Application of fuzzy preference relations method in AHP to improve judgment matrix consistency

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Abstract. Most issues when using AHP is the difficulty of getting the consistency of a judgment matrix. It can be affected due to decision-making subjectivity. This study proposes the usage of the fuzzy Preference Relations (FPR) method to ensure a judgment in decision-making is acceptable and high objectively due to its obstacle for satisfying consistent judgment matrix from decision-makers in AHP. Improving the consistency of decision matrix can be done through the following steps, namely: 1) Transform pairwise comparison matrix of \( A = (a_{ij}) \) into FPR \( R = (r_{ij}) \), 2) construct a new consistency matrix of FRP which satisfies the additive consistency, and 3) compose a new consistent pairwise matrix. As a result, the consistency index value was acceptable (< 0.10). Moreover, the procedure is applied in the determination of agro-industries based SMEs development.

1. Introduction
Most of the land in Banyumas Region, which is part of Central Java Province, Indonesia, is reserved for the agricultural field with an area of about 93.864 Ha or more than 70 percent of the total area in Banyumas Region [1]. In addition, Banyumas Region becomes one of the priorities for an agricultural area in Central Java Province [2]. According to land utility in Banyumas Region, one of the priorities for the development of SMEs in Banyumas Region is the industrial development of agricultural products. [3]. In 2018, The Department of Industry, Trade, and Cooperation of Banyumas region were targeting 300 SMEs would be assisted [3].

The issue of determination of SME’s assistance, namely the large of data and the vast number of parameters need to be judged. Regarding this problem, The Decision Support System (DSS) may be performed as a useful tool to assist decision-makers. One of the DSS models for supporting decision making in terms of establishment of agro-industries based SMEs development is the Analytical Hierarchy Process (AHP). AHP is a useful method of decision making, especially when it involves several attributes and preferences [4], which is enable decision-makers to simplify the problem into a hierarchical structure based on human being's perceptions [5]. Furthermore, Ho and Xin (2017) stated that AHP is ease of understanding, clearness, and highly adaptive [6].

In connection with its advantages, AHP is the widely employed decision-making approach that is used in various fields such as education [7] for supporting in the ranking ordering of scholar prospective and deciding the proper teaching process in higher learning institution [8]. Additionally, AHP was utilized for appraising the stage of information technology management that currently used and level of expected information technology management, which involved in the next phase [9],
multi-criteria decision making (MCDM) methods was also applied for specifying the most performing information system [10]. On the other hand, Wang et al. (2017) have studied the matching agricultural supply chain data in order to obtain suitable production and marketing models based on AHP [11].

Despite the benefits of AHP, at most times, there is a challenge to satisfy consistent judgment matrix from decision-makers [12] due to lack of information during criteria prioritization or subjective aspects of decision-makers in qualitative assessments are often inappropriate [13]. Moreover, when a consistent state of decision maker's perceptions fails to be achieved, then it has to correct the judgment matrix to obtain acceptable consistency index value, which is less than or equal to 0.1 [14]. It may lead to many problems, such as time-consuming, or requires a fairly large size in the calculations in decision making [12]. Besides that, the judgment of priority criteria will be influenced by the subjectivity of decision-makers [12].

This study aims a method that can be utilized for enhancing properly consistency index (CI) value of a received valuation matrix so that a generated decision matrix represents prioritization based on empirical situations and fulfills highly level of objectivity. According to [15], one approach for improving the consistency of judgment matrix in the AHP is the usage of Fuzzy Preference Relations (FPR). It will transforms pairwise comparison matrix of $A = (a_{ij})$ into FPR matrix of $R = (r_{ij})$ [15]. Based on the matrix of $R = (r_{ij})$, it may construct a new consistency matrix of $G = (g_{ik})$, which satisfies the additive consistency $G_{ik} = g_{ij} + g_{jk} - \frac{1}{2}$ where $1 \leq i \leq n$, $1 \leq j \leq n$, and $1 \leq k \leq n$ [16]. Then, a new consistent pairwise matrix is obtained depending on $G = (g_{ik})$ [15].

2. Literature review

2.1. Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision-making technique to determine the best from several alternatives based on several assessment criteria. It's invented to deal with human sensibility and impulse [14]. In using the AHP model, there are several steps as follow [12]:

a. Simplify the purpose of decision making by selecting the proper appraisal attributes and alternatives into relevant hierarchies.

b. Compare the priority of each criterion according to the notion of decision-makers by arranging a pairwise comparison matrix. The priority of the assessment criteria uses a scale, as shown in Table 1 [14].

| Intensity of importance | Definition                        | Explanation                                                   |
|------------------------|----------------------------------|---------------------------------------------------------------|
| 1                      | Equal importance                 | Two activities contribute equally to the objective            |
| 3                      | Moderate importance              | Experience and judgment slightly favor one activity over another |
| 5                      | Strong importance                | Experience and judgment strongly favor one activity over another |
| 7                      | Very strong or demonstrated importance | An activity is favored very strongly over another; its dominance demonstrated in practice |
| 9                      | Extreme importance               | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2,4,6,8                | notion between two proximate values | This value is specified when options are adjacent. For instance, four is given in-between 3 and 5 |

Reciprocals of above If activity $i$ has one of the above nonzero numbers assigned to it when compared with activity $j$, then $j$ has the reciprocal value when compared with $i$.
c. Calculate the priority vector of each decision element.
d. Check the consistency of the judgment matrix, which constructed in step 2 above. If the consistency fails to be obtained, refine the relevant pairwise comparison matrix. The consistency index of the judgment matrix can be measured by formula, as shown in Equation (1) [14].

\[ CI = \frac{\lambda_{\text{max}} - n}{(n-1)} \]  

where:
- CI: Consistency Index
- \( \lambda_{\text{max}} \): Maximum eigenvalue
- n: Number of criteria

The next phase is checking consistency, which represented by consistency ratio (C.R). C.R is obtained by calculating the differences between CI and one of the corresponding values from Table 2 Equation (2) [14]. If it is less or equal than 0.10, then the estimate of the matrix is acceptable. Otherwise, attempt to improve consistency.

\[ C.R = \frac{CI}{R.I} \]  

| N | Random consistency index (R.I.) |
|---|--------------------------------|
| 1 | 0                             |
| 2 | 0.52                          |
| 3 | 0.89                          |
| 4 | 1.11                          |
| 5 | 1.25                          |
| 6 | 1.35                          |
| 7 | 1.40                          |
| 8 | 1.45                          |
| 9 | 1.49                          |
| 10|                               |

Table 2. Random Consistency Index (r.i)
e. Finally, conduct absolute measurement of each alternative related to criteria to achieve the ranking of alternatives

2.2. Fuzzy preference relations
The Fuzzy Preference Relations (FPR) method is used to induce a pairwise comparison matrix in order to gain adequate consistency measures in AHP [15]. Consistency improvement can be made through three-steps as follow:

a. Transform pairwise comparison matrix of \( A = (a_{ij}) \) into FPR \( R = (r_{ij}) \) using the following function (Equation (3)) [15].

\[ r_{ij} = g(a_{ij}) = \frac{1}{2} \left( 1 + \log_{a} a_{ij} \right) \]  

b. According to Equation (2), we can construct a new consistency matrix of FRP which satisfies the additive consistency [16], where:

\[ g_{ik} = \left( \frac{1}{n} \sum_{j=1}^{n} (r_{ij} + r_{jk}) - \frac{1}{2} \right) \]  

c. A new consistent pairwise matrix based on additive consistency matrix (Equation (4)) can be acquired by Equation (5) [15]:

\[ a_{ij} = 9^{2(g_{ij} - 0.5)} \]  

3. Methodology
The aim of this study is utilizing the Analytic Hierarchy Process (AHP) method to work out issues associated with agroindustry-based SMEs in Banyumas Region, Central Java Province, Indonesia. This research is an attempt to apply the AHP technique to offer a recommendation for the empowerment of agroindustry-based SMEs. The second stage is determining the assessment criteria. The set of criteria were adapted from DSS application that has been developed by Ministry of Cooperation and Small and Medium Enterprises of The Republic Indonesia [17], then modified based on the condition of SMEs in Banyumas region namely 1) the level of technology is used in the
cultivation process, 2) number of cultivation phases, 3) market segmentation, 4) advertisement media, 5) marketing area, and 6) availability of raw materials. Definitions of each criterion are shown in Table 3. The third step is comparing the priority of each criterion based on 1 to 9 scale (Table 1). It will compose a pairwise comparison matrix of $A = (a_{ij})$.

### Table 3. Defining each criterion

| Criteria                                      | Description                                                                                                                                 |
|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| The level of technology is used in the cultivation process (P1) | The level of technology used, whether production is done entirely by humans, production is partly done by humans and partly supported by machines, or the overall production is carried out by modern technology. |
| Number of cultivation phases (P2)             | Stage of the cultivation process, whether it requires a lot of paths and each path takes several days, each path takes less than one day, or a relatively small path and each path takes less than one day. |
| Market segmentation (P3)                      | SMEs have plans for consumer segmentation such as age, gender, economic status and geography.                                               |
| Advertisement media (P4)                      | Advertisement media are used by SMEs such as newspapers, magazines, radio advertisements, television advertisements on, or advertisements on the Internet (social media). |
| Marketing area (P5)                           | Does the sales area covers only in the region, in the province, within the country, or abroad.                                              |
| Availability of raw materials (P6)            | The level of availability of raw materials for cultivation is always rare, available at certain times, quite available, or widely available. |

After constructing the pairwise comparison matrix, the next phase is computed priority vector ($w$) or priority significance of each criterion by counting any column in a row based on normalization of judgment matrix and then divide them with the number of criteria. In order to find the eigenvalue ($\lambda$), which is needed inconsistency assessment, is carried out by multiplying between judgment matrix and normalized eigenvector. In addition, to verify the consistency vector ($CV$), divide each of the eigenvalues with priority vector ($w$). Based on eigenvalue ($\lambda$), the maximum eigenvalue ($\lambda_{max}$) can be calculated using Equation (6) [14].

$$\lambda_{max} = \frac{CV_1 + CV_2 + .. + CV_n}{n}$$  \hspace{1cm} (6)

Regarding the maximum eigenvalue ($\lambda_{max}$) on Equation (6), it is necessary to perform consistency measurement ($CI$ and $CR$) of matrix ($A$) to make sure that judgment in decision making is acceptable and high objectively. The CI ($Consistency$ $Index$) and the CR ($Consistency$ $Ratio$) are then gained by equation 1, and by comparing CI with corresponding the random matrix (Table 2). The value of the R.I (Random Index) is set as about 1.25 (for $n = 6$ criteria). When the number of C.R is not adequate (more than 0.1), it will carry out the FPR method for improving consistency. The FPR method in this study is carried out sequentially using Equation (3), (4), and (5) [15, 16]. They both last stages are priority ranking alternatives toward each of the criteria and conducting the addition of all weights to gain the best alternative. The sequences of the research methodology are described in the form of a flowchart diagram, as shown in Figure. 1.
4. Results and discussion

4.1. Judgment scales of decision elements
According to the priority determination of each criterion from decision-makers, it can be composed of a judgment matrix presented in Table 4. In addition, Table 5 represents the normalization matrix, which is collected from the decision scale that has been compared by the addition of each column's grades. As a result, the priority significance of each criterion can be achieved.

Table 4. Pairwise comparison

| A   | P1 | P2 | P3   | P4 | P5 | P6 |
|-----|----|----|------|----|----|----|
| P1  | 1  | 3  | 1/5  | 5  | 1/5| 1/5|
| P2  | 1/3| 1  | 3    | 4  | 4  | 1/5|
| P3  | 5  | 1/3| 1    | 2  | 2  | 1/5|
| P4  | 1/5| 1/4| 1/2  | 1  | 1/3| 1/5|
| P5  | 5  | 1/4| 1/2  | 3  | 1  | 1/5|
| P6  | 5  | 5  | 5    | 5  | 5  | 1  |
| Total | 16.53| 9.83 | 10.20 | 11.00 | 12.53 | 2.00 |

Figure 1. The flowchart of research methodology
Table 5. Normalization and priority vector of each criteria

|   | A | P1 | P2 | P3 | P4 | P5 | P6 | Weight |
|---|---|----|----|----|----|----|----|--------|
| P1| 0.06 | 0.31 | 0.02 | 0.45 | 0.02 | 0.10 | 0.16 |
| P2| 0.02 | 0.10 | 0.29 | 0.36 | 0.32 | 0.10 | 0.20 |
| P3| 0.30 | 0.03 | 0.10 | 0.18 | 0.16 | 0.10 | 0.15 |
| P4| 0.01 | 0.03 | 0.05 | 0.09 | 0.03 | 0.10 | 0.05 |
| P5| 0.30 | 0.03 | 0.05 | 0.27 | 0.08 | 0.10 | 0.14 |
| P6| 0.30 | 0.51 | 0.49 | 0.45 | 0.40 | 0.50 | 0.44 |

4.2. Assess consistency of judgment matrix

With regard to fulfilling decision matrix consistency assessment, it is necessary to count the maximum eigenvalue (Equation (6)) as well as consistency index (CI) (Equation (1)). The marks for both \( \lambda_{\text{max}} \) and CI are \( \lambda_{\text{max}} = 8.33 \) and CI = 0.467. So, the consistency ratio (CR) can be computed using Equation (2).

\[
C.R = \frac{0.467}{1.25} = 0.373
\]

Because of CR > 0.10, then the judgment matrix was considered as inconsistent. Hence, it need to change into FPR \( R = (r_{ij}) \) matrix (Eq. 3). A FPR \( R = (r_{ij}) \) matrix is as follow:

\[
R_{ij} = \begin{bmatrix} 0.50 & 0.75 & 0.13 & 0.87 & 0.13 & 0.13 \\ 0.25 & 0.50 & 0.75 & 0.82 & 0.82 & 0.13 \\ 0.87 & 0.25 & 0.50 & 0.66 & 0.66 & 0.13 \\ 0.13 & 0.18 & 0.34 & 0.50 & 0.25 & 0.13 \\ 0.87 & 0.18 & 0.34 & 0.75 & 0.50 & 0.13 \\ 0.87 & 0.87 & 0.87 & 0.87 & 0.87 & 0.50 \end{bmatrix}
\]

In order to obtain a new consistency matrix of \( R = (r_{ij}) \) which satisfies the additive consistency, transform matrix \( R = (r_{ij}) \) into \( R = (r_{ik}) \) matrix using Equation (4). A \( R = (r_{ik}) \) matrix shown as follows

\[
R_{ik} = \begin{bmatrix} 0.52 & 0.38 & 0.41 & 0.66 & 0.46 & 0.11 \\ 0.62 & 0.50 & 0.53 & 0.79 & 0.58 & 0.24 \\ 0.59 & 0.47 & 0.50 & 0.75 & 0.55 & 0.21 \\ 0.34 & 0.21 & 0.25 & 0.50 & 0.29 & -0.05 \\ 0.54 & 0.42 & 0.45 & 0.71 & 0.50 & 0.16 \\ 0.89 & 0.76 & 0.79 & 1.05 & 0.84 & 0.50 \end{bmatrix}
\]

From the new consistency matrix of \( R = (r_{ik}) \), it can construct A new consistent pairwise matrix \( \tilde{A} = (a_{ij}) \) based on Equation (5). A new consistent pairwise matrix \( \tilde{A} = (a_{ij}) \) appear in Table 6.

Table 6. A new pairwise comparison

|   | A | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|----|----|----|----|----|----|
| P1| 1.00 | 0.58 | 0.67 | 2.04 | 0.83 | 0.18 |
| P2| 1.73 | 1.00 | 1.16 | 3.53 | 1.43 | 0.32 |
| P3| 1.49 | 0.86 | 1.00 | 3.05 | 1.24 | 0.27 |
| P4| 0.49 | 0.28 | 0.33 | 1.00 | 0.41 | 0.09 |
| P5| 1.21 | 0.70 | 0.81 | 2.47 | 1.00 | 0.22 |
| P6| 5.44 | 3.15 | 3.64 | 11.10 | 4.50 | 1.00 |
| Total| 11.37 | 6.58 | 7.61 | 23.18 | 9.40 | 2.09 |
With respect to phases in AHP, after pairwise matrix was constructed, the next step is conducting normalization matrix to obtain the priority significance of each criteria and validate consistency measurement (\(CI_{\text{and C.R}}\)) of matrix (\(\bar{A}\)). A new normalization matrix (\(\bar{A}\)) was revealed in Table 7.

### Table 7. A new normalization and priority vector of each criteria

| \(\bar{A}\) | P1  | P2  | P3  | P4  | P5  | P6  | Weight |
|------------|-----|-----|-----|-----|-----|-----|--------|
| P1         | 0.09| 0.09| 0.09| 0.09| 0.09| 0.09| 0.09   |
| P2         | 0.15| 0.15| 0.15| 0.15| 0.15| 0.15| 0.15   |
| P3         | 0.13| 0.13| 0.13| 0.13| 0.13| 0.13| 0.13   |
| P4         | 0.04| 0.04| 0.04| 0.04| 0.04| 0.04| 0.04   |
| P5         | 0.11| 0.11| 0.11| 0.11| 0.11| 0.11| 0.11   |
| P6         | 0.48| 0.48| 0.48| 0.48| 0.48| 0.48| 0.48   |
| Total      | 1.00| 1.00| 1.00| 1.00| 1.00| 1.00| 1.00   |

Regarding Table 7, the marks for both (\(\lambda_{\text{max}}\)) and CI are (\(\lambda_{\text{max}}\)) = 6 and CI = 00. So, the value of consistency ratio (CR) is 0. Because of CR < 0.10, then the judgment matrix was considered as consistent. With respect to analyses rating (Table 6) and calculating relative weight (Table 7), availability of raw materials (48%) is 3 times more important than number of cultivation phases (15%) and market segmentation (13%). Availability of raw materials was most critical criterion in the sustainability of agro-industrial SMEs, since it was the basic substances that is used in production. Furthermore, it was one of significant acquiring activity in supply chain [18] because naturally it depends on several elements, namely: recycling rate of a raw material, climate change (7.21), agricultural land occupation (0.39), and natural land transformation (1.02) [19]. In addition, its 3 times more important than number of cultivation phases (15%) and market segmentation (13%). The two lowest criteria are the level of technology is used in the cultivation process (9%) and advertisement media (4%). Comparison of the importance degree of criteria are revealed as a pie chart in Figure 2.
4.3. Compare the alternatives with respect to each criterion

The degree of importance of five alternatives with respect to each associated criteria is gained through pairwise comparison. Similarly, it needs to perform six pairwise comparisons (n = 6). The values in Table 8 are obtained from the weight calculation of each alternative to each criterion. The five alternatives are paired comparisons with each criterion P1, P2, P3, P4, P5, and P6 according to the comparison scale in Table 1. The comparison results are then normalized through the division of each value by the number of columns. Then the normalization results are summed and divided by the number of criteria to get the priority weights of each alternative to each criterion as shown in Table 8. Alternative weights 1 against criteria P1 = 0.32, weights against criteria P2 = 0.33, weights against criteria P3 = 0.51, weights with respect to criterion P4 = 0.21, weight for criterion P5 = 0.29, weight for criterion P5 = 0.27. And so on for alternative 2 to alternative 5. The results of the priorities of the alternatives shown in Table 8.

In accordance with AHP rules (step c and d). The results of pairwise comparison normalization were carried out consistency testing using Equation (1) and (2). Based on the sum of each normalized column, all of them are 1, then it can be ensured that the results of the pairwise comparison of all alternatives to each criterion are consistent.

Table 8. Importance degree of each alternative towards criteria

| Weight | P1 | P2 | P3 | P4 | P5 | P6 |
|--------|----|----|----|----|----|----|
| Alternative 1 | 0.32 | 0.33 | 0.51 | 0.21 | 0.29 | 0.27 |
| Alternative 2 | 0.10 | 0.25 | 0.19 | 0.11 | 0.16 | 0.09 |
| Alternative 3 | 0.29 | 0.18 | 0.10 | 0.37 | 0.29 | 0.09 |
| Alternative 4 | 0.11 | 0.11 | 0.10 | 0.21 | 0.10 | 0.27 |
| Alternative 5 | 0.18 | 0.12 | 0.10 | 0.11 | 0.14 | 0.27 |

4.4. Rank the best alternatives

Finally, the ranking of alternatives is achieved from the sum of the multiplication of each alternative weight (Table 8) with the weight of the corresponding criteria (Table 7), as shown in Table 9. The best alternative is the one that has the most significant weight results, which is alternative 1. On the other hand, it could be inferred that alternative 1 is strongly recommended as a SMEs would be assisted due to higher degree aspects such the level of technology is used in the cultivation process (P1), number of cultivation phases (P2), advertisement media (P3), and marketing area (P5) than other five alternatives. In addition, Whereas the second recommendation is alternative 2, which has a higher weight value on the two criteria with the second and third highest weights, namely number of cultivation phases (P2) and market segmentation (P3) compared to alternatives 3,4, and 5.

Table 9. Ranking of alternatives

| Ranking | Alternatives | Overall Weight |
|---------|--------------|---------------|
| 1       | Alternative 1 | 0.20          |
| 2       | Alternative 5 | 0.17          |
| 3       | Alternative 4 | 0.16          |
| 4       | Alternative 3 | 0.12          |
| 5       | Alternative 2 | 0.08          |
5. Conclusions
In this research, AHP has been implemented for suggesting agroindustry-based SMEs that would be encouraged. Moreover, it proposed a consistency enhancement procedure for the pairwise comparison matrix. As a result, there is priority vector refinement (See. Table 7) since the inadequate consistency index. In order to fulfill CR < 0.10, it proposed several procedures, namely 1) transformation pairwise comparison matrix fuzzy preference relations matrix \( R = (r_{ik}) \) (Eq. (3)), 2) compose a new consistency matrix of FRP which satisfies the additive consistency (Eq. (4)). Further, a matrix \( R = (r_{ik}) \) satisfies the additive consistency fuzzy preference relations where \( r_{ik} = r_{ij} + r_{jk} - 0.5 \) for \( i \in \{1, 2, ..., 6\}, j \in \{1, 2, ..., 6\} \) and \( k \in \{1, 2, ..., 6\} \), and 3) obtain a new consistent pairwise matrix \( \tilde{A} = (a_{ij}) \) (Eq. (5)) [16].

The offered procedure above has proven to improve the consistency of judgment matrix as the results of \( \lambda_{\text{max}} = 6 \) and \( C.R = 0 \) that related to matrix(\( \tilde{A} \)). From matrix(\( \tilde{A} \)), the availability of raw materials (C1) considered the most significant criterion (48%). Then, an alternative one is the best SMEs would be assisted because it has a larger amount in the level of technology is used in the cultivation process (C1), the number of cultivation phases (C2), advertisement media (C3), and marketing area (C5).

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