elemental Cost Analysis), namely by describing the project scope into elements according to their function (Fragkakis et al., 2015). The factor method uses the assumption that there is a correlation between the price of the main equipment and the related components (Shane et al., 2019). Quantity take-off, namely by making cost estimates by measuring the number of project components from drawings, specifications, and plans (Marinelli et al., 2015). The unit price method, namely by estimating costs based on unit prices, is carried out if the number indicating the total volume of work cannot be determined with certainty, but the cost per unit (per square meter, per cubic meter) can be calculated (Makovšek, 2014). Using the relevant project data and information, which is a method that uses input from the project being handled, so that the figures obtained reflect the actual situation (Kim, 2011).

3. Methodology

In this research, there are five criteria used as the basis for calculating the analytical hierarchy process. There is drainage, earthworks, grained pavement and cement concrete, paved pavement, and structure. On drainage criteria, there are alternatives which are (1) procurement of box culvert, (2) box culvert installation, (3) Batu Kali installation, and (4) plastering/shading work. On earth work criteria, there are alternatives which are (1) regular excavation, (2) heap of sand, (3) hard soil excavation, and (4) ordinary soil fill. On Grained Pavement and Cement Concrete criteria, there are alternative which is (1) aggregate base class A, (2) aggregate base class B, (3) aggregate base class A and (3) aggregate base class CTB. On Paved Pavement criteria, there are alternatives which are (1) binder absorb layer, (2) adhesive layer, (3) Laston Lapis Aus (AC-WC), and (4) Laston Lapis Aus between two sides. On structure criteria, there are alternatives which are (1) Bamboo Trucuk Diameter 10-meter, (2) pair of Batu Kali, and (3) unloading the paving. The result of this application is the smallest fuzzy AHP because those values mean the winner of the tender will provide the biggest profit to the contractor. These criteria and alternatives can be seen in Fig. 2.

In this application of FAHP, there are 2 actors which are the administrator and the project manager. The administrator must log in first to use this application using a username and password. Administrators could manage road improvement project criteria data according to Fig. 3 on the second level. The administrator could add the value of FAHP according to Table 1. After that administrator could manage the project cost budget and could view the result of FAHP. This process could be seen in Fig. 3.

The project manager could view the result of the road improvement project ranking and could view detailed ranking results and could view help read the instruction on how to use this application, and this process can be seen in Fig. 4.

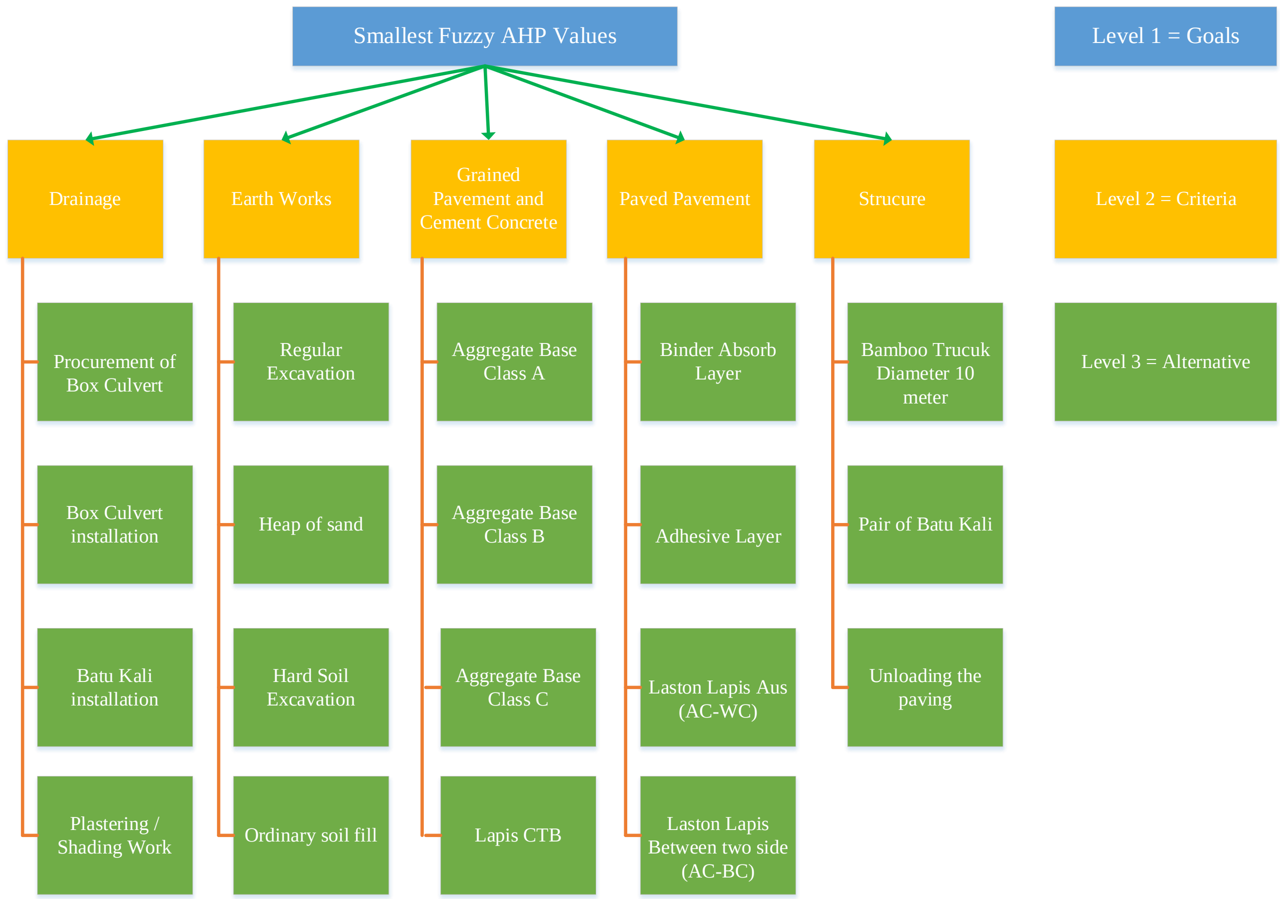


Fig. 2: Design of FAHP in this research

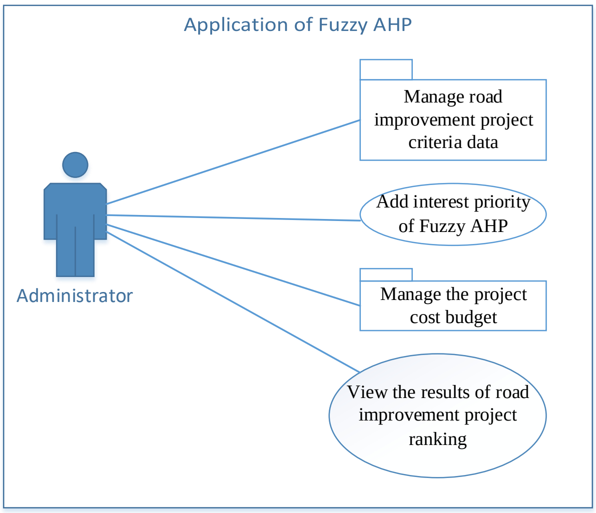


Fig. 3: Use case diagram of the administrator

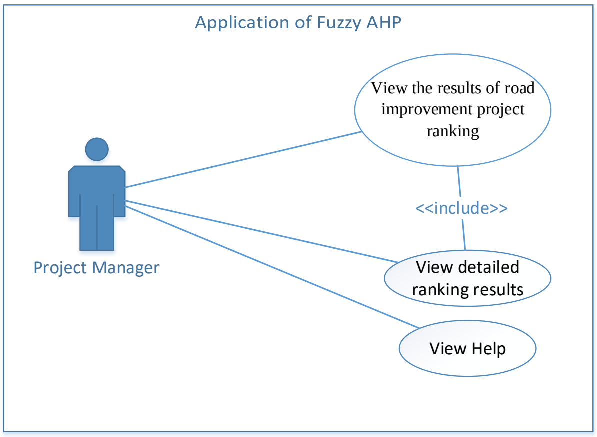


Fig. 4: Use case diagram of project manager

4. Findings

The application of FAHP for weight calculation is run by a local host because this application stores important data for the company and can only be accessed by admins and project managers. When the admin opens the application of FAHP, the admin can see the dashboard of this application, which can be seen in Fig. 5.

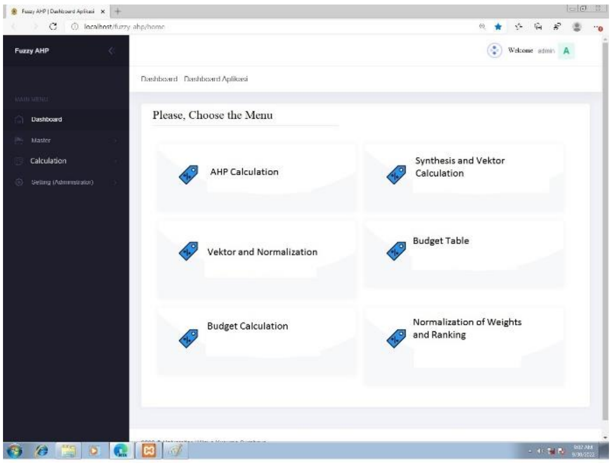


Fig. 5: Dashboard of application of fuzzy AHP

After defining the five sustainable project criteria, as shown in the previous subsection, the first step in determining the priority weights of these criteria is collecting the opinions of experts in sustainability and sustainable development regarding the relative importance of these criteria in sustainable project selection. In this research, some literature publications related to sustainable project selection and sustainable development as well as some prominent projects management literature covering the chosen criteria were selected and evaluated, as part of the Literature review for this research, to serve as the voice of experts in determining preferences among the seven different criteria shown in Table 1. These studies were closely reviewed to determine the relative importance of these criteria and preference patterns, as represented by the authors of those publications. The list of the chosen literature publication is shown in Table 2.

Table 2: Selected expert literature used for the evaluation of criteria

No	Expert	Source(s)
1	E1	(Van Damme et al., 2016)
2	E2	(Masoumi et al., 2022)
3	E3	(Roche, 2017)
4	E4	(Kwon et al., 2017)
5	E5	(Brenning et al., 2011)

The second step in determining the priority weights of the five sustainable project criteria is utilizing the expert opinions from the literature in Table 2 based on the linguistic variables and triangular fuzzy numbers (TFNs), shown in Table 1. In this step, expert opinions are gathered from the literature and translated into linguistic variables. After creating the pairwise comparison matrix representing the opinions of each of the ten experts shown in Table 1 using the linguistic variables, these seven matrices are then combined to form the combined pairwise comparison matrix shown in Table 2. Numbers in red indicate the criteria meet the criteria themselves, so the value automatically displays “1.” The implementation of Table 2 is shown in Fig. 6, where five sustainable project criteria are combined with TFNs.

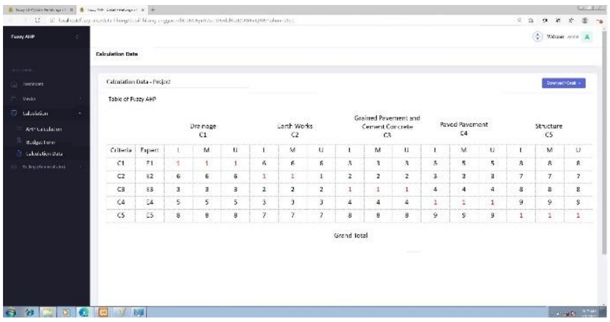


Fig. 6: Pairwise comparison matrix using linguistic variables

Determine the value of priority fuzzy synthesis (Si) with Eqs. 2, 3, and 4.

$$Si = \sum_{j=1}^{m} M_{gj}^{j} X \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gj}^{j}\right]^{-1} \quad (2)$$

where,

$$\sum_{j=1}^{m} M_{gj}^{j} = \left[\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj\right] \quad (3)$$

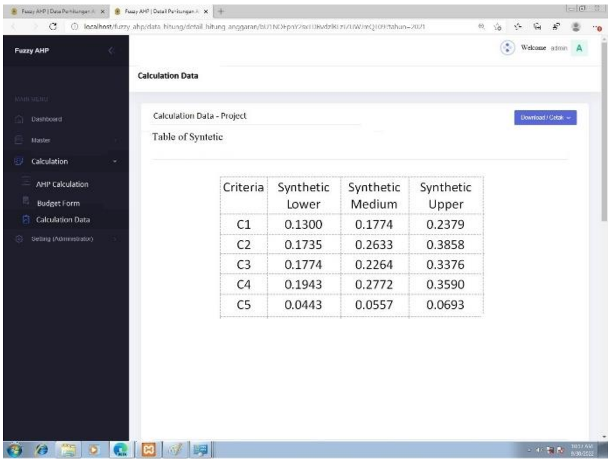
while,

$$\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} M_i^j} = \left(\frac{1}{\sum_{i=1}^{n} ui}, \frac{1}{\sum_{i=1}^{n} mi}, \frac{1}{\sum_{i=1}^{n} li}\right) \quad (4)$$

where, $\sum_{j=1}^{m} M_{gi}^{j}$ is the sum of the rows in the paired matrix.

Note:
M= (Criteria, Sub criteria, or alternative)
i= row i,
j= column j,
l= lower score,
m= medium score,
u= upper score

The fuzzy synthetic extent or the fuzzy relative importance weights result from applying the same process to the remaining criteria as shown in Fig. 7.



Criteria	Synthetic Lower	Synthetic Medium	Synthetic Upper
C1	0.1300	0.1774	0.2379
C2	0.1735	0.2633	0.3858
C3	0.1774	0.2264	0.3376
C4	0.1943	0.2772	0.3590
C5	0.0443	0.0557	0.0693

Fig. 7: Fuzzy synthetic extent of sustainable project selection criteria

Determine the vector value (V) and defuzzification ordinate value (d'). If the results obtained are on a fuzzy matrix, M2≥M1 where M1= (l1, m1, u1) and M2= (l2, m2, u2) then the vector value can be solved by Eq. 5.

$$V(M2 \geq M1) = \begin{Bmatrix} 1 \\ 0 \\ \frac{l1-u2}{(m2-u2)-(m1-l1)} \end{Bmatrix} \quad (5)$$

where, sub is the smallest upper limit of the minimum vector result. Or as shown in Eq. 6 to determine the vector value.

$$V(M2 \geq M1) = sup\left[min\left(\mu M1(x), \min\left(\mu M1(y)\right)\right)\right] \quad (6)$$

If the resulting fuzzy value is greater than k, Mi, (i=1, 2, k) then the vector value can be defined as Eq. 7.

$$V(M \geq M1, M2, \ldots, Mk) = V(M \geq M1) \text{ and } V(M \geq M2) \text{ and } V(M \geq Mk) = \min V(M \geq Mi) \quad (7)$$

The defuzzification ordinary is defined in Eq. 8.

$$d'(Ai) = minV(Si \geq Sk) \quad (8)$$

For k=1, 2, ..., n; k≠i, then the vector weight value is obtained as in Eq. 9.

$$W' = \left(d'(A1), d'\left(A2d'(An)\right)T\right) \quad (9)$$

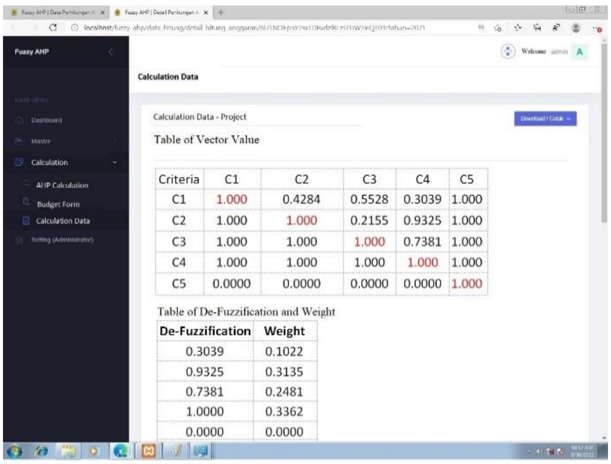
where, Ai=1, 2, ..., n is a fuzzy vector or weight (W).

The vector value of the criteria C1 to C5 using Eqs. 5, and 6 can be seen in Fig. 8, after that it can produce the defuzzification value of Eq. 8 and the Weight value of Eq. 9 can be seen in Fig. 8. Numbers in red indicate the criteria meet the criteria themselves, so the value automatically displays "1,000."

After getting the weight value, the admin can input the budget according to the road repair project in Gresik Regency which is used to calculate the normalization value. In this study, the Road Repair Project used is 3 years, namely 2018, 2019, and 2020. The Fuzzy AHP application provides facilities for admins to input a budget project for a minimum of 2 years and a maximum of 5 years. After that application, FAHP could give the output a normalization of the fuzzy vector weight value (W). The normalization of Eq. 10, is used to the normalized vector weight value is like Eq. 10:

$$W(d(A1), d(A2), \ldots, d(An),)T \quad (10)$$

The application of FAHP for choosing the best road repair project in the Gresik district gives the result that the project budget in 2019 is ranked first, the project budget for 2018 is ranked second, and the project budget for 2020 is ranked third. This is because the fuzzy AHP value in 2019 has the smallest value, which means that the application FAHP gives the best profit to the project manager than the project budget in 2018 or 2020, as can be seen in Fig. 9.



Criteria	C1	C2	C3	C4	C5
C1	1.000	0.4284	0.5528	0.3039	1.000
C2	1.000	1.000	0.2155	0.9325	1.000
C3	1.000	1.000	1.000	0.7381	1.000
C4	1.000	1.000	1.000	1.000	1.000
C5	0.0000	0.0000	0.0000	0.0000	1.000

De-Fuzzification	Weight
0.3039	0.1022
0.9325	0.3135
0.7381	0.2481
1.0000	0.3362
0.0000	0.0000

Fig. 8: Vector value, de-fuzzification, and weight

5. Conclusion

FAHP implementation has been widely developed in various fields, but making FAHP modeling has criteria that are tailored to each individual's needs.

According to Bilgen and Şen (2012), FAHP has been combined with Six Sigma to reduce the energy cost, and they used material transferring heat loss in an automotive supplier industry as criteria in their FAHP modeling.

Abbasimehr and Tarokh (2017) used FAHP with five critical phases for ranking reviewers in terms of credibility and combined with a fuzzy inference system. In collecting data processing, they used a web of trust data, data about users' reviews, and users' contributions as criteria in their FAHP modeling. In addition, according to the proposed framework, to compute a realistic credibility score based on trustworthiness and expertise, a cognitive approach was followed and a fuzzy inference system was designed. According to Hatefi and Tamošaitienė (2018), the FAHP method uses criteria of sustainable development in three aspects of the economy, society, and environment using literature and experts' ideas. Then two questionnaires related to fuzzy AHP and improved GRA were designed. According to Kubler et al. (2016), FAHP modeling were been used to carry out a literature review of 190 application papers (i.e., applied research papers), published between 2004 and 2016, by classifying them on the basis of the area of application, the identified theme, the year of publication, and so forth.

This research has five criteria used as criteria in our FAHP modeling. There is drainage, earthworks, grained pavement and cement concrete, paved pavement, and structure. On drainage criteria, there are alternatives which are (1) procurement of box culvert, (2) box culvert installation, (3) Batu Kali installation, and (4) plastering/shading work. On earth work criteria, there are alternatives which are (1) regular excavation, (2) heap of sand, (3) hard soil excavation, and (4) ordinary soil fill. On Grained Pavement and Cement Concrete criteria, there are alternative which is (1) aggregate base class A, (2) aggregate base class B, (3) aggregate base class A and (4) aggregate base class CTB. On Paved Pavement criteria, there are alternatives which are (1) binder absorb layer, (2) adhesive layer, (3) Laston Lapis Aus (AC-WC), and (4) Laston Lapis Aus between two sides. On structure criteria, there are alternatives which are (1) Bamboo Trucuk Diameter 10-meter, (2) pair of Batu Kali, and (3) unloading the paving. This research implements the FAHP method to choosing best project and give lowest cost estimation. This selection tool can be applied by any project manager when evaluating different sustainable project alternatives for selection regardless of the type, environment, and location of these projects. The criteria chosen in this research are novelty, uncertainty, team skill and experience, technology information transfer, and project cost. Prioritizing these criteria based on relative importance helps project manager identify more important project elements that require additional attention, better allocate resources, as well as improve the selection process when evaluating different sustainable project alternatives. This research utilizes the existing literature examined as part of the literature review process to represent the voice of experts on the relative importance of the selected criteria.

The FAHP method can be implemented in selecting the best project that can provide the lowest raw material purchase price and give the best profit to the project manager, which can be shown by the Application FAHP with the lowest Total Score value. This process is carried out by the admin doing pairwise comparisons with the AHP scale, transforming the pairwise comparison matrix into the TFN scale, calculating the fuzzy synthesis value (Si), the vector value (V), and the defuzzification ordinate (d'), input the project budget that has been implemented (or last year), normalization, calculating the consistency ratio and calculating the final alternative weight value to give result total score FAHP.

The limitations associated with this research include the small sample size of literature considered to act as the voice of experts in the pairwise comparison of the chosen criteria. A larger sample size in the future could yield more accurate results regarding the relative importance of the selected criteria. It is also important to note that these results are limited to the knowledge and experiences of the chosen experts. Another potential limitation of this research is the use of literature to act as the voice of experts. This could add another layer of uncertainty and subjective judgment that stems from the interpretations and opinions of the researchers utilizing the literature, which is not accounted for by the FAHP. Future research should focus on gathering input data from sustainable project researchers and practitioners in an effort to gather direct input and, thus, eliminate any need for interpretation by the researchers.

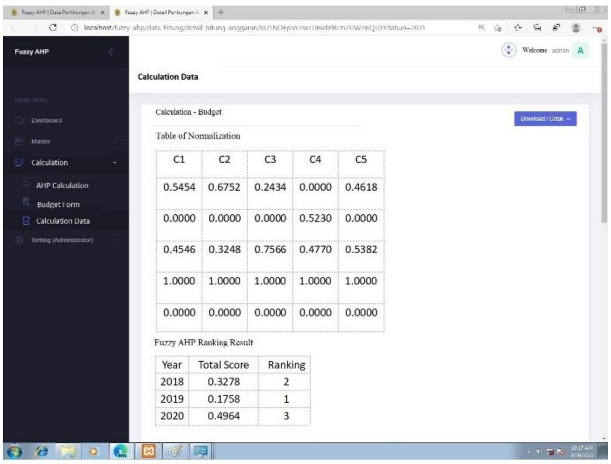


Fig. 9: Normalization and fuzzy AHP ranking result

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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