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Sensitivity Analysis Technique for Fuzzy TOPSIS using Improvised Sensitive-Simple Additive Weighting Method

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In the study of performance of decision-making methods, sensitivity analysis (SA) has been an important tool to check their stability and robustness. It is a tool to see the effect of the changes of certain parameters to the output. The investigation is usually focused on the alteration of the weight of the criteria in the problem and the changes to the output is analysed. This paper presents an SA technique using the Improvised Sensitive-Simple Additive Weighting (S-SAW) method to explore the stability of the fuzzy TOPSIS method, a well-known method in the field of decision making. The introduced SA offers a simpler and a systematic approach to performing SA and the effect of the changes are illustrated numerically and graphically. A numerical example on fuzzy TOPSIS is offered to demonstrate its effectiveness where to certain variation of inputs, the output values will be different from its original when the weights of criteria are altered.

Keywords: Decision making, sensitivity analysis, simple additive weighting, stability

I. INTRODUCTION

Sensitivity analysis (SA) deals with investigations in determining the stability of mathematical methods or models under changes in the parameter values (Kleijnen, 1997). It basically analyses the impact of changes of parameters towards the behaviour of the output and hence to the conclusion (Pannell, 2000). A better understanding of the problem is attained when SA is employed as the sensitivity and robustness analysis in the output of the methods are elaborated. Furthermore, the dominance and interaction between factors will prevail. Several approaches have been introduced to determine the sensitivity of methods (Pannell, 1997; Wallace, 2000; Zamali *et. al.,* 2012), however, most of them were directed to the investigation of the effect of changing the criteria weight towards the outputs. However, in many instances, the changes of criteria were randomly made by the decision makers.

Some common approaches of SA are reviewed from (Pannell, 1997; Wallace, 2000) as follows:

a. Objective function values
b. Slopes and elasticities
c. Sensitivity indices
d. Break-even values
e. Constrained comparison and unconstrained solutions
f. Probabilities.

In Butler *et. al.,* (1995), a Monte Carlo simulation is used in investigating sensitivity analysis where three classes of simulation models were introduced, which are:

- The random weight approach where no weight assessment is required,
- The rank model where a rank ordering of the weights of the criteria is used,

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- The inclusion of response variable in a manageable way.

Furthermore, in Ravalico *et. al.,* (2010),a new method to calculate the SA was proposed to cater the problem of high complexity when the size number of the integrated model is large, known as the Management Option Rank Equivalence (MORE).A numerical optimization method is used to check the robustness of the solutions.

Multi Criteria Decision Making Methods have been used for solving many problems related to finding best choice and preference (Rani *et. al.,* 2014; Shohaimay *et. al.,* 2014; Kamis *et. al.,* 2014). SA has been widely used in evaluating the performance of MCDM methods. Since the input in MCDM may vary or changeable, in many cases, the changes will affect the final result. Thus, SA is an important tool to impart in determining the stability of the methods. SA is discussed in Simanaviciene and Ustinovichius (2010) for two MCDM methods which are the TOPSIS and SAW methods. In addition, in Kamis *et. al.,* (2012), SA has been examined in TOPSIS method to determine the most sensitive attribute in the application problem.

A post-optimality step was introduced in sensitivity analysis to investigate the stability of Simple Additive Weighting (SAW) known as Sensitive-Simple Additive Weighting (S-SAW) (Goodridge, 2016). Due to its simplicity, this sensitivity analysis method has a vast potential to be applied to other MCDM methods as an extension of the sensitivity analysis investigation. However, in the analysis part of S-SAW, the changes of criteria weight were done without using a proper procedure that is it solely depends on the decision makers' discretion. In this paper, an improved S-SAW is introduced by incorporating a systematic way of changing the weight based on the method given in Shohaimay *et. al.,* (2014).

Fuzzy TOPSIS (FTOPSIS) is chosen as the subject of investigation of the SA. It is a well-known method in MCDM and has been applied to many areas of applications (Behzadian *et. al.,* 2012; Selemin *et. al.,* 2017; Mohamad *et. al.,* 2015). The investigation of its stability using sensitivity analysis is important since it will indicate how robust the FTOPSIS is when changes are imposed to the criteria weight in the evaluation process.

II. METHODOLOGY

Some basic definitions and concepts will be first given in the following:

A fuzzy set $\tilde{A}$ in X is characterized by a membership function $\mu_{\tilde{A}}(x)$ that maps each $x \in X$ into an interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ denotes the grade of membership of x in $\tilde{A}$. A fuzzy set $\tilde{A}$ is convex if and only if for any two elements x_1, x_2 in X, $\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq Min\,(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2))$ where $\lambda \in [0,1]$ and is called a normal fuzzy set if $\exists\, x_i \in X, \mu_{\tilde{A}}(x_i) = 1$. A fuzzy number is a fuzzy subset in X that is both convex and normal. A triangular fuzzy number (TFN) is denoted as $\tilde{A} = (a_1, a_2, a_3)$ such that $a_1 \leq a_2 \leq a_3$.

A. Fuzzy TOPSIS

The general steps of fuzzy TOPSIS (Chen, 2006) is given as follows:

Step 1: Form a committee of decision-makers, and then identify the evaluation criteria.

Step 2: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives with respects to criteria.

Let $w_j^k = (a_j, b_j, c_j),\ j = 1, 2, \ldots, n$ be the weight in the form of TFN assigned by the decision-maker D_k to criterion c_j. The aggregated importance weight w_j of criterion c_j assessed by a committee of k decision-makers can be evaluated as:

$$w_j^k = \frac{\sum_{j=1}^{n} w_j}{n} \tag{1}$$

where w_j is a crisp number whose value is the simple arithmetic mean of the fuzzy numbers. Let the suitability rating assigned to alternative a_i by decision-makers D_k with respect to criteria c_j is denoted by $x_{ij}^k = (o_{ij}, p_{ij}, q_{ij}), i = 1, 2, \ldots, m, j = 1, 2 \ldots, n$. The aggregated rating $x_{ij} = (o_{ij}, p_{ij}, q_{ij})$ of alternative A_i with respect to criteria c_j can be obtained as:

$$x_{ij} = \frac{\sum_{ij=1}^{mn} x_{ij}}{k} \tag{2}$$

where x_{ij} is the aggregated rating of alternatives and w_j is the aggregated importance weight.

Step 3: The normalization of value f_{ij} will be formed to build a fuzzy decision matrix with entries

$$f_{ij} = \left(\frac{o_{ij}}{q_j^+}, \frac{p_{ij}}{q_j^+}, \frac{q_{ij}}{q_j^+}\right) \quad (3)$$

Step 4: The product of normalized weight $\boldsymbol{w} = (w_1, w_2, \ldots, w_n)$ with fuzzy decision matrix will result a weighted normalized matrix $V = [v_{ij}]$ with

$$v_{ij} = w_j \otimes f_{ij}, i = 1, 2, \ldots, m; \;\; j = 1, 2, \ldots, n. \quad (4)$$

Step 5: The Fuzzy Positive Ideal Solution (FPIS), denoted as A^+, and Fuzzy Negative Ideal Solution (FNIS), denoted as A^- are obtained as

$$A^+ = \{v_1^+, v_2^+, \ldots, v_j^+, \ldots, v_k^+\} \quad (5)$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_k^-\} \quad (6)$$

Step 6: The distance between the alternatives with FPIS and FNIS are calculated and denoted as S_i^+ and S_i^- respectively where

$$S_i^+ = \sum_{j=1}^{n} d(v_{ij}, v_j^+) \quad ; i = 1,2,\ldots,m \quad (7)$$

$$S_i^- = \sum_{j=1}^{n} d(v_{ij}, v_j^-) \quad ; i = 1,2,\ldots,m \quad (8)$$

Step 7: The closeness coefficient CC_i is calculated as

$$CC_i = \frac{S_i^-}{S_i^- + S_i^+}, i = 1,2,\ldots,m \quad (9)$$

Step 8: The final stage of the fuzzy TOPSIS is to develop the ranking order of candidates based on the value of CC_i. The candidates who are closest to the FPIS and farthest to the FNIS will be selected as the highest value of CC_i.

B. S-SAW Method

The steps in fuzzy S-SAW method (Goodridge, 2016) is given by follows:

Step 1: Calculate the normalized decision matrix.

$$s_{ij} = \frac{2(x_{ij} - n_j)}{(m_j - n_j)} - 1, \; i = 1,\ldots,t; j \in \Omega_b \quad (10)$$

$$s_{ij} = 1 - \frac{2(x_{ij} - n_j)}{(m_j - n_j)}, \; i = 1,\ldots,t; j \in \Omega_c \quad (11)$$

where

s_{ij}= normalized criterion values for alternatives i and criterion j,

m_j= the max (x_{ij}) for criterion j,

n_j= the min (x_{ij}) for criterion j,

Ω_b = sets of benefit,

Ω_c = sets of cost,

w_m= weight of the criteria.

Step 2: Set the objective coefficient.

The S-SAW method has a function F^* which accept a criterion j and maps it to the set {-1, 0, 1} or we can write it as $F^*(j) \in \{-1, 0, 1\}$ where $j \in \{1,2,\ldots,m\}$. The decision maker will decide the value of j and the objective coefficient is denoted as $F^*(j)$.

Step 3: Calculate the largest value of y_i as a preferred alternative.

The main operation of the S-SAW method is to find the largest value of y_i that represents the preferred alternative such that

$$\begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1m} \\ s_{21} & s_{22} & \cdots & s_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ s_{n1} & s_{n2} & \cdots & s_{nm} \end{bmatrix} \begin{bmatrix} w_1 F^*(1) \\ w_2 F^*(2) \\ \cdots \\ w_m F^*(m) \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_n \end{bmatrix} \quad (12)$$

Step 4: Determine the MIR and LIR.

The Most Important Resistant (MIR) and Least Important resistant (LIR) are well-defined in terms of the preferred alternative which results of the S-SAW final ranking. In order to find the minimum number of the most important criteria, the step of Most Important Resistant Ratio (MIRR) will be evaluated to measure how stable the preferred alternative depends on the minimum values for criteria with the maximum weights. The value of x is defined as the smallest number of the most important criteria which caused the change in the preferred alternative and the MIRR is denoted as x/m. The preferred alternative highly depends on criteria with high weights when the values of x are smaller than m.

On the other hand, to find the minimum number of the most important criteria, the step of Least Important Resistant Ratio (LIRR) will be evaluated to measure how stable the preferred an alternative depends on the minimum values for criteria with the lowest weights. The value of y is defined as the smallest number of the least important criteria which caused the change in the preferred an alternative and the LIRR is denoted as y/m.

C. Determination of Weight Change

In general, the vector for weights of criterion is $\boldsymbol{w} = (w_1, w_2, \ldots, w_k)$ and are normalized with sum of one, that is:

$$\sum_{p=1}^{k} w_p = 1 \quad (13)$$

If the weight of criterion changes, then the weight of other criterion change accordingly, and the new vector of weights converted into $\boldsymbol{w'} = (w'_1, w'_2, \ldots, w'_k)$. By using the following theorem adapted from Shohaimay et al. (2014), a systematically change of each criterion weight is attained. Hence, we have an improvised S-SAW.

Theorem 1. If the weight of the *r*th criteria in an MCDM method changes by Δ_r, then the weight of other criterion change by Δ_p, where:

$$\Delta_p = \frac{\Delta_r . w_p}{w_r - 1} \ ; \ \ p = 1,2,\ldots,q \ , p \neq r \qquad (14)$$

The process of the investigation of SA on FTOPSIS is given as in Figure 1.

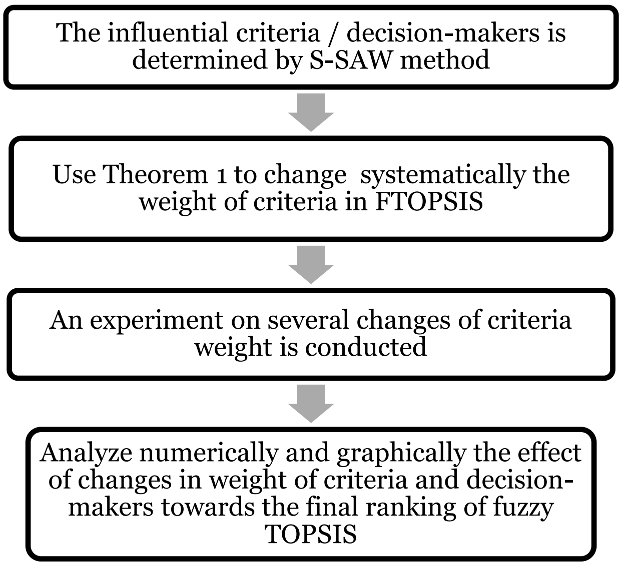

Figure 1. Process flow of investigation of SA on FTOPSIS

III. SENSITIVITY ANALYSIS OF FTOPSIS - NUMERICAL EXAMPLE

The investigation of the SA of FTOPSIS is done by considering a numerical input on a case study on risk assessment using FTOPSIS given in (Yazdani et al., 2011). It is a rail transportation example of a fictitious hydrocarbon tank truck transportation system. This numerical example used eight critical assets as risky assets to be analysed:

- Railcars of petroleum products (RPP) – (A1)
- Rural section of track to switch yard (RST) – (A2)
- Mainline section of track in rural area – (A3)
- Switch yard (SY) – (A4)
- River crossing (RC) – (A5)
- Mainline section of track in urban area– (A6)
- Siding in Urban Area (SUA) – (A7)
- Tunnel in Urban Area (TUA) – (A8).

Five benefit criteria are considered in the selection process:

1) Threat (C1)
2) Vulnerability (C2)
3) Consequence (C3)
4) Detectability (C4)
5) Reaction against event (C5)

Table 1 shows a decision matrix of evaluation of the 8 alternatives with respect to the 5 criteria under consideration. The sensitivity analysis is performed using the S-SAW method using the calculated values of fuzzy negative ideal solutions (FNIS, A*) as in Table 2since the FNIS is used in attaining the closeness coefficient CC_i (Equation 9).

Table 1. Decision matrix of evaluation by decision makers

	C1	C2	C3	C4	C5
A1	0.1413	0.1473	0.2591	0.0280	0.0982
A2	0.0982	0.2120	0.1800	0.0098	0.0587
A3	0.0982	0.1473	0.1076	0.0280	0.1413
A4	0.1413	0.0394	0.1076	0.0164	0.1680
A5	0.0982	0.2120	0.1076	0.0164	0.1680
A6	0.1680	0.1473	0.1800	0.0098	0.1413
A7	0.0262	0.0964	0.2591	0.0280	0.1413
A8	0.1413	0.2120	0.1800	0.0098	0.0982

Table 2. Example of S-SAW Method Under Optimization Function $F^*(j)=1$ *for* $j=1, \ldots, m$

	Decision Matrix					**Normalized Decision Matrix**						
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5		
w_j	0.182	0.273	0.333	0.030	0.182	0.182	0.273	0.333	0.030	0.182		
$F^*(j)$						1	1	1	1	1	y_i	Rank
A1	0.141	0.147	0.259	0.028	0.098	0.623	0.250	1.000	1.000	-0.277	0.495	1
A2	0.098	0.212	0.180	0.010	0.059	0.015	1.000	-0.044	-1.000	-1.000	0.049	6
A3	0.098	0.147	0.108	0.028	0.141	0.015	0.250	-1.000	1.000	0.511	-0.139	7
A4	0.141	0.039	0.108	0.016	0.168	0.623	-1.000	-1.000	-0.277	1.000	-0.319	8
A5	0.098	0.212	0.108	0.016	0.168	0.015	1.000	-1.000	-0.277	1.000	0.116	5
A6	0.168	0.147	0.180	0.010	0.141	1.000	0.250	-0.044	-1.000	0.511	0.298	3
A7	0.026	0.096	0.259	0.028	0.141	0.623	-0.339	1.000	1.000	0.511	0.478	2
A8	0.141	0.212	0.180	0.010	0.098	0.623	1.000	-0.044	-1.000	-0.277	0.291	4
m_j	0.168	0.212	0.259	0.028	0.168							
n_j	0.026	0.039	0.108	0.010	0.059							

The left part of Table 2 shows the decision matrix before normalization and the m_j and n_j values for each criterion are obtained as in equation (10) and (11). The right part of Table 2 is the normalized values using Equation (13) and the value of y_i are produced by using Equation (15) and thus the rank order of the alternatives is determined.

The Most Important Resistant Ratio (MIRR) and Least Important Resistant Ratio (LIRR) were obtained using Step 4 of the S-SAW. Using the inputs in Table 2, the MIRR value of 1/5 or 0.2 and depicted in Table 3. The change of order/rank may happen when C3 is changed. It can be concluded that the preferred alternative is very sensitive to C3 since the MIRR is relatively small. On the other hand, the preferred alternative is said to be stable if MIRR is sufficiently large. It is also observed that the preferred alternative is sensitive to C2. In other words, by maintaining the optimization coefficient value for the C2 and change at least one of the criterions, it shows that the ranking order of alternatives was changed.

Now, let C2 is increased by $\Delta_2 = 0.2$ where the original weight for C2 is 0.27273. Using the Theorem 1, the new vector weight for C2 is now $w'_2=w_2+\Delta_2 =0.27273+0.2=0.47273$. Hence, the weight of other criteria is then systematically changed as follows:

$$w_k' = \frac{1-w_2'}{1-w_2}.w_k\,; \quad w_k = w_1, w_3, w_4, w_5$$
$$= \frac{1-0.47273}{1-0.27273}.w_k$$
$$= 0.725w_k$$
$$= (0.13182, 0.24167, 0.02197, 0.13182)$$

These new weights are then integrated in the computation of FTOPSIS. The effect of these changes of weight to the final ranking of alternatives is then analysed. Some values of changes on the criteria weight are also experimented and the observation is summarized in Table 4.

The top ranking starts to change when the value of the weight of C2 is altered from 0.08 to 0.09. When the weight is 0.08, the top two ranking is A1 ≽ A8 while when the weight is 0.09, the top two ranking is changeable to A8 ≽ A1. A significant change of ranking occurs in the interval weight [0.08,0.09] of C2.

Table 3. *Sensitivity Measure of MIRR and LIRR*

	C1	C2	C3	C4	C5	Rank Order of Alternatives	Change?	Ratio
w_j	0.181 8	0.272 7	0.333 3	0.030 3	0.181 8			
F(j)= 1*	1	1	1	1	1	A1⩾ A7⩾ A6⩾A8⩾ A5A ⩾ A2⩾ A3⩾ A4	Original	
F(p)= -1*	-1	-1	-1	-1	-1	A4⩾ A3⩾ A2⩾ A5⩾ A8⩾ A6⩾ A7⩾ A1	Reversing	
F(p)= -1*	-1	1	1	1	1	A1⩾ A7⩾ A5⩾ A8⩾ A2⩾ A6⩾ A3⩾ A4	No	
F(p)= -1*	1	1	-1	1	1	A5⩾ A3⩾ A4⩾ A6⩾ A8⩾ A2⩾ A1⩾ A7	Yes	1/5 (MIRR)
F(p)= -1*	1	-1	1	1	1	A7⩾ A1⩾ A4⩾ A6⩾ A8⩾ A3⩾ A5⩾ A2	Yes	
F(p)= -1*	1	1	1	-1	1	A1⩾ A7⩾ A6⩾ A8⩾ A5⩾ A2⩾ A3⩾ A4	No	
F(p)= -1*	1	1	1	1	-1	A1⩾ A2⩾ A8⩾ A7⩾ A6⩾ A5⩾ A3⩾ A4	No	
F(p)= -1*	-1	-1	1	1	1	A7⩾ A1⩾A4⩾ A6⩾ A3⩾ A5⩾ A8⩾ A2	Yes	
F(p)= -1*	-1	1	1	-1	1	A1⩾ A7⩾ A5⩾ A8⩾ A2⩾ A6⩾ A3⩾ A4	No	
F(p)= -1*	-1	-1	1	-1	1	A7⩾ A1⩾ A4⩾ A6⩾ A3⩾ A5⩾ A8⩾ A2	Yes	
F(p)= -1*	-1	-1	1	-1	-1	A7⩾ A1⩾ A2⩾ A8⩾ A6⩾ A4⩾ A3⩾ A5	Yes	
F(p)= -1*	1	-1	1	-1	1	A7⩾ A1⩾ A4⩾ A6⩾A8⩾ A3⩾ A5⩾ A2	Yes	
F(p)= -1*	1	-1	1	-1	-1	A7⩾ A1⩾A6⩾ A2⩾ A8⩾ A4⩾ A3⩾ A5	Yes	
F(p)= -1*	1	-1	1	1	-1	A7⩾ A1⩾ A6⩾ A2⩾ A4⩾ A8⩾ A3⩾ A5	Yes	
F(p)= -1*	1	1	1	-1	-1	A1⩾ A2⩾ A8⩾ A7⩾ A6⩾ A5⩾ A3⩾A4	No	
F(p)= -1*	-1	-1	1	1	-1	A7⩾ A1⩾ A2⩾ A4⩾ A8⩾ A6⩾ A3⩾ A5	Yes	
F(p)= 1*	1	1	1	0	1	A1⩾ A7⩾ A6⩾ A8⩾A5⩾ A2⩾ A3⩾ A4	No	
F(p)= -1*	-1	1	-1	-1	-1	A2⩾ A5⩾ A3⩾ A8⩾ A6⩾ A4⩾ A1⩾ A7	Yes	
F(p)= -1*	-1	-1	1	-1	-1	A7⩾A1⩾ A2⩾ A8⩾ A6⩾ A4⩾ A3⩾ A5	Yes	4/5 (LIRR)

Table 4. Examples of changes of the weight of $C_2$and their effect to the ranking

Δ	**0**	**0.05**	**0.06**	**0.08**	**0.09**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
W_{C_1}	0.181	0.169	0.166	0.161	0.159	0.156	0.131	0.106	0.081	0.056
W_{C_2}	**0.272**	**0.322**	**0.332**	**0.352**	**0.362**	**0.372**	**0.472**	**0.572**	**0.672**	**0.772**
W_{C_3}	0.333	0.310	0.305	0.296	0.292	0.287	0.241	0.195	0.150	0.104
W_{C_4}	0.030	0.028	0.027	0.027	0.026	0.026	0.022	0.017	0.013	0.009
W_{C_5}	0.181	0.131	0.166	0.161	0.159	0.026	0.131	0.106	0.081	0.056
A1	0.133(1)	0.127(1)	0.132(1)	0.131(1)	0.130(2)	0.116(2)	0.126(3)	0.127(4)	0.119(4)	0.115(4)
A2	0.110(5)	0.111(5)	0.114(5)	0.115(5)	0.116(5)	0.108(3)	0.123(4)	0.129(3)	0.134(3)	0.140(3)
A3	0.103(7)	0.097(7)	0.104(7)	0.104(7)	0.104(7)	0.083(7)	0.104(6)	0.105(6)	0.105(6)	0.106(6)
A4	0.093(8)	0.082(8)	0.088(8)	0.009(8)	0.009(8)	0.061(8)	0.076(8)	0.067(8)	0.058(8)	0.049(8)
A5	0.119(4)	0.114(4)	0.122(4)	0.123(4)	0.124(4)	0.100(5)	0.129(2)	0.134(2)	0.138(2)	0.143(2)
A6	0.128(2)	0.121(3)	0.127(3)	0.126(3)	0.126(3)	0.105(4)	0.122(5)	0.119(5)	0.116(5)	0.113(5)
A7	0.109(6)	0.101(6)	0.106(6)	0.105(6)	0.105(6)	0.084(6)	0.099(7)	0.093(7)	0.088(7)	0.083(7)
A8	0.127(3)	0.125(2)	0.129(2)	0.130(2)	0.131(1)	0.117(1)	0.135(1)	0.138(1)	0.142(1)	0.145(1)

The effect of the changes of the criteria weight to the ranking can be graphically represented in Figure 1.

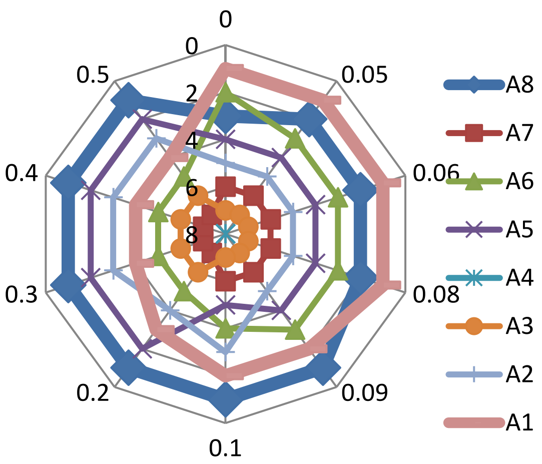

Figure 1: Graphical representation of ranking of alternatives when the weight C2 is changed.

IV. CONCLUSION

In this paper, a sensitivity analysis of FTOPSIS was investigated using the improved S-SAW method. The stability of the results on the fuzzy TOPSIS was determined by using the sensitivity analysis approach which is the Sensitive-Simple Additive Weighting (S-SAW) method. In addition, the sensitivity analysis is improvised by introducing a systematic process of changing the weight of criteria using a theorem given in Shohaimay et al. (2014). The illustrated numerical example shows the effectiveness of the proposed method. The observation is made on the changes of the top ranking when the criteria weight is altered which will indicate the stability of the FTOPSIS method. The results obtained show the influence of criteria on the final ranking. By using the improvised S-SAW method, the sensitivity analysis can be carried out in a simpler manner depends on the Most Important Resistant (MIR) and Least Important Resistant (LIR). In future, the stability of the FTOPSIS can be further investigated using the proposed method when the evaluation of the decision maker is altered. This improvised S-SAW can also be used to investigate the stability of other MCDM methods.

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