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Hesitant Fuzzy-Stochastic Data Envelopment Analysis (HF-SDEA) Model for Benchmarking

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***Abstract*—The Data Envelopment Analysis (DEA) method is a method commonly used in benchmarking. The Dynamic Data Envelopment Analysis (DDEA) method was proposed to improve the DEA method in the benchmarking process. The DDEA method proposed can determine the effectiveness of the Decision Making Unit (DMU). The disadvantage of the DDEA model is that it cannot handle problems that involve benchmarking for stochastic data. To improve the DDEA method, the Stochastic Data Envelopment Analysis (SDEA) method is proposed which can be used for benchmarking involving stochastic data. The SDEA method itself has weaknesses in dealing with noise and uncertainty problems that will appear in the assessment process. The purpose of the research conducted by the researcher was to use the Hesitant Fuzzy method in optimizing the SDEA method so that the Hesitant Fuzzy model - Stochastic Data Envelopment Analysis (HF-SDEA) could be carried out benchmarking process in a situation where the assessment contained many elements of uncertainty. The results of this study are benchmarking methods that can do benchmarking for stochastic data on conditions that contain elements of uncertainty.**

***Keywords*—Data envelopment analysis; dynamic data envelopment analysis; stochastic data envelopment analysis; hesitant fuzzy.**

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I. Introduction

Data Envelopment Analysis (DEA) is a widely used tool for determining viability or productivity in fields such as decision-making, benchmarking, and organizational research. This approach uses a number of Decision Making Units (DMUs) made up of Inputs and Outputs to determine the degree of performance [1]. Crisp-formatted inputs and outputs are required in the DEA. However, in fact, due to conditions containing elements of ambiguity, crisp input and output can often be difficult to obtain [2]. As a result, a number of researchers have created DEA to address the DEA's uncertainty issues. Kahraman and Tolga [3] conducted research that included fuzzy elements in the calculation of efficiency in the benchmarking process, and the approach they suggest is known as Fuzzy Data Envelopment Analysis (FDEA). Furthermore, the FDEA method is based on a study conducted by Tavana et al. [4] can be grouped into 4 (four) groups, namely: Tolerance Approach, Fuzzy Ranking Approach, The α-level based approach, and The Possibility Approach.

Guo et al. [5] Charnes et al. [6] with a probability approach in a Fuzzy Data Envelopment Analysis. They take into account the possibility and requirement in their approach so that the ideal measurement results in the triangular membership function can be obtained. Yousefi et al. [7] propose the Dynamic Data Envelopment Analysis (DDEA) mode, which is a refinement of the DEA system in a benchmarking framework for determining the Decision Making Unit's performance (DMU). The DDEA model has the drawback of being unable to handle problems involving stochastic data benchmarking. The Stochastic Data Envelopment Analysis (SDEA) model proposed by Olesen and Petersen [8] can be used for benchmarking with stochastic data. Olesen and Petersen's research [8] was unable to address the noise and ambiguity problems that would arise during the evaluation process.

Ahmadvand and Pishvaee [9] suggested the Fuzzy CSWDEA system, which is based on a reputation approach and can be used in decision-making. Peykani et al. [10]

proposed the Robust Fuzzy DEA (RFDEA), a Fuzzy-DEA model that bases the benchmarking model on the probability, requirement, and credibility in the efficiency measurement method. On the other hand, in real life, decision making is particularly difficult in the process of benchmarking with DEA, where, in addition to dealing with DMU Inputs and Outputs that include elements of ambiguity, one must also deal with circumstances in which one's judgment is clouded by doubt. This is the context in which the Hesitant Fuzzy method was developed [11]. Fuzzy hesitant models proposed by Ashtiani and Asgomi [12] can be used for measurement processes in a state of noise with several elements of uncertainty. The researcher will use the fuzzy hesitant approach to refine Stochastic Data Envelopment Analysis (SDEA) so that it can manage valuations with elements of uncertainty due to the many parties involved in the benchmarking phase. This study would be interesting because benchmarking can only be performed if the appraiser believes their truth fully, but benchmarking cannot be done in situations where there is doubt or where the appraiser is unsure. Furthermore, in the benchmarking phase, fuzzy hesitant methods are required, particularly in determining assessment consistency [13].

As a consequence, HF-SDEA model is a benchmarking model that can solve this by taking into account the degree of ambiguity and hesitation when making a decision. The study's findings, in the form of an HF-SDEA model, are expected to provide efficiency values based on assessor evaluations with elements of doubt and uncertainty. The remainder of the paper is organized in the following manner. Our approach is presented in Section II. Section III describes the HF-SDEA experimental procedure. In Section IV, the findings are presented along with the experimental procedure. Finally, Section V brings our paper to a close and provides ideas for potential study.

II. Material and Method

Wang et al. is the first to propose the Stochastic Data Envelopment Analysis Method [14]. The basic principle is to establish quantile functions that can avoid crossing quantiles while also proposing estimates for stochastic frontier measurements [15]. Due to restricted knowledge from many parameters, the probability theory is used in the benchmarking model, which is one of the key factors in developing the Stochastic Data Envelopment Analysis [16]. The focus of Stochastic Data Envelopment Analysis research then shifts to deciding the upper and lower bounds for output and input, but no researchers have addressed the stochastic issue that includes a situation where the assessor gives an uncertain assessment [17]. Since a number of researchers recognize that there are unknown inputs and outputs, and humans are more at ease making decisions in the form of linguistic variables, the Fuzzy Data Envelopment Analysis (FDEA) method was created [18].

Many FDEA models have been developed such as the ideal-seeking FDEA [19], the tolerance and possibility FDEA[20] the FDEAwith double frontiers [21] and the cross-efficiency FDEA [22]. However, sometimes qualitative data sourced from linguistic variables are inaccurate and the time available for decision makers is limited so that doubts arise. In this situation, Hesitant Fuzzy developed into Hesitant Fuzzy Data Envelopment Analysis can be used [23]. This research will develop a Hesitant Fuzzy DEA model which in addition can perform the benchmarking process on the stochastic problem, it can also benchmark the conditions that contain Hesitant Fuzzy elements.

The benchmarking process will be carried out to measure the efficiency of the study programs at Malikussaleh University using the HF-SDEA method. There are a number of DMUs with input and output that are qualitative in nature so that they require measurements involving the Hesitant Fuzzy method and Stochastic Data Envelopment Analysis. The stages of research can be seen in Figure 1.

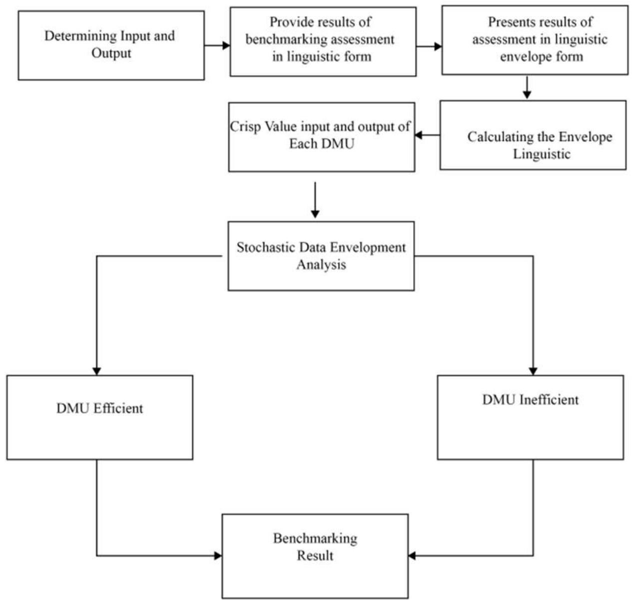

Fig. 1 Research Method

Figure 1 shows that the Hesitant Fuzzy approach is required in the benchmarking phase where there are inputs and outputs that contain elements of uncertainty, where the evaluation cannot be given in the form of crisp values and the assessor has reservations about giving an assessment. The assessors will begin by conducting a benchmarking process and providing an evaluation in the form of a linguistic form for Fuzzy Hesitant. In the linguistic envelope type, all of the assessments will be combined. The crisp value of each input and output for each DMU will then be determined using the linguistic values found in the linguistic envelope. The next step will be to perform a Stochastic Data Development Analysis, which will produce measurement results indicating which DMU is efficient and which DMU is inefficient, particularly if the data contains stochastic data.

A. Linguistic Form

As can be seen in Equation 1, linguistic forms are represented as a collection of linguistic words.

$$S = \{neither, very\ low, low, medium, high, very\ high, absolute\} \quad (1)$$

One of the benefits of Hesitant Fuzzy is that assessors can provide evaluation results in linguistic form during the benchmarking process. It can be shown in Equation 1 that there are many words that can be used to make an evaluation.

B. Envelope Form

Equation 2 shows the envelope form, which is a linguistic set of intervals.

$$env(H_s) = [H_{S^-}, H_{S^+}], H_{S^-} \leq H_{S^+} \quad (2)$$

Where H_{S^-} and H_{S^+} are defined as follows:

$$H_{S^+} = max(s_i) = s_j \in H_s \text{ and } s_i \leq s_j \forall i$$

$$H_{S^-} = min(s_i) = s_j \in H_s \text{ and } s_i \geq s_j \forall i \quad (3)$$

The envelope type incorporates a negative and positive evaluation in one unit, as shown by Equations 2 and 3. If assessors are reluctant to evaluate an evaluation value, they may include an assessment in the form of a variety of assessments during the benchmarking process. This will assist the appraiser in making an evaluation and increase the accuracy of the assessment during the benchmarking process.

C. Calculating the Envelope Linguistic

Equations 4 and 5 can be used to figure out what the linguistic envelope values are.

$$p_i^+ = \Delta(\delta(\Delta^{-1}(s_t, \propto)_{ij}^+)) \ \forall j \epsilon \{1, \ldots,)T\}$$

$$p_i^- = \Delta(\delta(\Delta^{-1}(s_t, \propto)_{ij}^-)) \ \forall j \epsilon \{1, \ldots,)T\} \quad (4)$$

$$V^t = (p_1^t, p_2^t, \ldots, p_T^t) \quad (5)$$

Equations 4 and 5 demonstrate the outcomes of each assessor's negative and positive evaluations during the benchmarking phase. The final values of inputs and outputs for each DMU will be obtained in the form of crisp values by integrating this assessment in the form of a negative and positive value.

D. DEA with CCR Model

Equation 6 reveals a classic DEA with the CCR Model.

$$Maximize \propto = \frac{\sum_{r=1}^{k} u_r y_{r0}}{\sum_{s=1}^{l} v_s x_{s0}} \quad (6)$$

Limit or constraint function:

$$u_r, v_s \geq 0; r = 1, \ldots, k; s = 1, \ldots, l$$

Where:

α = Efficiency object s

k = observed output object s

y_{is} = the number of outputs I produced as a result of object s

x_{js} = number of inputs i used by object s

u_i = the output weight i produced by object s

v_j = the input weight i given by object s

The aim of the above equation is to find the maximum number of outputs from DMU_n that are weighted, by holding the number of inputs weighted on a value less than or equal to one and the ratio of outputs weighted by the input weighted, of all DMUs.

E. Stochastic Data Envelopment Analysis (SDEA)

SDEA model proposed by Olesen and Petersen[8] can be used for benchmarking with stochastic data. The benchmarking method is a stochastic phenomenon in the form of probability that can often only be measured by its frequency distribution and can be approached by an interval function whose shape will mimic, i.e. it will reach a maximum value at some times while others will reach a minimum point. Equations 7 and 8 can be used to measure the efficiency of each DMU using the SDEA equation.

$$\ln C = f(w, y) + \ln u + \ln v \quad (7)$$

Where C is the total cost required, w is the input vector, y is the output vector, and e = u + v is the term error. Where u is a variable that can be managed and represents inefficiency. v is an uncontrollable (random) factor as well as a noise word. The performance ratio can be expressed in the following way.

$$CEFF_n = \frac{C_{min}}{C_n} = \frac{\exp[fc(w^n, y^n) + \ln(u_{c_{min}})]}{\exp[fc(w^n, y^n) + \ln(u_{c_n})]} \frac{u_{c_{min}}}{u_{c_n}} \quad (8)$$

The determination of variable v, which is a random entity with noise, has its own set of issues. Especially if there are many people involved in the evaluation and each one has a different point of view. This is a distinct fault in the SDEA process.

F. Hesitant Fuzzy – Stochastic Data Envelopment Analysis (HF-SDEA)

Equation 9 illustrates the use of the fuzzy reluctant approach in deciding the index ranking of the Decision Making Unit (DMU).

$$I(\tilde{E}_r) = \frac{\sum_{i=0}^{n}((E_r)_{\propto_i}^{u} - c)}{\sum_{i=0}^{n}((E_r)_{\propto_i}^{u} - c) - \sum_{i=0}^{n}((E_r)_{\propto_i}^{L} - d)} \quad (9)$$

Where is C_{Min} for Equation 8 based on Equation 9 that can be seen in Equation 10.

$$C_{Min} = \min_{i,j}\{(\acute{E}_r)_{\propto_i}^{L}\} \quad (10)$$

And C_n for Equation 8 is based on the Equation 9 that can be seen in Equation 11.

$$C_n = \max_{i,j}\{(\acute{E}_r)_{\propto_i}^{U}\} \quad (11)$$

III. Result and Discussion

A. Decision Making Unit (DMU)

As shown in Table I, the DMU used in this analysis is in the context of Malikussaleh University study programs.

TABLE I
DECISION MAKING UNIT (DMU)

DMU	**Input**		**Output**	
	No. of Lecturers	**No. of Students**	**No. of Research**	**No. of Graduates**
Information Technology	18	567	7	671
Civil Engineering	27	750	6	535
Architectural Engineering	16	387	6	187
Industrial Engineering	18	451	6	311

Chemical Engineering	26	351	6	261
Mechanical Engineering	24	501	6	236
Electrical Engineering	20	432	6	331
Agribusiness	18	701	6	284
Agro-Technology	35	837	6	291
Aquaculture	11	576	6	243
Communication Science	12	734	6	291
Political Science	12	273	6	201
Sociology	14	491	6	211
Anthropology	10	189	6	127
Jurisprudence	51	1101	6	473
Medicine	31	291	6	301
Management	49	1307	6	1379
Economic Development	12	862	6	301
Accounting	24	1273	6	421

Table 1 displays inputs and outputs in the form of direct values that can be calculated, but there are also inputs in the form of stochastic values that include uncertainties, such as: The university environment for input and output is measured by graduate users' satisfaction levels. As a result, HF-SDEA can be used to quantify input values for the university setting and output values for stakeholder satisfaction. Assume the results of the calculations are as shown in Table II.

TABLE II
THE RESULT OF HF-SDEA

DMU	Input			Output		
	Number of Lecturers	**Number of Students**	**University Environment**	**Number of Research**	**Number of Graduates**	**Stakeholder Satisfaction**
Information Technology	18	567	0.77	7	671	0.91
Civil Engineering	27	750	0.35	6	535	0.51
Architectural Engineering	16	387	0.61	6	187	0.59
Industrial Engineering	18	451	0.69	6	311	0.69
Chemical Engineering	26	351	0.56	6	261	0.79
Mechanical Engineering	24	501	0.62	6	236	0.62
Electrical Engineering	20	432	0.71	6	331	0.59
Agribusiness	18	701	0.76	6	284	0.66
Agro-Technology	35	837	0.81	6	291	0.76
Aquaculture	11	576	0.61	6	243	0.56
Communication Science	12	734	0.71	6	291	0.81
Political Science	12	273	0.61	6	201	0.74
Sociology	14	491	0.59	6	211	0.72
Anthropology	10	189	0.66	6	127	0.69
Jurisprudence	51	1101	0.57	6	473	0.49
Medicine	31	291	0.62	6	301	0.81
Management	49	1307	0.63	6	1379	0.79
Economic Development	12	862	0.67	6	301	0.69
Accounting	24	1273	0.74	6	421	0.83

B. Testing resuts

The following is the complete type of programming with HF-SDEA.

Maximize:
671 U1 + 7 U2+0.91 U3
Subject to:
18 V1 + 567 V2+0.77 V3= 1

671 U1 + 7 U2+0.91 U3 - 18 V1 - 567 V2-0.77 V3 <= 0
535 U1 + 6 U2+0.51 U3 - 27 V1 - 750 V2-0.35 V3 <= 0
187 U1 + 6 U2+0.59 U3 - 16 V1 - 387 V2-0.61 V3 <= 0
311 U1 + 6 U2+0.69 U3 - 18 V1 - 451 V2-0.69 V3 <= 0
261 U1 + 6 U2+0.79 U3 - 26 V1 - 351 V2-0.56 V3 <= 0
236 U1 + 6 U2+0.62 U3 - 24 V1 - 501 V2-0.62 V3 <= 0
331 U1 + 6 U2+0.59 U3 - 20 V1 - 432 V2-0.71 V3 <= 0
284 U1 + 6 U2+0.66 U3 - 18 V1 - 701 V2-0.76 V3 <= 0
291 U1 + 6 U2+0.76 U3 - 35 V1 - 837 V2-0.81 V3 <= 0
243 U1 + 6 U2+0.56 U3 - 11 V1 - 576 V2-0.61 V3 <= 0
291 U1 + 6 U2+0.81 U3 - 12 V1 - 734 V2-0.71 V3<= 0
201 U1 + 6 U2+0.74 U3 - 12 V1 - 273 V2-0.61 V3 <= 0
211 U1 + 6 U2+0.72 U3 - 14 V1 - 491 V2-0.59 V3<= 0
127 U1 + 6 U2+0.69 U3 - 10 V1 - 189 V2-0.66 V3 <= 0
473 U1 + 6 U2+0.49 U3 - 51 V1 - 1101 V2-0.57 V3<= 0
301 U1 + 6 U2+0.81 U3 - 31 V1 - 291 V2-0.62 V3<= 0
1379 U1 + 6 U2+0.79 U3 - 49 V1 - 1307 V2-0.63 V3<= 0
301 U1 + 6 U2+0.69 U3 - 12 V1 - 862 V2-0.67 V3 <= 0
421 U1 + 6 U2+0.83 U3 - 24 V1 - 1273 V2-0.74 V3 <= 0
U1>=0
U2>=0
U3>=0
V1>=0
V2>=0
V3>=0
END

The efficiency testing results for each DMU based on the HF-SDEA are shown in Table III.

TABLE III
DECISION MAKING UNIT (DMU)

DMU	DEA Efficiency
Information Technology	1
Civil Engineering	1
Architectural Engineering	0.92
Industrial Engineering	0.84
Chemical Engineering	1
Mechanical Engineering	0.85
Electrical Engineering	0.85
Agribusiness	0.77
Agrotechnology	0.68
Aquaculture	1
Communication Science	1
Political Science	1
Sociology	0.99
Anthropology	1
Jurisprudence	0.65
Medical	1
Management	1
Economic Development	0.99
Accounting	0.88

Table 3 shows that the most powerful DMUs were Information Technology, Civil Engineering, Chemical Engineering, Aquaculture, Communication Science, Political Science, Anthropology, Medical, and Management, with a total of 9 (nine) DMUs.

The test results show that the HF-SDEA conducted a good benchmarking process for stochastic data under conditions that included elements of uncertainty and hesitancy. Centered on the HF-SDEA, the results of this study also include an effective and inefficient DMU. Future research should consider feasibility, need, and reputation.

IV. CONCLUSIONS

The results showed that the Hesitant Fuzzy model - Stochastic Data Envelopment Analysis (HF-SDEA) can be used to benchmark stochastic data under uncertain conditions. Future research should be able to assess the productive rating of each DMU in order to determine the university's future growth priorities.

REFERENCES

[1] A. Emrouznejad and G. Yang, “A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016,” *Socio-Economic Planning Sciences*, vol. 61, pp. 4–8, Mar. 2018.

[2] M. Ehrgott, A. Holder, and O. Nohadani, “Uncertain Data Envelopment Analysis,” *European Journal of Operational Research*, vol. 268, no. 1, pp. 231–242, Jul. 2018.

[3] C. Kahraman and E. Tolga, “Data envelopment analysis using fuzzy concept,” in *Proceedings. 1998 28th IEEE International Symposium on Multiple- Valued Logic (Cat. No.98CB36138)*, 1998, pp. 338–343.

[4] M. Tavana, A. Hatami-Marbini, and A. Emrouznejad, “Productivity Growth and Efficiency Measurements in Fuzzy Environments with an Application to Health Care,” *Int. J. Fuzzy Syst. Appl.*, vol. 2, no. 2, pp. 1–35, Apr. 2012.

[5] Peijun Guo, H. Tanaka, and M. Inuiguchi, “Self-organizing fuzzy aggregation models to rank the objects with multiple attributes,” *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 30, no. 5, pp. 573–580, Sep. 2000.

[6] A. Charnes, W. W. Cooper, and E. Rhodes, “Measuring the efficiency of decision making units,” *European Journal of Operational Research*, vol. 2, no. 6, pp. 429–444, Nov. 1978.

[7] S. Yousefi, H. Shabanpour, R. Fisher, and R. F. Saen, “Evaluating and ranking sustainable suppliers by robust dynamic data envelopment analysis,” *Measurement*, vol. 83, pp. 72–85, Apr. 2016.

[8] O. B. Olesen and N. C. Petersen, “Stochastic Data Envelopment Analysis—A review,” *European Journal of Operational Research*, vol. 251, no. 1, pp. 2–21, May 2016.

[9] S. Ahmadvand and M. S. Pishvaee, “An efficient method for kidney allocation problem: a credibility-based fuzzy common weights data envelopment analysis approach,” *Health Care Manag Sci*, vol. 21, no. 4, pp. 587–603, Dec. 2018.

[10] P. Peykani, E. Mohammadi, M. Rostamy-Malkhalifeh, and F. Hosseinzadeh Lotfi, “Fuzzy Data Envelopment Analysis Approach for Ranking of Stocks with an Application to Tehran Stock Exchange,” *Advances in Mathematical Finance and Applications*, vol. 4, no. 1, pp. 31–43, Mar. 2019.

[11] S.-P. Wan, Y.-L. Qin, and J.-Y. Dong, “A hesitant fuzzy mathematical programming method for hybrid multi-criteria group decision making with hesitant fuzzy truth degrees,” *Knowledge-Based Systems*, vol. 138, pp. 232–248, Dec. 2017.

[12] M. Ashtiani and M. A. Azgomi, “A hesitant fuzzy model of computational trust considering hesitancy, vagueness and uncertainty,” *Applied Soft Computing*, vol. 42, pp. 18–37, May 2016.

[13] H. Liu, Y. Ma, and L. Jiang, “Managing incomplete preferences and consistency improvement in hesitant fuzzy linguistic preference relations with applications in group decision making,” *Information Fusion*, vol. 51, pp. 19–29, Nov. 2019.

[14] Y. Wang, S. Wang, C. Dang, and W. Ge, “Nonparametric quantile frontier estimation under shape restriction,” *European Journal of Operational Research*, vol. 232, no. 3, pp. 671–678, Feb. 2014.

[15] S. Jradi and J. Ruggiero, “Stochastic data envelopment analysis: A quantile regression approach to estimate the production frontier,” *European Journal of Operational Research*, vol. 278, no. 2, pp. 385–393, Oct. 2019.

[16] A. Azadeh, S. Motevali Haghighi, M. Zarrin, and S. Khaefi, “Performance evaluation of Iranian electricity distribution units by using stochastic data envelopment analysis,” *International Journal of Electrical Power & Energy Systems*, vol. 73, pp. 919–931, Dec. 2015.

[17] W. Liu, Y.-M. Wang, and S. Lyu, “The upper and lower bound evaluation based on the quantile efficiency in stochastic data envelopment analysis,” *Expert Systems with Applications*, vol. 85, pp. 14–24, Nov. 2017.

[18] S. Lertworasirikul, S.-C. Fang, J. A. Joines, and H. L.W. Nuttle, “Fuzzy data envelopment analysis (DEA): a possibility approach,” *Fuzzy Sets and Systems*, vol. 139, no. 2, pp. 379–394, Oct. 2003.

[19] A. Hatami-Marbini, S. Saati, and M. Tavana, “An ideal-seeking fuzzy data envelopment analysis framework,” *Applied Soft Computing*, vol. 10, no. 4, pp. 1062–1070, Sep. 2010.

[20] A. Hatami-Marbini, A. Emrouznejad, and M. Tavana, “A taxonomy and review of the fuzzy data envelopment analysis literature: Two decades in the making,” *European Journal of Operational Research*, vol. 214, no. 3, pp. 457–472, Nov. 2011.

[21] N. Ahmady, M. Azadi, S. A. H. Sadeghi, and R. F. Saen, “A novel fuzzy data envelopment analysis model with double frontiers for supplier selection,” *International Journal of Logistics Research and Applications*, vol. 16, no. 2, pp. 87–98, Apr. 2013.

[22] M. Dotoli, N. Epicoco, M. Falagario, and F. Sciancalepore, “A cross-efficiency fuzzy Data Envelopment Analysis technique for performance evaluation of Decision Making Units under uncertainty,” *Computers & Industrial Engineering*, vol. 79, pp. 103–114, Jan. 2015.

[23] W. Zhou, J. Chen, Z. Xu, and S. Meng, “Hesitant fuzzy preference envelopment analysis and alternative improvement,” *Information Sciences*, vol. 465, pp. 105–117, Oct. 2018.