An application of fuzzy multiple-attribute decision making model based on simple additive weighting with triangular fuzzy numbers to distribute the decent homes for impoverished families

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Abstract. The Aceh government through a social housing refurbishment program has periodically provided decent homes for impoverished families in the last three years. However, the selection process of decent homes' recipient is currently still using assessments based on the personal judgment of a decision maker so the process becomes subjectivity and fuzziness. In order to overcome this problem, a fuzzy Multi-Attribute Decision Making (FMADM) technique can offer a solution. In this research, we apply an FMADM model based on Simple Additive Weighting (SAW) with triangular fuzzy numbers to express the fuzziness of decision making information and criteria weight. After normalizing the fuzzy decision making and criteria weight matrices, the alternative ranking process uses SAW to evaluate those two matrices where all criteria weight elements are crisp values converted from the triangular fuzzy numbers using Defuzzification of Minkowski. Furthermore, we demonstrated this model by showing a numerical example to a case study of the decent homes distribution of impoverished families in Aceh. The result shows that the model can be applied to this case study.

1. Introduction

In the last three years, poverty incidence among families in Aceh has increased every year. According to Statistics Indonesian or Central Agency on Statistics (Badan Pusat Statistika), the poverty rate in Aceh reached 16.43% in 2017. In reality, most of this families still lived in a non-decent home with poor material constructions so that their daily lives can be very apprehensive. In order to overcome this problem, the Aceh government through the Social Affairs Office provided a social housing refurbishment program offering decent homes for impoverished families. However, the families that will obtain the decent homes were personally selected by a decision maker through assessments based on his or her personal judgments. As a result, it is very vulnerable to occur a coalition between the decision maker and applicants.

Multiple-attribute Decision Making (MADM) has become a crucial issue in daily life to find the best alternative to many proposed alternatives and become a solution to selection problems. Recently, this decision making process divided into two approaches. One is classical MADM and the other one is fuzzy MADM[1]. The classical MADM presented criteria weight and evaluation ratings through crisp
values. Meanwhile, criteria weights and evaluation ratings in fuzzy MADM used linguistic terms transformed into fuzzy numbers to express the fuzziness of information.

Many experts and scholars have proposed new multiple-attribute decision making (MADM) models with the approach of fuzzy numbers either using theoretical or practical application. Chen and Chang [2] provided a new MADM based on intuitionistic fuzzy geometric averaging operations. The result shown that the new model presented a useful way for MADM in the environments of intuitionistic fuzzy. Fu and Fun [3] proposed a model based on exponential fuzzy numbers by calculating the expected value and variance of the fuzzy numbers. Wang and Chen [4] applied interval-valued intuitionistic fuzzy sets in developing their MADM models and used linear programming methodology and TOPSIS method to rank the alternatives in their case studies. Fu and Zhou [5] applied triangular fuzzy numbers to express the fuzziness of decision information and used set-pair analysis method to rank the alternatives. The ranking process was done after the fuzzy numbers were converted into dual connection numbers.

In recent years, research on fuzzy multiple-attribute decision making based simple additive weighting (SAW) method has been increasingly conducted by plenty of researchers. This method is easy to be implemented and is able to be applied to various applications. Their research interests focus on the modification of SAW methodology and the improvement of fuzzy numbers in order to avoid uncertainty, subjectivity and vagueness. Irvanizam [6] implemented an application of SAW to distribute the academic scholarships at a university in Aceh by using Saaty’s principle to determine criteria weights. Wang [7] extended a new MADM model by combining SAW and relative preference relation that can handle the comparison of fuzzy numbers and the reservation of fuzzy messages. This model can generalize SAW under fuzzy environment and solve fuzzy MADM problems quickly. Raj and Kumar [8] presented a fuzzy generalized SAW by showing multiplication of two triangular fuzzy numbers into a pooled fuzzy number which is not a triangular fuzzy number. In this research, we also would like to apply the concepts of SAW under fuzzy environment where the fuzziness of decision making information including criteria weight will be expressed by triangular fuzzy numbers. After normalizing the criteria weight in this fuzzy number format, the criteria weight will be converted into crisp values by using defuzzification of Minkowski. Furthermore, we used a decent homes distribution problem in the Province of Aceh as our case study to demonstrate the application of this FMADM model.

The rest of this paper is structurally described as follows: in the second section, the basic concepts of SAW consisting of preliminaries and triangular fuzzy numbers are explained in brief. Section 3 describes the methodology of SAW. Section 4 shows the calculation of SAW via a numerical example. In the last section, some conclusions are discussed.

2. Preliminaries

In this section, we present three related definitions which are the definition of triangular fuzzy number, three arithmetic operations of fuzzy numbers, and defuzzification Minkowski. Additionally, we also introduce a theorem related to this research.

**Definition 1.** Suppose \( \tilde{a} = (a_1, a_2, a_3) \) where \( 0 < a_1 \leq a_2 \leq a_3 \) be a triangular fuzzy number, then the membership function \( \mu(x, a_1, a_2, a_3) \) of \( \tilde{a} \) can be defined as [9]:

\[
\mu_{\tilde{a}}(x, a_1, a_2, a_3) = \begin{cases} 
0, & x \leq a_1 \\
\frac{x-a_1}{a_2-a_1}, & a_1 < x \leq a_2 \\
\frac{a_3-x}{a_3-a_2}, & a_2 < x \leq a_3 \\
0, & a_3 < x
\end{cases}
\]

where \( a_1, a_2, a_3 \) are the lower, the midium and the upper limit value of the fuzzy number \( \tilde{a} \) respectively.

**Definition 2.** Suppose \( \tilde{a} = (a_1, a_2, a_3) \) and \( \tilde{b} = (b_1, b_2, b_3) \) be two triangular fuzzy numbers and then the following arithmetic methods can be defined as [10]:
- \( \bar{a} + \bar{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \)
- \( \bar{a} \times \bar{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3) \)
- \( \varphi \bar{a} = (\varphi a_1, \varphi a_2, \varphi a_3) \), where \( \varphi > 0 \).

**Definition 3.** Defuzzification of Minkowski. Suppose \( \bar{a} = (a, a_2, a_3) \) where \( 0 < a_1 \leq a_2 \leq a_3 \) be a triangular fuzzy number and then the triangular fuzzy number can be converted into a crisp value [11]:

\[
\bar{x} = a_1 + \frac{(a_2 - a_3)}{4}.
\]

**Theorem 1.** Let \( \bar{a}_1 = (a_1^1, a_2^1, a_3^1) \) and \( \bar{a}_2 = (a_1^2, a_2^2, a_3^2) \) be two triangular fuzzy numbers and suppose \( x_{w_1} \) and \( x_{w_2} \) are a crisp value of the criterion \( w_1 \) and \( w_2 \) respectively, then

\[
\bar{a}_1 x_{w_1} + \bar{a}_2 x_{w_2} = x_{w_1} a_{11} + x_{w_2} a_{12} = a_{11} + \frac{(a_{12} - a_{13})}{4}.
\]

**Proof.**

According to definition 3, the triangular \( \bar{a}_1 \) and \( \bar{a}_2 \) can be converted into \( x_{w_1} = a_{11} + \frac{(a_{12} - a_{13})}{4} \) and \( x_{w_2} = a_{11} + \frac{(a_{22} - a_{13})}{4} \) such that

\[
\bar{a}_1 x_{w_1} + \bar{a}_2 x_{w_2} = (a_{11}, a_{21}, a_{31}) x_{w_1} + (a_{12}, a_{22}, a_{32}) x_{w_2}
\]

\[
= (x_{w_1} a_{11} + x_{w_2} a_{12}) + (x_{w_1} a_{21} + x_{w_2} a_{22}) + (x_{w_1} a_{31} + x_{w_2} a_{32})
\]

\[
= x_{w_1} a_{11} + x_{w_2} a_{12} + \left( x_{w_1} a_{21} + x_{w_2} a_{22} \right) + \left( x_{w_1} a_{31} + x_{w_2} a_{32} \right)
\]

\[
= x_{w_1} a_{11} + x_{w_2} a_{12} + \left( x_{w_1} a_{21} + x_{w_2} a_{22} \right) + \left( x_{w_1} a_{31} + x_{w_2} a_{32} \right)
\]

**3. Methodology**

In this section, we describe a fuzzy multiple-attribute decision making model based on SAW with approach of triangular fuzzy numbers. Assume that we have an alternative set \( A = \{ A_1, A_2, \ldots, A_n \} \) consisting of \( m \) alternatives \( A_i = \{ i = 1, 2, \ldots, m \} \) and a criteria set \( C = \{ C_1, C_2, \ldots, C_n \} \) consisting of \( n \) criteria \( C_j = \{ j = 1, 2, \ldots, n \} \). Suppose that a decision maker constructs a triangular fuzzy number \( \bar{a}_{ij} = (a_{11}^i, a_{21}^i, a_{31}^i) \) where \( a_{11}^i, a_{21}^i, \) and \( a_{31}^i \) are respectively the lower, the medium, and the upper limit value of the fuzzy number \( \bar{a}_{ij} \), and \( \mu_{ij} = (x, a_{11}^i, a_{21}^i, a_{31}^i) \) is the membership of the alternative \( A_i \) with respect to the criterion \( C_j \) given by the decision maker and \( 0 < a_{ij}^1 \leq a_{ij}^2 \leq a_{ij}^3 \).

Furthermore, we use a model of fuzzy simple additive weighting with triangular fuzzy numbers. The triangular fuzzy numbers are converted into crisp values using defuzzification of Minkowski. Steps of this model are listed as follows:

**Step 1:** Identify a fuzzy decision making matrix \( \bar{F} \) based on the attribute value of each scheme.

**Step 2:** Build a normalized decision making matrix \( \bar{F} \). The matrix \( \bar{F} \) can be expressed concisely as equation (1).

\[
\bar{F} = \begin{pmatrix}
C_1 & C_2 & C_3 & \cdots & C_n \\
A_1 & (a_{11}^1, a_{12}^1, a_{13}^1) & (a_{11}^2, a_{12}^2, a_{13}^2) & (a_{11}^3, a_{12}^3, a_{13}^3) & \cdots & (a_{11}^m, a_{12}^m, a_{13}^m) \\
A_2 & (a_{21}^1, a_{22}^1, a_{23}^1) & (a_{21}^2, a_{22}^2, a_{23}^2) & (a_{21}^3, a_{22}^3, a_{23}^3) & \cdots & (a_{21}^m, a_{22}^m, a_{23}^m) \\
A_3 & (a_{31}^1, a_{32}^1, a_{33}^1) & (a_{31}^2, a_{32}^2, a_{33}^2) & (a_{31}^3, a_{32}^3, a_{33}^3) & \cdots & (a_{31}^m, a_{32}^m, a_{33}^m) \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
A_m & (a_{m1}^1, a_{m2}^1, a_{m3}^1) & (a_{m1}^2, a_{m2}^2, a_{m3}^2) & (a_{m1}^3, a_{m2}^3, a_{m3}^3) & \cdots & (a_{m1}^m, a_{m2}^m, a_{m3}^m)
\end{pmatrix}
\]
where the attribute types could be the benefit type for a greater value and the cost type for a smaller value. The value for benefit type and cost type are respectively constructed using equation (2) and (3).

\[
\begin{align*}
    a^1_{ij} &= \frac{a_{ij}^1}{\sum_{i=1}^{m} a_{ij}^1}; & a^2_{ij} &= \frac{a_{ij}^2}{\sum_{i=1}^{m} a_{ij}^2}; & a^3_{ij} &= \frac{a_{ij}^3}{\sum_{i=1}^{m} a_{ij}^3}; \\
    a^1_{ij} &= \frac{1}{\sum_{i=1}^{m} 1/a_{ij}^1}; & a^2_{ij} &= \frac{1}{\sum_{i=1}^{m} 1/a_{ij}^2}; & a^3_{ij} &= \frac{1}{\sum_{i=1}^{m} 1/a_{ij}^3};
\end{align*}
\]

(2)

(3)

**Step 3:** Construct a weight matrix \( W = [w_1, w_2, w_3, \ldots, w_n] \) where \( w_j = (w_j^1, w_j^2, w_j^3) \) is a triangular fuzzy number with respect to the criterion \( C_j \in \mathbb{C} \) given by the decision maker and \( 0 < w_j^1 \leq w_j^2 \leq w_j^3 \leq 1 \). \( C_j = \{ j=1, 2, 3, \ldots, n \} \) and convert all elements of the matrix \( W \) into a crisp value \( x_j \) using defuzzification of Minkowski as presented by definition 2.

**Step 4:** Determine a normalized weight vector, \( \tilde{W} = [\tilde{w}_1, \tilde{w}_2, \tilde{w}_3, \ldots, \tilde{w}_n] \) where \( \tilde{w}_j \) is a crisp value and \( \sum_{j=1}^{n} \tilde{w}_j = 1 \). Each element of the vector \( \tilde{W} \) is calculated as equation (4).

\[
\tilde{w}_j = \frac{x_j}{\sum_{j=1}^{n} x_j}
\]

(4)

**Step 5:** Calculate a weighted decision matrix \( \tilde{R} \) by multiplying the normalized decision matrix \( \tilde{F} \) and the normalized weighted matrix \( \tilde{W} \). Let \( \tilde{A}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \times \tilde{w}_j \) be the evaluation index of alternative \( A_i \) to determine a weighted decision matrix for \( i = 1, 2, 3, \ldots, m \) and \( j = 1, 2, 3, \ldots, n \). Finally, convert the evaluation index \( \tilde{A}_i \) into a crisp value \( x\tilde{A}_i \) using definition 2.

\[
\tilde{R} = \begin{pmatrix} \frac{x\tilde{A}_1}{x\tilde{A}_2} \\ \frac{x\tilde{A}_3}{x\tilde{A}_4} \\ \vdots \\ \frac{x\tilde{A}_m}{x\tilde{A}_m} \end{pmatrix}
\]

(5)

**Step 6:** Rank alternatives based on evaluation indices. Alternatives \( A_1, A_2, A_3, \ldots, A_m \) are ranked based on the evaluation indices \( \tilde{A}_1, \tilde{A}_2, \tilde{A}_3, \ldots, \tilde{A}_m \).

4. Numerical example

In section 4, we demonstrate the proposed model by using a numerical example. Assume that the Social Affairs Office of the Province of Aceh desires to select four of six poor families that will obtain the decent homes provided by the government. In this case study, there is an expert or a decision maker who identify criteria and assign weights criterion. As all alternative values are in linguistic term, the decision maker use triangular fuzzy numbers to represent those alternative values. Moreover, the decision maker evaluates four impoverished families based on six related criteria which are Marital Status (\( C_1 \)), Floor Material Type (\( C_2 \)), Exterior Wall Material Type (\( C_3 \)), Roof Material Type (\( C_4 \)), Number of Family Members (\( C_5 \)) and Family Income (\( C_6 \)). In addition to Family Income (\( C_6 \) unit: IDR) belonging to criterion type, the others are belonging to benefit criterion type. The linguistic term variables with their corresponding triangular fuzzy numbers for evaluation ranking and criteria weights and criteria name with their corresponding triangular fuzzy numbers are respectively listed in Table 1 and Table 2.

| Table 1. The linguistic term variables and triangular fuzzy numbers for evaluation rankings. |
|-----------------------------------------------|
| Variable                  | A triangular fuzzy number (TFN) |
|------------------------------|--------------------------------|
| Very low (VL)               | (0.1, 0.10, 0.2)               |
| Low (L)                     | (0.1, 0.25, 0.4)               |
| Medium (M)                  | (0.3, 0.50, 0.7)               |
High (H) 
Very high (VH)

The decision maker expresses evaluation ratings for impoverished families on six related criteria in a decision making matrix and then constructs a normalized decision making matrix as respectively shown in Table 4 and Table 5. The normalized weight matrix is calculated by using equation (4). In Table 6, the proposed model calculates a weighted decision matrix $\tilde{R}$ using equation (5). Finally, All alternatives are ranked based on evaluation indices from the matrix $\tilde{R}$. The bigger evaluation index is the better alternative.

### Table 2. Criteria names and their corresponding triangular fuzzy numbers.

| Criteria Names               | Linguistic Variable | Fuzzy Number |
|------------------------------|---------------------|--------------|
| Marital Status (C₁)          | VH                  | (0.8, 0.9, 1) |
| - Widowed                    | H                   | (0.6, 0.75, 0.9) |
| - Married                    | L                   | (0.1, 0.25, 0.4) |
| Floor Material Type (C₂)     | L                   | (0.1, 0.25, 0.4) |
| - earth floor                | H                   | (0.6, 0.75, 0.9) |
| - cement floor               | M                   | (0.3, 0.5, 0.7) |
| - ceramics floor             | VL                  | (0.1, 0.1, 0.2) |
| Exterior Wall Material Type (C₃) | M              | (0.3, 0.5, 0.7) |
| - thatched wall              | H                   | (0.6, 0.75, 0.9) |
| - wood wall                  | M                   | (0.3, 0.5, 0.7) |
| - cement wall                | VL                  | (0.1, 0.1, 0.2) |
| Roof Material Type (C₄)      | M                   | (0.3, 0.5, 0.7) |
| - thatched roofs             | H                   | (0.6, 0.75, 0.9) |
| - tile roofs                 | VL                  | (0.1, 0.1, 0.2) |
| - Zinc metal roofs           | L                   | (0.1, 0.25, 0.4) |
| #Family Members (C₅)         | H                   | (0.6, 0.75, 0.9) |
| - 0 - 2 persons              | VL                  | (0.1, 0.1, 0.2) |
| - 3 - 5 persons              | L                   | (0.1, 0.25, 0.4) |
| - 6 - 8 persons              | M                   | (0.3, 0.5, 0.7) |
| Family Income Rate (C₆)      | H                   | (0.6, 0.75, 0.9) |
| - Income < 500K (IDR)        | H                   | (0.6, 0.75, 0.9) |
| - 500K < Income < 1M         | M                   | (0.3, 0.5, 0.7) |
| - Income Uncertainty         | VH                  | (0.8, 0.9, 1) |

### Table 3. The collected data of impoverished families

|      | C₁ | C₂ | C₃ | C₄ | C₅ | C₆ |
|------|----|----|----|----|----|----|
| A₁   | L  | H  | H  | H  | VL | VH |
| A₂   | L  | M  | M  | VL | L  | H  |
| A₃   | H  | H  | M  | L  | L  | VH |
| A₄   | H  | M  | M  | VL | VL | H  |
### Table 4. The decision making matrix

|    | $C_1$          | $C_2$          | $C_3$          | $C_4$          | $C_5$          | $C_6$          |
|----|----------------|----------------|----------------|----------------|----------------|----------------|
| $A_1$ | $(0.1,0.25,0.4)$ | $(0.6,0.75,0.9)$ | $(0.6,0.75,0.9)$ | $(0.6,0.75,0.9)$ | $(0.1,0.1,0.2)$ | $(0.8,0.9,1)$  |
| $A_2$ | $(0.1,0.25,0.4)$ | $(0.3,0.5,0.7)$  | $(0.3,0.5,0.7)$  | $(0.1,0.1,0.2)$ | $(0.1,0.25,0.4)$ | $(0.6,0.75,0.9)$ |
| $A_3$ | $(0.6,0.75,0.9)$ | $(0.6,0.75,0.9)$ | $(0.3,0.5,0.7)$  | $(0.1,0.25,0.4)$ | $(0.1,0.25,0.4)$ | $(0.8,0.9,1)$  |
| $A_4$ | $(0.6,0.75,0.9)$ | $(0.3,0.5,0.7)$  | $(0.3,0.5,0.7)$  | $(0.1,0.1,0.2)$ | $(0.1,0.1,0.2)$ | $(0.6,0.75,0.9)$ |
| $A_5$ | $(0.6,0.75,0.9)$ | $(0.6,0.75,0.9)$ | $(0.6,0.75,0.9)$ | $(0.1,0.1,0.2)$ | $(0.1,0.1,0.2)$ | $(0.8,0.9,1)$  |
| $A_6$ | $(0.1,0.25,0.4)$ | $(0.3,0.5,0.7)$  | $(0.1,0.1,0.2)$ | $(0.1,0.25,0.4)$ | $(0.1,0.25,0.4)$ | $(0.3,0.5,0.7)$ |

### Table 5. The normalized decision making matrix

|    | $C_1$          | $C_2$          | $C_3$          | $C_4$          | $C_5$          | $C_6$          |
|----|----------------|----------------|----------------|----------------|----------------|----------------|
| $A_1$ | $(0.03,0.08,0.19)$ | $(0.13,0.20,0.33)$ | $(0.15,0.24,0.41)$ | $(0.20,0.34,0.56)$ | $(0.06,0.10,0.33)$ | $(0.15,0.19,0.26)$ |
| $A_2$ | $(0.03,0.08,0.19)$ | $(0.06,0.13,0.26)$ | $(0.07,0.16,0.32)$ | $(0.03,0.05,0.13)$ | $(0.06,0.24,0.67)$ | $(0.11,0.16,0.23)$ |
| $A_3$ | $(0.15,0.25,0.43)$ | $(0.13,0.20,0.33)$ | $(0.07,0.16,0.32)$ | $(0.03,0.11,0.25)$ | $(0.06,0.24,0.67)$ | $(0.15,0.19,0.26)$ |
| $A_4$ | $(0.15,0.25,0.43)$ | $(0.06,0.13,0.26)$ | $(0.07,0.16,0.32)$ | $(0.03,0.05,0.13)$ | $(0.06,0.10,0.33)$ | $(0.11,0.16,0.23)$ |
| $A_5$ | $(0.15,0.25,0.43)$ | $(0.13,0.20,0.33)$ | $(0.15,0.24,0.41)$ | $(0.20,0.34,0.56)$ | $(0.06,0.10,0.33)$ | $(0.15,0.19,0.26)$ |
| $A_6$ | $(0.03,0.08,0.19)$ | $(0.06,0.13,0.26)$ | $(0.02,0.03,0.09)$ | $(0.03,0.11,0.25)$ | $(0.06,0.24,0.67)$ | $(0.05,0.11,0.18)$ |

### Table 6. The criteria weights matrix

|    | $C_1$          | $C_2$          | $C_3$          | $C_4$          | $C_5$          | $C_6$          |
|----|----------------|----------------|----------------|----------------|----------------|----------------|
| TFN | $(0.80,0.90,1.00)$ | $(0.10,0.25,0.40)$ | $(0.30,0.50,0.70)$ | $(0.30,0.50,0.70)$ | $(0.60,0.75,0.90)$ | $(0.60,0.75,0.90)$ |
| Crisp | 0.83 | 0.14 | 0.35 | 0.35 | 0.64 | 0.64 |

### Table 7. The normalized criteria weights matrix

| Criteria weight | 0.28 | 0.05 | 0.12 | 0.12 | 0.22 | 0.22 |

### Table 8. The weighted normalized fuzzy decision matrix

|    | $\tilde{A}_i$ | Crisp value ($\tilde{c}_i \tilde{A}_i$) | Rank |
|----|----------------|--------------------------------------|------|
| $A_1$ | $(0.098,0.164,0.313)$ | 0.13505 | 3   |
| $A_2$ | $(0.059,0.141,0.313)$ | 0.1017 | 5   |
| $A_3$ | $(0.105,0.206,0.404)$ | 0.15498 | 2   |
| $A_4$ | $(0.095,0.156,0.308)$ | 0.13239 | 4   |
A5 (0.134,0.211,0.380) 0.17607 1
A6 (0.041,0.122,0.290) 0.08292 6

5. Conclusion
In this case study, we have demonstrated a multiple-attribute decision making model based on SAW with triangular fuzzy numbers in order to distribute the decent homes for impoverished families. The model used defuzzification of Minkowski to convert triangular fuzzy numbers into crisp values. This model can be used to solve this decision making problem. As the computation of this model is easy and simple, it does not need a complicated programming language to implement the code. In addition, the ranking order for the six alternatives is given by $A_5 > A_3 > A_1 > A_4 > A_2 > A_6$.

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