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Multi-Criteria Decision-Making for Airport Operation Performance Using Triangular Fuzzy Numbers

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Abstract

This paper advocates Multi-Criteria Decision-Making (MCDM) which evaluates the operation performance of airports using Fuzzy Simple Additive Weighting (FSAW) method. Assigned weights by decision-makers were in a linguistic form. These linguistic forms were converted into triangular fuzzy numbers. We chose three airports designated as A_1, A_2 and A_3 and examined by four decision makers D_1, D_2, D_3 and D_4 under a fuzzy environment for performance against the chosen criteria. FSAW method gives similar decision results which shows that this method is effective, relevant and reliable for this kind of MCDM.

Keywords: airport operation performance, fuzzy simple additive weighting, multi-criteria decision-making, simple additive weighting method

Introduction

Making decisions has always been a critical activity in everyone's life. Today, purchasing a product such as a personal car requires a wise decision from an individual so that he/she may not regret his/her decision afterwards. The purchasing criteria directly and significantly affect decision-making [1].

Various approaches have been developed and adopted to help individuals and organizations to make the best decision. This work is intended to propose quantitative evaluation methods based on Multi-Criteria Decision-Making (MCDM) by considering the quality of the attributes of cars which lead to appropriate purchases [2, 3].

MCDM is the study of strategies and techniques through which concerns about the criteria can be included in administrative planning process, officially. Indeed, more than one MCDM technique is defined in international society [4].

MCDM is divided into two types of problems [5, 6]. The first is the classic MCDM problem in which classification and weight criteria are evaluated. The second is Fuzzy Multi-Criteria Decision-Making (FMCDM) problem, which measures classification and weight criteria and is mentally, neutrally and commonly expressed by linguistic form and fuzzy numbers [7].

For example, in buying a vehicle, price, comfort, security, and fuel economy may be part of the principles based on the decision-making criteria and it is unusual that the least expensive vehicle is the most comfortable one. In portfolio management, we are interested in getting a lot of return but, at the same time, we face the risk of losing cash. In the management industry, the cost of customer satisfaction and the administration are the basic conflicting criteria [1, 4].

2. Linguistic Variable and Fuzzy Triangular Number

Therefore, Zadeh introduced the first fuzzy set theory [8]. There is a class of articles regarding the assessment of a fuzzy set subscription. One of these articles is described by a membership function in which everyone is rated in membership between 0 and 1 [8]. Linguistic forms have been found instinctively and simply by using them in communicating the qualitative and subjective imprecision of a decision-maker's appraisal, these linguistic forms are transformed into Triangular Fuzzy Numbers (TFN) [9].

3. Fuzzy Simple Additive Weighting

Simple Additive Weighting (SAW) method is a simple and most frequently utilized MCDM, detail is found in [10]. Fuzzy SAW depends on the weighted average. Various steps of Fuzzy SAW methods are presented as follows [11].

Step-1: Select criteria that will be utilized in decision-making (P_j; j = 1, 2…m) and then choose the team of experts for decision-making (D_k; k = 1, 2 … n).

Step-2: Decision-makers assign suitable rating to all criterion in linguistic form.

Step-3: For all criterion, decide the fuzzy decision matrix in the form of TFN.

$$DM_{IJ} = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix}$$

Step-4: Determine the average fuzzy scores (A_{jk}),

$(A_{jk}) = (f_{j1}^{k} + f_{j2}^{k} + \cdots f_{jn}^{k})$ / n; j = 1, 2…m; k = 1, 2…n

defuzzified values (e), e = $\frac{(a+b+c)}{3}$, and normalized weight (W_j) of each criterion [12].

$$W_j = \frac{\text{defuzzified values}}{\text{sum of total defuzzified values}}$$

$$W_j = \frac{e_j}{\sum_{j=1}^{n} e_j} \; ; \quad j = 1,2 \ldots n.$$

Step-5: Decision-makers assign suitable rating in the form of linguistic terms for every maintenance strategy (A_i; i = 1, 2...) of all the criteria.

Step-6: Fuzzy average and defuzzified scores are calculated for every criterion [12].

Step-7: Decision matrix is determined for all maintenance strategies and all criteria $[X_{ij}]$.

Step-8: Normalized matrix is calculated for all strategies and criteria $[R_{ij}]$.

$$r_{ij} = {x_{ij}}\big/{\max\,(x_{1j}, x_{2j}, x_{3j})} \qquad i = 1,2.3 \ldots$$

Step-9: By Simple Additive Weighting (SAW) method calculate the Total Scores (TS) for every maintenance strategy. $TS = [R_{ij}]\,[W_j]$

Step-10: Finally, the greatest value of A_i is the best maintenance strategy and obtained ranking as a solution.

An illustrated example solved by Fuzzy SAW method to evaluate airport operation performance with group decision-making [13].

4. Airport Operation Performance

A practical example is demonstrated by applying Fuzzy SAW method to calculate airport operation performance with MCDM. Three airports AP_1, AP_2 and AP_3 are evaluated by four decision-makers DM_1, DM_2, DM_3 and DM_4 under a fuzzy setting for operation performance [14, 15, 16, 17, 18] against 15 criteria, P_1, P_2, . . ., P_{15} . These criteria are as follows:

P_1 = Noise pollution control
P_2 = Navigation equipment
P_3 = Aircraft loading and take-off time
P_4 = Courtesy of crew
P_5 = Flight safety control
P_6 = Signal and direction
P_7 = Aerodrome control
P_8 = Airport scale
P_9 = Security measures
P_{10} = Out-bound or traffic connecting city
P_{11} = Profit to capital
P_{12} = Cleanness and comfort of airport terminal
P_{13} = Check-out and check-in time
P_{14} = Parking lots
P_{15} = Trolleys approach travellers

5. Implementation of Fuzzy SAW

Step 1: Select criteria that will be utilized by decision-makers, {VP, P, MP, F, MG, G, VG}, then set them into fuzzy numbers.

Table 1. Criteria Settings for Decision-makers

S. No	Code	Fuzzy Number
1	VP	(0.00, 0.00, 0.20)
2	P	(0.00, 0.20, 0.40)
3	MP	(0.20, 0.40, 0.50)
4	F	(0.40, 0.50, 0.60)
5	MG	(0.5o, 0.60, 0.80)
6	G	(0.60, 0.80, 1.00)
7	VG	(0.80, 1.00, 1.00)

Select criteria for weight that will be utilized by decision-makers, {VL, L, M, H, VH}, then set them into fuzzy numbers.

Table 2. Criteria for Weight

S.No	Code	Fuzzy Number
1	VL	(0.00, 0.00, 0.30)
2	L	(0.00, 0.30, 0.50)
3	M	(0.30, 0.50, 0.70)
4	H	(0.50, 0.70, 1.00)
5	VH	(0.70, 1.00, 1.00)

Step 2: Linguistic weights for 15 criteria.

Table 3. Linguistic Weights

	$\mathbf{DM_1}$	$\mathbf{DM_2}$	$\mathbf{DM_3}$	$\mathbf{DM_4}$
P_1	M	VH	M	H
P_2	H	H	M	VH
P_3	M	M	H	M
P_4	L	M	VH	M
P_5	VH	VH	VH	VH
P_6	VH	H	VH	VH
P_7	H	VH	M	H
P_8	M	H	VH	M
P_9	M	M	H	M
P_{10}	L	M	H	VH
P_{11}	VH	H	VH	M
P_{12}	H	H	M	L
P_{13}	H	M	H	H
P_{14}	M	H	M	H
P_{15}	H	VH	H	VH

Step 3: Fuzzy decision matrix DM_{ij} found for every criterion in the form of fuzzy triangular number.

Table 4. Fuzzy Decision Matrix

	$\mathbf{DM_1}$	$\mathbf{DM_2}$	$\mathbf{DM_3}$	$\mathbf{DM_4}$
P_1	(0.3,0.5,0.7)	(O.7,1.0,1.0)	(0.3,0.5,0.7)	(0.5,0.7,1.0)
P_2	(0.5,0.7,1.0)	(0.5,0.7,1.0)	(0.3,0.5,0.7)	(0.7,1.0,1.0)
P_3	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.3,0.5,0.7)
P_4	(0.0,0.3,0.5)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	(0.3,0.5,0.7)
P_5	(0.7,1.0,1.0)	(0.7,1.0,1.0)	(0.7,1.0,1.0)	(0.7,1.0,1.0)
P_6	(0.7,1.0,1.0)	(0.5,0.7,1.0)	(0.7,1.0,1.0)	(0.7,1.0,1.0)
P_7	(0.5,0.7,1.0)	(0.7,1.0,1.0)	(0.3,0.5,0.7)	(0.5,0.7,1.0)
P_8	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.7,1.0,1.0)	(0.3,0.5,0.7)
P_9	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.3,0.5,0.7)
P_{10}	(0.0,0.3,0.5)	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.7,1.0,1.0)
P_{11}	(0.7,1.0,1.0)	(0.5,0.7,1.0)	(0.7,1.0,1.0)	(0.3,0.5,0.7)
P_{12}	(0.5,0.7,1.0)	(0.5,0.7,1.0)	(0.3,0.5,0.7)	(0.0,0.3,0.5)
P_{13}	(0,5,0.7,1.0)	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.5,0.7,1.0)
P_{14}	(0.3,0.5,0.7)	(0.5,0.7,1.0)	(0.3,0.5,0.7)	(0.5,0.7,1.0)
P_{15}	(0.5,0.7,1.0)	(0.7,1.0,1.0)	(0.5,0.7,1.0)	(0.7,1.0,1.0)

Step 4: Calculate fuzzy average scores (A_{jk}), defuzzified values (e) and normalized weight (W_j) of every criterion.

Table 5. Fuzzy Average Scores, Defuzzified Values and Normalized Weights

	Average Fuzzy Score (A_{jk})	**Defuzzified Value (e)**	**Normalized weight (W_j)**
P_1	(0.45,0.68,0.85)	0.660	0.065

P_2	(0.50,0.73,0.93)	0.720	0.071
P_3	(0.35,0.55,0.76)	0.553	0.055
P_4	(0.33,0.58,0.73)	0.547	0.054
P_5	(0.70,1.00,1.00)	0.900	0.089
P_6	(0.65,0.93,1.00)	0.860	0.085
P_7	(0.50,0.50,0.93)	0.643	0.063
P_8	(0.45,0.68,0.85)	0.660	0.065
P_9	(0.35,0.55,0.78)	0.560	0.055
P_{10}	(0.38,0.63,0.80)	0.603	0.059
P_{11}	(0.55,0.80,0.93)	0.760	0.075
P_{12}	(0.33,0.55,0.80)	0.560	0.055
P_{13}	(0.45,0.65,0.93)	0.677	0.067
P_{14}	(0.40,0.60,0.85)	0.617	0.061
P_{15}	(0.60,0.85,1.00)	0.817	0.081

Step 5: Suitable rating assigned by decision-makers in the form of linguistic terms for all approaches (A_i; i = 1, 2...) under all the conditions.

Table 6. Suitable Rating Assigned by Decision-makers

Criteria	Strategies	Decision-makers			
		DM_1	DM_2	DM_3	DM_4
P_1	A_1	VG	MG	G	G
	A_2	MG	VG	G	MG
	A_3	F	MG	F	MG
P_2	A_1	MG	MG	VG	G
	A_2	G	G	G	VG
	A_3	G	G	VG	G
P_3	A_1	MG	F	F	F
	A_2	G	VG	G	MG
	A_3	G	VG	VG	G
P_4	A_1	VG	VG	G	VG

	A_2	MG	F	MG	MG
	A_3	MG	MG	MG	G
P_5	A_1	G	G	MG	F
	A_2	G	MG	G	F
	A_3	MG	F	VG	G
P_6	A_1	VG	VG	G	VG
	A_2	G	MG	VG	G
	A_3	G	G	F	MG
P_7	A_1	G	F	G	MG
	A_2	G	G	MG	VG
	A_3	G	VG	MG	VG
P_8	A_1	G	MG	VG	MG
	A_2	G	VG	F	VG
	A_3	MG	G	G	VG
P_9	A_1	VG	VG	G	G
	A_2	VG	MG	G	G
	A_3	VG	VG	G	VG
P_{10}	A_1	F	G	G	G
	A_2	G	G	MG	G
	A_3	MG	G	VG	G
P_{11}	A_1	MG	MG	VG	MG
	A_2	MG	VG	MG	G
	A_3	G	VG	MG	G
P_{12}	A_1	MG	G	VG	G
	A_2	G	VG	G	VG
	A_3	MG	G	G	VG
P_{13}	A_1	G	F	MG	MG
	A_2	MG	F	MG	F
	A_3	VG	G	G	VG
P_{14}	A_1	VG	VG	MG	MG
	A_2	VG	MG	MG	G
	A_3	MG	F	MG	G
P_{15}	A_1	G	G	VG	F
	A_2	G	MG	F	VG
	A_3	F	F	F	F

Step 6: Calculate fuzzy average scores (A_{jk}) and defuzzified scores of all airports based on every criterion.

Table 7. Fuzzy Average Scores

Criteria	Strategies	Average Fuzzy Score (A_{jk})	Defuzzified Score
P_1	A_1	(0.625, 0.800, 0.950)	0.792
	A_2	(0.600, 0.750, 0.900)	0.750
	A_3	(0.450, 0.550, 0.700)	0.567
P_2	A_1	(0.600, 0.750, 0.900)	0.767
	A_2	(0.650, 0.850, 1.000)	0.833
	A_3	(0.650, 0.850, 1.000)	0.833
P_3	A_1	(0.425, 0.525, 0.650)	0.533
	A_2	(0.625, 0.800, 0.950)	0.792
	A_3	(0.700, 0.900, 1.000)	0.867
P_4	A_1	(0.750, 0.950, 1.000)	0.900
	A_2	(0.475, 0.575, 0.750)	0.600
	A_3	(0.525, 0.650, 0.850)	0.675
P_5	A_1	(0.400, 0.500, 0.600)	0.500
	A_2	(0.525, 0.675, 0.850)	0.683
	A_3	(0.575, 0.725, 0.850)	0.717
P_6	A_1	(0.750, 0.950, 1.000)	0.900
	A_2	(0.625, 0.800, 0.950)	0.792
	A_3	(0.525, 0.675, 0.850)	0.683
P_7	A_1	(0.525, 0.675, 0.850)	0.683
	A_2	(0.600, 0.750, 0.900)	0.750
	A_3	(0.675, 0.850, 0.950)	0.825

P_8	A_1	(0.600, 0.750, 0.900)	0.750
	A_2	(0.650, 0.825, 0.900)	0.792
	A_3	(0.625, 0.800, 0.950)	0.792
P_9	A_1	(0.700, 0.900, 1.000)	0.867
	A_2	(0.625, 0.800, 0.950)	0.792
	A_3	(0.750, 0.950, 1.000)	0.900
P_{10}	A_1	(0.550, 0.725, 0.900)	0.792
	A_2	(0.575, 0.750, 0.950)	0.758
	A_3	(0.625, 0.800, 0.950)	0.792
P_{11}	A_1	(0.575, 0.700, 0.850)	0.708
	A_2	(0.600, 0.750, 0.900)	0.750
	A_3	(0.625, 0.800, 0.950)	0.792
P_{12}	A_1	(0.625, 0.800, 0.950)	0.792
	A_2	(0.700, 0.900, 1.000)	0.867
	A_3	(0.625, 0.800, 0.950)	0.792
P_{13}	A_1	(0.500, 0.625, 0.800)	0.642
	A_2	(0.450, 0.550, 0.700)	0.567
	A_3	(0.700, 0.900, 1.000)	0.867
P_{14}	A_1	(0.650, 0.800, 0.900)	0.783
	A_2	(0.600, 0.750, 0.900)	0.750
	A_3	(0.500, 0.625, 0.800)	0.758
P_{15}	A_1	(0.600, 0.775, 0.900)	0.758
	A_2	(0.575, 0.725, 0850)	0.717
	A_3	(0.400, 0.500, 0.600)	0.500

Step 7: Determine decision matrix $[X_{ij}]$.

Table 8. Decision Matrix

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
A_1	.792	.767	0.533	.900	.500	.900	.683	.750	.867	.792	.708	.792	.642	.783	.758
A_2	.750	.833	0.792	.600	.683	.792	.750	.792	.792	.758	.750	.867	.567	.750	.717
A_3	.567	.833	0.867	.675	.717	.683	.825	.792	.900	.792	.792	.792	.867	.758	.500

Step 8: Calculate normalized matrix $[R_{ij}]$.

Table 9. Normalized Matrix

1.000	0.921	0.615	1.000	0.697	1.000	0.828	0.947	0.963	0.915	0.894	0.913	0.740	1.000	1.000
0.947	1.000	0.913	0.667	0.953	0.880	0.909	1.000	0.847	0.957	0.947	1.000	0.654	0.958	0.946
0.716	1.000	1.000	0.750	1.000	0.759	1.000	1.000	1.000	1.000	1.000	0.913	1.000	0.820	0.660

Step 9: By Simple Additive Weighting (SAW) method calculate the Total Scores (TS) for every maintenance strategy.

$$TS = [R_{ij}]\,[W_j]$$

$$\begin{vmatrix} 1.000 & 0.921 & 0.615 & 1.000 & 0.697 & 1.000 & 0.828 & 0.947 & 0.963 & 0.915 & 0.894 & 0.913 & 0.740 & 1.000 & 1.000 \\ 0.947 & 1.000 & 0.913 & 0.667 & 0.953 & 0.880 & 0.909 & 1.000 & 0.847 & 0.957 & 0.947 & 1.000 & 0.654 & 0.958 & 0.946 \\ .716 & 1.000 & 1.000 & 0.750 & 1.000 & 0.759 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.913 & 1.000 & 0.820 & 0.660 \end{vmatrix}$$

TS for A_1 based on all criteria is

(1X0.065)+(0.921X0.071)+(0.615X0.055)+(1X0.045)+(0.697X0.089)+(1X0.085)+

(0.828X0.063)+(0.947X0.065)+(0.963X0.055)+(0.915X0.059)+(0.894X0.075)+(0.913X0.055)+(0.740X0.067)+(1X0.061)+(1X0.081)=0.8948

$$A_1=0.8948$$

Similarly,

$$A_2 = 0.9086$$

$$A_3 = 0.9043$$

Step 10: Finally, the greatest value of A_i is obtained and the ranking as a solution.

Table 10. Best Maintenance Strategy, Final Score and Ranks

Strategy	Final Score	Ranks
A_1	0.8948	3
A_2	0.9086	1
A_3	0.9043	2

6. Result

Finally, using FSAW method the ranking of airports is $A_2 > A_3 > A_1$. The result shows that (A_2) is the best and predictively, (A_1) is the poorest.

7. Conclusion

This paper recommends MCDM which evaluates the operation performance of airports by using Fuzzy Simple Additive Weighting (FSAW) method. Assigned weights by decision-makers were in linguistic form. These linguistic forms were converted into TFN. Three airports AP_1, AP_2 and AP_3 were evaluated by four decision makers DM_1, DM_2, DM_3 and DM_4 under a fuzzy environment for performance against fifteen criteria. State-of-art methods produce similar decision results [14, 15, 16, 17, 18] which shows that FSAW method is effective, relevant and reliable for this kind of Multi-Criteria Decision-Making (MCDM).

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