Notes on Intuitionistic Fuzzy Sets
Print ISSN 1310–4926, Online ISSN 2367–8283
2025, Volume 31, Number 4, 532–552
DOI: 10.7546/nifs.2025.31.4.532-552

A multi-criteria decision making method to measure offset printing quality according to paper type: Intuitionistic fuzzy entropy based TOPSIS method

Gökhan Çuvalcıoğlu [1], **Dilara Gündoğdu** [2] **and Fatma Özel** [3]

[1] Department of Mathematics, Faculty of Science,
Mersin University, Mersin, Türkiye
e-mail: gcuvalcioglu@mersin.edu.tr

[2] Department of Mathematics, Graduate School of Natural and Applied Sciences,
Mersin University, Mersin, Türkiye
e-mail: dilaragundogdu8@gmail.com

[3] Department of Mathematics, Graduate School of Natural and Applied Sciences,
Mersin University, Mersin, Türkiye
e-mail: dfatmaozel@gmail.com

Received: 12 October 2025 **Revised:** 17 November 2025
Accepted: 19 November 2025 **Online First:** 27 November 2025

Abstract: The purpose of this study is to create a decision-making mechanism that evaluates papers according to offset printing quality. For this purpose, paper types were determined first. Then, each of the CMYK colors were measured for the selected papers and the numerical values of print contrast, print density, color values, and color range features were obtained. These numerical values were fuzzified with the sigmoid fuzzification function. After determining these fuzzy values for the Intuitionistic Fuzzy entropy (IFE) concept with the conversion method to IF values, entropy measurements were calculated, and the decision-making process was completed with the TOPSIS decision-making modeling using these IF entropy measurements. Separate

calculations were made according to ten different IF entropies to prove the accuracy of the obtained result. Although the results obtained according to all entropies selected the same paper type as the most useful and least useful according to CMYK colors, they gave different results for the few other paper types in between according to quality order. According to the findings, when all colors are examined, the best paper in terms of offset printing quality is coated papers; the worst paper is III low grade paper.
Keywords: Intuitionistic fuzzy entropy, Multi-criteria decision-making, Print quality, TOPSIS, CMYK.
2020 Mathematics Subject Classification: 90B50, 03E72, 47S40.

1 Introduction

The purpose of this article is to evaluate papers selected according to different features, considering the offset printing quality, separately for each color. For this purpose, the features between colors and papers were fuzzified and a TOPSIS-based decision-making algorithm was created through current IF entropy values. In the study, 10 different IF entropies were selected and the results obtained for each entropy were compared.

Many methods are used for selection, evaluation and decision-making problems that are encountered as current problems. One of the current methods among these is the TOPSIS-based decision-making process with the help of IF entropies defined on intuitionistic fuzzy (IF) sets. Thanks to this method, it is possible to rank the data investigated by solving the problems not only from best to worst but also give ranking from best to worst.

It is expected that a judgement will be true or false, but it is not expected that the situations encountered in daily life will indicate an absolute judgement. This situation can be explained as it is not expected to be classified as absolutely and definitely positive or negative according to the characteristics of the data studied. Measuring the level of the characteristics of the data studied is much more important for usability success and benefit. This means that even if a data has a certain quality on its own in its raw form, if it produces a result with other variables it interacts with, it is not expected that this product will be of high quality. In that case, the true-false (numerically $1-0$) judgement put forward in the propositions will not be sufficient in solving many problems. Therefore, it is important to evaluate a data according to the degree of its characteristics. As a result of this discussion, the belonging of an element to a set should be graded. For this purpose, Fuzzy Set (FS) Theory was first defined by [38]. According to the logical rules that constitute Fuzzy Set Theory, the truth value of an expression is $0, 1$ or any real number between them. There are many theories expressed differently with similar perspectives. The common name of these theories is many-valued logic. Since fuzzy theory also uses the values 0 and 1, it is actually a generalization of the classical theory. The elements in a set are determined by the degree of belonging to the set and the degree of not belonging to it.

In fact, although fuzzy set theory tries to overcome the sharpness of classical theory, this theory is also precise due to the rigid structure of membership and non-membership degrees. The reason for this numerically is that the sum of membership and non-membership degrees is 1. Therefore, the membership degree definitely affects the non-membership degree. However, it would be more realistic for the membership degree of an element to be more independent of the membership degree. This discussion reveals that in addition to the membership and non-membership degrees of an element, its hesitation degree is also important. This problem was solved by K. T. Atanassov in 1983 by defining the concept of intuitionistic fuzzy sets [1]. According to the intuitionistic fuzzy theory, an element is expressed by its membership, non-membership and hesitation degree.

Definition 1. *Let X be a universe of discourse, then an Intuitionistic Fuzzy Set (IFS) on X is defined as:*

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in X\},$$

where $\mu_A(x),\ \nu_A(x),\ (\mu_A(x) + \nu_A(x)) : X \to [0, 1]$.

For $x \in X$, the degrees of membership and non-membership are represented by $\mu_A(x),\ \nu_A(x)$, respectively. The value $\pi_A(x) = 1 - (\mu_A(x) + \nu_A(x))$ is called the hesitancy degree or intuitionistic fuzzy index of the element x.

The family of intuitionistic fuzzy sets defined on a universe of discourse X is denoted by IFS(X).

The fact that the criteria that constitute the multiple data decision-making problem are single or multiple plays an important role in the success of making a choice for the solution of the problem. If the criterion is single, it is quite easy to achieve a perfect result. However, as the number of criteria increases, the success of choosing the most appropriate one among the data changes inversely proportionally. Therefore, the purpose of MCDM is to evaluate multiple criteria with common relationships for different data and make the most accurate choice by checking all situations. Intuitionistic fuzzy sets are the expression of fuzziness with three dependent variables instead of two. The reason why IFSs play an important role in decision-making processes is that the degree of hesitation is also of decisive importance. IFSs are widely used in many areas such as measuring quantitative information in modeled structures, supplier selection, training, personnel selection, decision making, image enhancement, pattern recognition and many other areas [5, 8–11].

MCDM methods have an important value among the methods used in solving many similar problems. Various MCDM methods are used depending on the type of data affecting the problem. Among the MCDM methods based on single and multiple criteria, WSM, MEW, ELECTRE, VIKOR, COPRAS, PROMETHEE, TOPSIS etc. are used. EDAS, TODIM, Cardinal Reconciliation Method, etc. methods are widely used in probabilistic evaluations. In short, many MCDM methods can be mentioned according to the characteristic features of the data constituting the problem. Algorithms for the application of known MCDM methods are given by researchers. The measurement functions affecting each step of the algorithm and the method of calculating the coefficients for the data are defined.

In order to develop an MCDM technique, [29] studied the cardinal compromise method and TODIM method with exponential hesitation fuzzy, [39] studied the construction of TOPSIS technique with cross entropy on interval-valued intuitionistic fuzzy sets, [11] studied the correlation of time-sequential hesitation fuzzy entropy, cross entropy and correlation coefficients with MCDM.

The concept of IF entropy was first described by [3]. In this work, entropies were used to express the degree of uncertainty and fuzziness of IFSs. In fact, IF entropy represents a different way of measuring the level of uncertain information, like other information.

Szmidt and others [17–21] intuitionistic fuzzy sets geometrically. Apart from the geometric approach, new IF entropy concepts were introduced by different authors [26, 30, 40] with studies based on function theory. In these studies, special functions such as logarithmic, trigonometric and exponential functions were used.

2 Materials and methods

2.1 Intuitiontistic fuzzy sets

This section provides basic concepts and related tables. IF Entropy definition is as follows [3].

Definition 2. *Let X be the universe of discourse. E : IFS$(X) \to [0,1]$ is a function such that if the following axioms are satisfied for $A, B \in$ IFS(X), then E is called the IF entropy on IFS(X).*

E1. $E(A) = 0 \iff A$ *is a crisp set, i.e.,*
$(\mu_A(x) = 1 \text{ and } \nu_A(x) = 0)$ *or* $(\mu_A(x) = 0 \text{ and } \nu_A(x) = 1)$.

E2. $E(A) = 1 \iff \mu_A(x_i) = \nu_A(x_i)$.

E3. $E(A) = E(A^c)$.

E4. $$E(A) \le E(B) \text{ when } \begin{cases} \mu_A(x) \le \mu_B(x) \text{ and } \nu_A(x) \ge \nu_B(x) & \text{for } \mu_B(x) \le \nu_B(x), \text{ or} \\ \mu_A(x) \ge \mu_B(x) \text{ and } \nu_A(x) \le \nu_B(x) & \text{for } \mu_B(x) \ge \nu_B(x). \end{cases}$$

With the definition of the concept of Intuitionistic Fuzzy entropy, the hesitation option has been added to the processes in MCDM methods and much more successful results have been obtained in decision-making processes. Thus, the comparison of the success of the results obtained from the solution of decision-making process problems can be easily made.

There is no study conducted in determining the offset printing quality by associating the Intuitionistic Fuzzy entropy concept with the TOPSIS method. The number of known IF entropy functions is not more than 40. In this study, 10 different entropies were selected from among these entropies, from the old to the new, according to the group they belong to and the preference density. Thus, the results of the offset printing quality problem were obtained according to each entropy and these results were compared. The entropies used are given in Table 1.

2.2 Recent studies on offset printing

The expected quality level from a print varies according to the job. Of course, using the highest quality paper is the shortest and most guaranteed way for print quality. However, the importance of paper selection is great both in terms of not harming nature and its economic contributions. Therefore, it is clear that paper selection will contribute to both nature and the economy in order to achieve the desired quality print. In this study, the IF entropy-based TOPSIS method is used to evaluate the advantageous and disadvantageous situations of the evaluated paper according to its

Table 1. Entropy formulas and their references

Entropy formulas	**References**
$E_Y = \left(\cos\left(\left(\frac{\mu(x_i)+1-\upsilon_A(x_i)}{4}\right)\pi\right) + \cos\left(\left(\frac{\upsilon_A(x_i)+1-\mu(x_i)}{4}\right)\pi\right) - 1\right)\left(\frac{1}{\sqrt{2}-1}\right)$	[30]
$E_V = \frac{1}{n\sqrt{e-1}} \sum_{i=1}^{n} \left[\left(\frac{\mu_A(x_i)+1-\upsilon_A(x_i)}{2} e^{1-\left(\frac{\mu_A(x_i)+1-\upsilon_A(x_i)}{2}\right)} + \frac{\upsilon_A(x_i)+1-\mu_A(x_i)}{2} e^{1-\left(\frac{\upsilon_A(x_i)+1-\mu_A(x_i)}{2}\right)}\right) - 1\right]$	[26]
$E_W = \sum_{i=1}^{n} \cot\left((1 + \lvert\mu_A(x_i) - \upsilon_A(x_i)\rvert)\frac{\pi}{4}\right)(1 + \pi_A(x_i))$	[27]
$E_B = \sum_{i=1}^{n}(1 - \mu_A(x_i) - \upsilon_A(x_i))$	[3]
$E_S = \sum_{i=1}^{n} \frac{\min\{\mu_A(x_i),\upsilon_A(x_i)\}+\pi_A(x_i)}{\max\{\mu_A(x_i),\upsilon_A(x_i)\}+\pi_A(x_i)}$	[17]
$E_T = 1 - \sum_{i=1}^{n} \left(2\lvert\mu_A(x_i) - \upsilon_A(x_i)\rvert - \lvert\mu_A(x_i) - \upsilon_A(x_i)\rvert^2\right)$	[24]
$E_P = 1 - \frac{1}{3n\log\left(\frac{3}{\sqrt[3]{4}}\right)} \sum_{i=1}^{n} \frac{(\mu_A(x_i)+\upsilon_A(x_i)+2)(\mu_A(x_i)+\upsilon_A(x_i))^2}{(\mu_A(x_i)+1)(\upsilon_A(x_i)+1)} \log \frac{\mu_A(x_i)+\upsilon_A(x_i)+2}{2\sqrt{(\mu_A(x_i)+1)(\upsilon_A(x_i)+1)}}$	[13]
$E_G = \sum_{i=1}^{n} \frac{1-(\mu_A(x_i)-\upsilon_A(x_i))^2+\pi_A(x_i)^2}{2}$	[28]
$E_H = \sum_{i=1}^{n} \left(1 - \mu_A(x_i)^2 - \upsilon_A(x_i)^2 - \pi_A(x_i)^2\right)$	[7]
$E_M = -2\sum_{i=1}^{n} \left[\log\left(\frac{\mu_A(x_i)+1-\upsilon_A(x_i)}{2} e^{\frac{\mu_A(x_i)+1-\upsilon_A(x_i)}{2}} + \frac{\upsilon_A(x_i)+1-\mu_A(x_i)}{2} e^{\frac{\upsilon_A(x_i)+1-\mu_A(x_i)}{2}}\right) - 1\right]$	[12]

quality group, and each paper is evaluated separately according to the main colors, and the most appropriate ranking for print quality is determined. Offset printing system is the most preferred printing system today due to its compatibility with technology, printing speed and quality, and economic aspects. Regardless of the system, including laser and inkjet printing systems, the quality of the harmony of the physical properties of the paper with the color types has a main role in determining the quality of the product obtained. When papers, printing systems, and ink types are taken into account, many conclusions can be reached about print quality. According to these features, there are many important studies on print quality [4, 16, 22, 23, 31–37]. The prominent studies in these studies are:

- Print quality according to the physical properties of papers,
- Effects of printing systems (Offset, laser and inkjet, etc.) on color properties,
- Effect of recycling repeat on ink removal efficiency;
- Effect of recycling repeat on print properties;
- Color values of prints made on recycled papers with ink and laser spray method;
- The efficiency of offset printing methods on print quality;
- Dot gain obtained when weighting pressure is taken into account.

In parallel with the development of computers and machines, the offset printing system is a new printing system that is preferred more today due to its compatibility with technology. In addition to time and energy savings, ease of use is also one of the most important factors in its preference [23]. As a result, as in all printing systems, the material that stands out for measuring print quality is again paper. Therefore, paper quality is the most important criterion for printing success. In the study conducted by [31], he printed on papers that were physically different and measured these print results by means of print control strips and obtained the data in Tables 2–5.

The type of paper as data and the print quality according to colors as criteria were determined numerically beforehand [31]. Although it seems difficult to blur these values, some appropriate functions (basic sigmoid, Gaussian, etc.) are used to blur numerical data [2].

The size change and growth of the dots forming the image on the plate due to reasons such as the absorbent properties of the paper and the printing pressure is called dot gain [23]. We will denote Dot gain values by C1. The difference between the brightest and darkest parts of the image obtained after printing is called printing contrast. High printing contrast is a positive feature. We will denotePrint contrast values by C2. The amount of ink on a printed page is called print density. The print density value is determined according to the ISO 12647-2 standard. We will denotePrint density values by C3. The color saturation of a print is called chroma. The chroma value (C) is calculated according to the red-green value (a) and yellow-blue (b) value of the print with $C = \sqrt{a^2 + b^2}$. The print quality is directly proportional to the high chroma value [15]. We will denoteChroma values by C4. It expresses all the color tones in the universe as the light and dark of CMYK colors. As the gamut value increases, the color universe that can be formed in printing expands [6]. We will denoteColor gamut by C5.

Let

- P1: American Bristol Cardboard 230 gr.,
- P2: American Bristol Cardboard 350 gr.,
- P3: Matte Coated 115 gr.,
- P4: Glossy Coated 115 gr.,
- P5: 70 gr. I. high grade paper,
- P6: 80 gr. I. high grade paper,
- P7: 54 gr. II. medium grade paper,
- P8: 48 gr. II. medium grade paper,
- P9: 70 gr. III. low grade paper,
- P10: 80 gr. III. low grade paper.

While creating the MCDM mechanism, the alternatives for C, M, Y and K colors are papers and the criteria are the factors affecting the printing quality. Therefore, in this study the set of alternatives and the set of criteria are chosen {P1, P2, ..., P10} and {C1, C2, C3, C4, C5}, respectively. In order to use it in the decision-making process, the previously obtained data [25] as given in Tables 2–5 will be taken into consideration. Thus, it will be possible to compare the results with previous studies.

Table 2. Cyan

	C1	**C2**	**C3**	**C4**	**C5**
P1	16.8	29.1	1.64	60.59	299
P2	17.2	30.4	1.56	60.17	322
P3	16.3	31.2	1.66	60.30	318
P4	16.2	30.8	1.66	60.33	322
P5	13.6	24.6	1.31	55.70	172
P6	14.2	26.5	1.17	56.79	159
P7	16.6	21.3	1.30	55.45	129
P8	15.6	20.6	1.35	55.86	154
P9	15.3	24.3	1.16	52.02	84
P10	16.2	22.7	1.23	58.87	153

Table 3. Magenta

	C1	**C2**	**C3**	**C4**	**C5**
P1	13.2	33.0	1.37	88.70	299
P2	13.7	33.7	1.30	87.44	322
P3	14.4	31.7	1.31	88.96	318
P4	14.0	30.9	1.34	88.96	322
P5	12.6	23.5	1.12	83.41	172
P6	13.5	25.5	1.05	83.73	159
P7	16.2	21.7	1.14	80.40	129
P8	15.8	20.9	1.15	78.56	154
P9	13.9	25.4	1.00	73.92	84
P10	13.9	25.1	1.00	83.73	153

Table 4. Yellow

	C1	**C2**	**C3**	**C4**	**C5**
P1	14.9	23.8	1.33	86.65	299
P2	15.4	24.8	1.29	85.26	322
P3	15.2	27.3	1.21	87.69	318
P4	15.0	25.3	1.30	87.56	322
P5	12.5	23.0	1.19	85.54	172
P6	13.1	24.4	1.15	85.95	159
P7	15.5	21.3	1.12	79.70	129
P8	15.4	19.7	1.15	77.30	154
P9	14.6	21.5	0.98	74.81	84
P10	15.8	18.0	1.06	86.89	153

Table 5. Black

	C1	**C2**	**C3**	**C4**	**C5**
P1	8.2	41.9	1.58	18.21	299
P2	9.2	47.9	1.56	16.99	322
P3	9.2	50.9	1.50	18.67	318
P4	8.6	49.9	1.52	18.42	322
P5	12.6	39.6	1.47	25.35	172
P6	13.6	40.9	1.42	27.63	159
P7	14.9	30.5	1.22	22.03	129
P8	13.6	28.3	1.25	22.37	154
P9	12.7	37.6	1.21	21.78	84
P10	13.7	33.7	1.34	23.03	153

Since the values of the C5 criterion are too large to be related to the other criteria, they must first be consistent among themselves. Therefore, it is necessary to normalize the values at Step 1 and Step 2, and then use fuzzification functions. For example, in order to evaluate three machines with different capacities for painting a full, a half, a quarter wall, first numerating their capabilities in the work per unit will make the result of a job problem where all of them are evaluated consistently. For this purpose, the following method steps were used to obtain the intuitionistic fuzzy values in Tables 2–5 [22].

Step 1: To find the equivalent of Pn in the range $[0, 1]$, the formula $\frac{\text{value} - \min\{\text{value}\}}{\max\{\text{value}\} - \min\{\text{value}\}}$ was used to ensure that the value range of the data was $[0, 1]$.

Step 2: A basic sigmoid function with two parameters (c1 and c2) as commonly used for subitizing calculations [14]. The membership degree $\frac{\alpha(x) - \min\{\text{value}(x)\}}{0.5 - \min\{\text{value}(\alpha(x))\}}$ was obtained by using the (x) value found with the coefficients a and b, the basic sigmoid membership degree function $\frac{1}{1 + e^{-a(x-b)}}$.

There are various methods for converting fuzzy values into intuitionistic fuzzy values. Although all of these methods are numerically different, the error margin between them is as small as possible. Therefore, the choice of method does not affect the result.

Step 3: The process of intuitionistic fuzzification used in this study was performed with the function $\nu(x) = 1 - \mu(x)^{\ 1-\mu(x)}$ for the membership degree $\mu(x)$ and the non-membership degree $\nu(x)$.

As a result of these steps, the following intuitionistic fuzzy values between papers and colors are obtained.

Table 6. Cyan Intuitionistic Fuzzy Values

Alternative	Value	C1	C2	C3	C4	C5
P1	μ_{C,P_1,C_k}	0.887	0.799	0.96	1	0.902
	ν_{C,P_1,C_k}	0.013	0.044	0.002	0	0.01
	π_{C,P_1,C_k}	0.1	0.157	0.038	0	0.088
P2	μ_{C,P_2,C_k}	1	0.924	0.798	0.949	1
	ν_{C,P_2,C_k}	0	0.006	0.045	0.003	0
	π_{C,P_2,C_k}	0	0.07	0.157	0.048	0
P3	μ_{C,P_3,C_k}	0.745	1	1	0.965	0.983
	ν_{C,P_3,C_k}	0.072	0	0	0.001	0
	π_{C,P_3,C_k}	0.183	0	0	0.034	0.017
P4	μ_{C,P_4,C_k}	0.717	0.961	1	0.969	1
	ν_{C,P_4,C_k}	0.09	0.002	0	0.001	0
	π_{C,P_4,C_k}	0.193	0.037	0	0.03	0
P5	μ_{C,P_5,C_k}	0	0.37	0.297	0.415	0.366
	ν_{C,P_5,C_k}	1	0.465	0.574	0.402	0.471
	π_{C,P_5,C_k}	0	0.165	0.129	0.183	0.163
P6	μ_{C,P_6,C_k}	0.162	0.551	0.02	0.544	0.311
	ν_{C,P_6,C_k}	0.782	0.235	0.978	0.242	0.553
	π_{C,P_6,C_k}	0.056	0.214	0.002	0.214	0.136
P7	μ_{C,P_7,C_k}	0.83	0.064	0.277	0.386	0.186
	ν_{C,P_7,C_k}	0.031	0.924	0.605	0.443	0.746
	π_{C,P_7,C_k}	0.139	0.012	0.118	0.171	0.068
P8	μ_{C,P_8,C_k}	0.548	0	0.376	0.434	0.291
	ν_{C,P_8,C_k}	0.238	1	0.457	0.377	0.583
	π_{C,P_8,C_k}	0.214	0	0.167	0.189	0.126
P9	μ_{C,P_9,C_k}	0.465	0.342	0	0	0
	ν_{C,P_9,C_k}	0.336	0.506	1	1	1
	π_{C,P_9,C_k}	0.199	0.152	0	0	0
P10	μ_{C,P_{10},C_k}	0.717	0.193	0.138	0.792	0.287
	ν_{C,P_{10},C_k}	0.09	0.735	0.819	0.047	0.589
	π_{C,P_{10},C_k}	0.193	0.072	0.043	0.161	0.124

Table 7. Magenta Intuitionistic Fuzzy Values

Alternative	Value	C1	C2	C3	C4	C5
P1	μ_{M,P_1,C_k}	0.162	0.944	1	0.982	0.902
	ν_{M,P_1,C_k}	0.782	0.003	0	0	0.01
	π_{M,P_1,C_k}	0.056	0.053	0	0.018	0.088
P2	μ_{M,P_2,C_k}	0.299	1	0.809	0.895	1
	ν_{M,P_2,C_k}	0.571	0	0.04	0.012	0
	π_{M,P_2,C_k}	0.13	0	0.151	0.093	0
P3	μ_{M,P_3,C_k}	0.494	0.842	0.836	1	0.983
	ν_{M,P_3,C_k}	0.3	0.027	0.029	0	0
	π_{M,P_3,C_k}	0.206	0.131	0.135	0	0.017
P4	μ_{M,P_4,C_k}	0.382	0.779	0.918	1	1
	ν_{M,P_4,C_k}	0.448	0.054	0.007	0	0
	π_{M,P_4,C_k}	0.17	0.167	0.075	0	0
P5	μ_{M,P_5,C_k}	0	0.2	0.319	0.62	0.366
	ν_{M,P_5,C_k}	1	0.724	0.541	0.166	0.471
	π_{M,P_5,C_k}	0	0.076	0.14	0.214	0.163
P6	μ_{M,P_6,C_k}	0.244	0.355	0.132	0.641	0.311
	ν_{M,P_6,C_k}	0.656	0.487	0.828	0.148	0.553
	π_{M,P_6,C_k}	0.1	0.158	0.04	0.211	0.136
P7	μ_{M,P_7,C_k}	1	0.062	0.373	0.418	0.186
	ν_{M,P_7,C_k}	0	0.926	0.461	0.398	0.746
	π_{M,P_7,C_k}	0	0.012	0.166	0.184	0.068
P8	μ_{M,P_8,C_k}	0.887	0	0.4	0.297	0.291
	ν_{M,P_8,C_k}	0.013	1	0.423	0.574	0.583
	π_{M,P_8,C_k}	0.1	0	0.177	0.129	0.126
P9	μ_{M,P_9,C_k}	0.355	0.348	0	0	0
	ν_{M,P_9,C_k}	0.487	0.498	1	1	1
	π_{M,P_9,C_k}	0.158	0.154	0	0	0
P10	μ_{M,P_{10},C_k}	0.355	0.324	0	0.641	0.287
	ν_{M,P_{10},C_k}	0.487	0.533	1	0.148	0.589
	π_{M,P_{10},C_k}	0.158	0.143	0	0.211	0.124

Table 8. Yellow Intuitionistic Fuzzy Values (Compact Format)

Alternative	Type	C1	C2	C3	C4	C5
P1	μ_{Y,P_1,C_k}	0.724	0.615	1	0.914	0.902
	ν_{Y,P_1,C_k}	0.085	0.171	0	0.008	0.01
	π_{Y,P_1,C_k}	0.191	0.214	0	0.078	0.088
P2	μ_{Y,P_2,C_k}	0.877	0.724	0.883	0.8	1
	ν_{Y,P_2,C_k}	0.016	0.085	0.014	0.044	0
	π_{Y,P_2,C_k}	0.107	0.191	0.103	0.156	0
P3	μ_{Y,P_3,C_k}	0.816	1	0.65	1	0.983
	ν_{Y,P_3,C_k}	0.037	0	0.14	0	0
	π_{Y,P_3,C_k}	0.147	0	0.21	0	0.017
P4	μ_{Y,P_4,C_k}	0.754	0.779	0.912	0.989	1
	ν_{Y,P_4,C_k}	0.067	0.054	0.008	0	0
	π_{Y,P_4,C_k}	0.179	0.167	0.08	0.011	0
P5	μ_{Y,P_5,C_k}	0	0.528	0.592	0.823	0.366
	ν_{Y,P_5,C_k}	1	0.26	0.193	0.034	0.471
	π_{Y,P_5,C_k}	0	0.212	0.215	0.143	0.163
P6	μ_{Y,P_6,C_k}	0.178	0.68	0.477	0.857	0.311
	ν_{Y,P_6,C_k}	0.758	0.116	0.321	0.022	0.553
	π_{Y,P_6,C_k}	0.064	0.204	0.202	0.121	0.136
P7	μ_{Y,P_7,C_k}	0.908	0.345	0.391	0.358	0.186
	ν_{Y,P_7,C_k}	0.009	0.502	0.436	0.483	0.746
	π_{Y,P_7,C_k}	0.083	0.153	0.173	0.159	0.068
P8	μ_{Y,P_8,C_k}	0.877	0.176	0.477	0.177	0.291
	ν_{Y,P_8,C_k}	0.016	0.761	0.321	0.76	0.583
	π_{Y,P_8,C_k}	0.107	0.063	0.202	0.063	0.126
P9	μ_{Y,P_9,C_k}	0.632	0.365	0	0	0
	ν_{Y,P_9,C_k}	0.155	0.473	1	1	1
	π_{Y,P_9,C_k}	0.213	0.162	0	0	0
P10	μ_{Y,P_{10},C_k}	1	0	0.221	0.934	0.287
	ν_{Y,P_{10},C_k}	0	1	0.691	0.004	0.589
	π_{Y,P_{10},C_k}	0	0	0.088	0.062	0.124

Table 9. Black Intuitionistic Fuzzy Values (Compact Format)

Alternative	Type	C1	C2	C3	C4	C5
P1	μ_{K,P_1,C_k}	0	0.594	1	0.112	0.902
	ν_{K,P_1,C_k}	1	0.191	0	0.857	0.01
	π_{K,P_1,C_k}	0	0.215	0	0.031	0.088
P2	μ_{K,P_2,C_k}	0.143	0.864	0.944	0	1
	ν_{K,P_2,C_k}	0.811	0.02	0.003	1	0
	π_{K,P_2,C_k}	0.046	0.116	0.053	0	0
P3	μ_{K,P_3,C_k}	0.143	1	0.777	0.154	0.983
	ν_{K,P_3,C_k}	0.811	0	0.055	0.795	0
	π_{K,P_3,C_k}	0.046	0	0.168	0.051	0.017
P4	μ_{K,P_4,C_k}	0.057	0.955	0.833	0.13	1
	ν_{K,P_4,C_k}	0.933	0.002	0.03	0.831	0
	π_{K,P_4,C_k}	0.01	0.043	0.137	0.039	0
P5	μ_{K,P_5,C_k}	0.649	0.491	0.694	0.782	0.366
	ν_{K,P_5,C_k}	0.141	0.304	0.106	0.052	0.471
	π_{K,P_5,C_k}	0.21	0.205	0.2	0.166	0.163
P6	μ_{K,P_6,C_k}	0.801	0.55	0.556	1	0.311
	ν_{K,P_6,C_k}	0.043	0.236	0.229	0	0.553
	π_{K,P_6,C_k}	0.156	0.214	0.215	0	0.136
P7	μ_{K,P_7,C_k}	1	0.093	0.025	0.467	0.186
	ν_{K,P_7,C_k}	0	0.884	0.973	0.334	0.746
	π_{K,P_7,C_k}	0	0.023	0.002	0.199	0.068
P8	μ_{K,P_8,C_k}	0.801	0	0.102	0.499	0.291
	ν_{K,P_8,C_k}	0.043	1	0.871	0.294	0.583
	π_{K,P_8,C_k}	0.156	0	0.027	0.207	0.126
P9	μ_{K,P_9,C_k}	0.664	0.403	0	0.443	0
	ν_{K,P_9,C_k}	0.129	0.419	1	0.365	1
	π_{K,P_9,C_k}	0.207	0.178	0	0.192	0
P10	μ_{K,P_{10},C_k}	0.817	0.232	0.339	0.562	0.287
	ν_{K,P_{10},C_k}	0.036	0.674	0.511	0.223	0.589
	π_{K,P_{10},C_k}	0.147	0.094	0.15	0.215	0.124

3 Results

In this study, TOPSIS based decision making process will be used employing IF entropy functions. It is known that the quality of offset printing varies according to the physical properties of the papers. One of the factors affecting the printing quality of a paper is the harmony of the paper quality with the colors. In other words, the success of the color applied to a paper is important according to the type of paper. The four main colors that form the printed image are cyan, magenta, yellow and black. In that case, instead of all colors, determining the relationship between the physical properties of the paper and the main colors will directly affect the printing result to be obtained from different colors. Therefore, the main purpose of this study is to evaluate the quality of offset printing by considering the four main colors cyan, magenta, yellow and key and the physical quality of the selected paper. As a result, a new modeling can be obtained that will guide printers to achieve high quality printing high-quality printing according to the desired quality scale. In this modeling, the prominence of the intuitionistic fuzzy value for data and the use of the concept of intutiontist fuzzy entropy are innovations, as well as the emergence of a new application area for the TOPSIS method in decision-making processes.

3.1 The steps of the IFEB-TOPSIS MCDM method

The steps of the IFEB-TOPSIS method to be applied for the IF values of the above discussions and the obtained data are as follows.

Step 1: The following intuitionistic fuzzy decision matrix is defined with m alternatives and n attributes.

$$\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_m \end{array} \begin{bmatrix} (\mu_{11},\nu_{11}) & (\mu_{12},\nu_{12}) & \dots & (\mu_{1n},\nu_{1n}) \\ (\mu_{21},\nu_{21}) & (\mu_{22},\nu_{22}) & \dots & (\mu_{2n},\nu_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (\mu_{m1},\nu_{m1}) & (\mu_{m2},\nu_{m2}) & \dots & (\mu_{mn},\nu_{mn}) \end{bmatrix}$$

Step 2: Using the above matrix, the IF entropy values are determined as follows.

$$\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_i \\ \vdots \\ G_m \end{array} \begin{bmatrix} E_{11} & E_{12} & \dots & E_{1j} & \dots & E_{1n} \\ E_{21} & E_{22} & \cdots & E_{2j} & \dots & E_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ E_{i1} & \dots & \dots & E_{ij} & \dots & E_{in} \\ \vdots & \dots & \dots & \vdots & \ddots & \vdots \\ E_{m1} & E_{m2} & \dots & E_{mj} & \dots & E_{mn} \end{bmatrix}$$

Using the following equation, the IF entropy values in the decision matrix are normalized:

$$h_{ij} = \frac{E_{i1}}{\max(E_{i1})}, \frac{E_{i2}}{\max(E_{i2})} \cdots \frac{E_{ij}}{\max\left(E_{ij}\right)}$$

in which $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$.

Therefore the normalized decision matrix is calculated as follows:

$$\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_i \\ \vdots \\ G_m \end{array}\begin{bmatrix} h_{11} & h_{12} & \dots & h_{1j} & \dots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2j} & \dots & h_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ h_{i1} & \dots & \dots & h_{ij} & \dots & h_{in} \\ \vdots & \dots & \dots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \dots & h_{mj} & \dots & h_{mn} \end{bmatrix}$$

The objective attribute weights are determined as follows:

- $w_j = \frac{1}{n-T} \times (1 - a_j)$,
- $a_j = \sum_{i=1}^{m} h_{ij}$,
- $T = \sum_{i=1}^{n} a_j$.

Step 3: Determination of weighted intuitionistic fuzzy decision matrix.

$$\lambda I = \left(1 - (1 - \mu_I)^{\lambda}, (\nu_I)^{\lambda}\right), \qquad 0 < \lambda < 1$$

Using the weight of each criterion, the weighted IF decision matrix is created as

$$\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_m \end{array}\begin{bmatrix} (\mu_{11w}, \nu_{11w}) & (\mu_{12w}, \nu_{12w}) & \dots & (\mu_{1nw}, \nu_{1nw}) \\ (\mu_{21w}, \nu_{21w}) & (\mu_{22w}, \nu_{22w}) & \dots & (\mu_{2nw}, \nu_{2nw}) \\ \vdots & \vdots & \ddots & \vdots \\ (\mu_{m1w}, \nu_{m1w}) & (\mu_{m2w}, \nu_{m2w}) & \cdots & (\mu_{mnw}, \nu_{mnw}) \end{bmatrix}$$

Step 4: Determination of Intuitionistic fuzzy positive ideal solution (IFPIS) and intuitionistic fuzzy negative ideal solution (IFNIS).

The IFEB-TOPSIS method categorizes evaluation criteria into two categories: benefit and cost. Let G be a collection of benefit criteria and B be a collection of cost criteria.

$$A^{+} = \Big[\big\{C_j, \langle \max_i\{\mu_{ij}(C_j) \mid j \in G\}, \min_i\{\mu_{ij}(C_j) \mid j \in B\}\rangle, \\ \langle \min_i\{\nu_{ij}(C_j) \mid j \in G\}, \max_i\{\nu_{ij}(C_j) \mid j \in B\}\rangle\big\} \,\big|\, i \in M\Big]$$

$$A^{-} = \Big[\big\{C_j, \langle \min_i\{\mu_{ij}(C_j) \mid j \in G\}, \max_i\{\mu_{ij}(C_j) \mid j \in B\}\rangle, \\ \langle \max_i\{\nu_{ij}(C_j) \mid j \in G\}, \min_i\{\nu_{ij}(C_j) \mid j \in B\}\rangle\big\} \,\big|\, i \in M\Big]$$

Step 5: To determine distance of each alternative from IFPIS and IFNIS, the intuitionistic separation measure is calculated:

$$S_i^{+} = \sum_{i=1}^{n} \max\left(\left|\mu_{A^{+}}(x_i) - \mu_B(x_i)\right|, \left|\nu_{A^{+}}(x_i) - \nu_B(x_i)\right|\right),$$

$$S_i^{-} = \sum_{i=1}^{n} \max\left(\left|\mu_{A^{-}}(x_i) - \mu_B(x_i)\right|, \left|\nu_{A^{-}}(x_i) - \nu_B(x_i)\right|\right)$$

Step 6: Determination of relative closeness coefficient:

$$C_j = \frac{S^-}{S^+ + S^-}, \;\; j = 1, 2, \;\ldots, \; m.$$

The ranking of the alternatives from the most preferred to the least preferred is the ordering of the closeness coefficient values from largest to smallest.

If this method is applied to the data in Tables 6–9, the final results obtained with the IFEB-TOPSIS MCDM method for each entropy are as follows:

Table 10. Aggregated intuitionistic fuzzy scores for alternatives (Cyan, C)

Alt.	**EB**	**EG**	**EH**	**EM**	**EP**	**ES**	**ET**	**EV**	**EW**	**EY**
P1	0.576	0.581	0.579	0.581	0.577	0.578	0.574	0.581	0.579	0.581
P2	0.662	0.671	0.670	0.672	0.672	0.679	0.691	0.671	0.676	0.671
P3	**0.719**	**0.715**	**0.714**	**0.716**	**0.704**	**0.725**	**0.733**	**0.714**	**0.721**	**0.715**
P4	0.698	0.696	0.698	0.696	0.688	0.703	0.705	0.696	0.701	0.696
P5	0.104	0.110	0.108	0.111	0.108	0.116	0.127	0.110	0.113	0.110
P6	0.129	0.134	0.134	0.135	0.129	0.142	0.152	0.134	0.139	0.134
P7	0.177	0.165	0.167	0.164	0.159	0.164	0.156	0.165	0.165	0.165
P8	0.142	0.135	0.136	0.135	0.131	0.137	0.137	0.135	0.137	0.135
P9	0.074	0.069	0.071	0.068	0.066	0.067	0.059	0.069	0.068	0.069
P10	0.215	0.206	0.207	0.206	0.198	0.212	0.213	0.205	0.210	0.205

Table 11. Aggregated intuitionistic fuzzy scores for alternatives (Magenta, M)

Alt.	**EB**	**EG**	**EH**	**EM**	**EP**	**ES**	**ET**	**EV**	**EW**	**EY**
P1	0.552	0.544	0.545	0.544	0.548	0.544	0.540	0.544	0.545	0.544
P2	0.588	0.577	0.579	0.576	0.582	0.570	0.563	0.577	0.572	0.577
P3	0.537	0.534	0.534	0.535	0.534	0.544	0.550	0.535	0.541	0.535
P4	**0.601**	**0.591**	**0.592**	**0.591**	**0.592**	**0.596**	**0.598**	**0.592**	**0.595**	**0.591**
P5	0.121	0.112	0.113	0.111	0.118	0.108	0.103	0.112	0.109	0.112
P6	0.135	0.132	0.132	0.131	0.132	0.130	0.128	0.131	0.130	0.131
P7	0.271	0.264	0.265	0.264	0.269	0.261	0.258	0.264	0.262	0.264
P8	0.184	0.196	0.195	0.198	0.185	0.200	0.206	0.196	0.198	0.197
P9	0.058	0.063	0.062	0.064	0.056	0.068	0.072	0.063	0.067	0.063
P10	0.134	0.134	0.134	0.134	0.131	0.133	0.132	0.134	0.133	0.134

Table 12. Aggregated intuitionistic fuzzy scores for alternatives (Yellow, Y)

Alt.	EB	EG	EH	EM	EP	ES	ET	EV	EW	EY
P1	0.501	0.489	0.491	0.488	0.505	0.491	0.478	0.490	0.493	0.489
P2	0.533	0.522	0.525	0.521	0.522	0.525	0.515	0.522	0.526	0.522
P3	**0.640**	**0.656**	**0.652**	**0.659**	**0.651**	**0.667**	**0.679**	**0.657**	**0.663**	**0.657**
P4	0.586	0.567	0.572	0.564	0.574	0.563	0.539	0.567	0.567	0.566
P5	0.220	0.207	0.209	0.205	0.212	0.198	0.195	0.206	0.200	0.206
P6	0.239	0.224	0.227	0.222	0.230	0.217	0.209	0.224	0.219	0.223
P7	0.207	0.205	0.206	0.205	0.205	0.215	0.208	0.205	0.213	0.205
P8	0.185	0.188	0.188	0.190	0.186	0.200	0.198	0.189	0.198	0.189
P9	0.092	0.094	0.095	0.094	0.090	0.104	0.098	0.094	0.102	0.094
P10	0.342	0.315	0.320	0.312	0.340	0.304	0.282	0.316	0.310	0.314

Table 13. Aggregated intuitionistic fuzzy scores for alternatives (Black, K)

Alt.	EB	EG	EH	EM	EP	ES	ET	EV	EW	EY
P1	0.362	0.360	0.359	0.362	0.359	0.358	0.371	0.360	0.357	0.361
P2	0.421	0.409	0.414	0.406	0.415	0.401	0.390	0.408	0.404	0.407
P3	**0.446**	**0.439**	**0.441**	**0.438**	**0.446**	**0.440**	**0.436**	**0.439**	**0.440**	**0.438**
P4	0.423	0.412	0.416	0.410	0.416	0.403	0.395	0.411	0.406	0.410
P5	0.276	0.276	0.276	0.275	0.271	0.280	0.281	0.275	0.279	0.275
P6	0.388	0.386	0.386	0.386	0.387	0.393	0.390	0.386	0.392	0.386
P7	0.257	0.259	0.258	0.260	0.254	0.259	0.264	0.259	0.258	0.259
P8	0.159	0.166	0.163	0.168	0.159	0.179	0.184	0.167	0.176	0.167
P9	0.138	0.144	0.142	0.145	0.135	0.151	0.155	0.145	0.149	0.145
P10	0.202	0.206	0.204	0.207	0.200	0.216	0.220	0.207	0.214	0.207

If the results obtained in Tables 10–13 are listed, the most suitable paper will be determined. The comments on the obtained result are as follows.

4 Comparative analysis

In previous studies [4, 15, 16, 22, 31] decisions regarding offset printing quality were made by examining paper quality and the criteria affecting offset printing separately. However, in the study conducted by [25], all factors were evaluated together using the Intuitionistic Fuzzy (IF) PROMETHEE Multi-Criteria Decision Making (MCDM) method, and the suitability level of the factors considered was determined. In this way, a single ranking result of the alternatives was obtained for each color. These results enabled both positive and negative rankings among the alternatives.

According to study [25], the following rankings for the alternatives were obtained using the IF PROMETHEE method:

Table 14. Ranking the alternatives using the IF PROMETHEE method

Cyan	P3	P4	P2	P1	P10	P5	P6	P8	P7	P9
Magenta	P3	P4	P2	P1	P7	P8	P5	P6	P10	P9
Yellow	P3	P4	P2	P1	P7	P8	P5	P6	P10	P9
Black	P3	P4	P2	P1	P7	P8	P5	P6	P10	P9

Considering all these findings, study [25] concluded that, the P3 and P4 alternatives exhibited the highest offset printing quality for cyan, magenta, yellow and black colors. Conversely, the P9 alternative showed the lowest performance across all colors.

Given that the concepts of IF theory and IF entropy balance the fuzziness in the data, the IFEB-TOPSIS MCDM method was employed in the present study to resolve the aforementioned problem. Based on the results obtained using ten different IF entropies (which are used to analyze the success of the ranking obtained by this method) as presented in Table 1, the success ranking of the alternatives in terms of offset printing quality according to the criteria is as follows:

Table 15. Ranking the alternatives using the IFEB-TOPSIS method.

Cyan	P3	P4	P2	P1	P10	P7	P8	P6	P5	P9
Magenta	P4	P2	P1	P3	P7	P8	P10	P6	P5	P9
Yellow	P3	P4	P2	P1	P10	P6	P5	P7	P8	P9
Black	P3	P4	P2	P6	P1	P5	P7	P10	P8	P9

In this study, the P4 and P2 alternatives are identified as the most successful for the magenta color, whereas the P3 and P4 alternatives are the most successful for the cyan, yellow and black colors. The P9 alternative is the least successful across all colors.

The ranking obtained in this study is considered more precise as IF entropy measures reduce the limitations associated with expertise and knowledge accumulation during the data acquisition process. Consequently, the success ranking for offset printing quality differs from that reported in study [25] for the magenta color. Similar discrepancies can also be observed among the other alternatives in the overall ranking.

5 Conclusions

This study proposes a comprehensive decision-making framework based on the Intuitionistic Fuzzy Entropy-Based TOPSIS (IFEB-TOPSIS) method to assess how offset printing quality varies across different paper types. By integrating multiple print-quality-related criteria—dot gain, print contrast, print density, chroma, and color gamut—the model evaluates paper performance for each of the four primary CMYK colors. Unlike traditional evaluation methods that examine criteria independently, the IFEB-TOPSIS approach simultaneously incorporates all criteria and the inherent uncertainty in measurement data through intuitionistic fuzzy entropy functions, thus offering a more robust and realistic evaluation tool.

The results obtained using ten different intuitionistic fuzzy entropy measures demonstrate that coated papers, particularly Matte Coated (P3) and Glossy Coated (P4), consistently achieve the highest quality across cyan, yellow, and black colors. For the magenta color, Glossy Coated (P4) and Bristol-type coated papers (P2) show superior performance. On the contrary, low-grade papers—especially P9—are found to be the least suitable for offset printing across all colors. Importantly, the rankings produced by the IFEB-TOPSIS method show certain variations from previous studies, particularly for the magenta color. These differences highlight the stronger discriminatory power of entropy-based fuzzy modeling in reducing expert-dependent biases and reflecting the true uncertainty structure of the data.

Overall, this study contributes to the literature by establishing a novel decision-making model capable of evaluating multiple print-quality criteria simultaneously through the integration of intuitionistic fuzzy entropy and TOPSIS. The findings provide practical guidance for printers, material designers, and paper manufacturers in selecting paper types that yield optimal print performance.

Future work may extend the proposed methodology to additional printing systems (e.g., flexographic, digital, electrophotographic), diverse ink–paper interactions, and wider ranges of coated and uncoated substrates. Moreover, incorporating hybrid fuzzy frameworks or deep learning-supported fuzzy decision systems could further enhance the reliability and applicability of print-quality assessment models.

References

[1] Atanassov, K. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20(1), 87–96.

[2] Benitez, J. M., Castro, J. L., & Requena, I. (1997). Are artificial neural networks black boxes. *IEEE Transactions on Neural Networks*, 8(5), 1156–1164.

[3] Burillo, P., & Bustince, H. (1996). Entropy on intuitionistic fuzzy sets and on interval-valued fuzzy sets. *Fuzzy Sets and Systems*, 78(3), 305–316.

[4] Elmas, G. M., Karabulut, B., & Sönmez, S. (2022). The effect of some office papers quality characteristics on offset printing process. *Nordic Pulp & Paper Research Journal*, 37(2), 270–281.

[5] Gohain, B., Chutia, R., & Dutta, P. (2022). Distance measure on intuitionistic fuzzy sets and its application in decision-making, pattern recognition and clustering problems. *International Journal of Intelligent Systems*, 37, 2458–2501.

[6] Gong, R., Fleming, P. D. III, & Sönmez, S. (2010). Application of nano pigments in inkjet paper coating. In: *NIP & Digital Fabrication Conference*, 26(1), 507–511.

[7] Hung, W. L., & Yang, M. S. (2006). Fuzzy entropy on intuitionistic fuzzy sets. *International Journal of Intelligent Systemts*, 21, 443–451.

[8] Jiang, Q., Jin, X., Lee, S.-J., & Yao, S. W. (2019). A new similarity/distance measure between intuitionistic fuzzy sets based on the transformed isosceles triangles and its applications to pattern recognition. *Expert Systems With Applications*, 116, 439–453.

[9] Joshi, R. (2020). A new multi-criteria decision making method based on intuitionistic fuzzy information and its application to fault detection in a machine, *Journal of Ambient Intelligence and Humanized Computing*, 11, 739–753.

[10] Joshi, R., & Kumar, S. (2018). A new parametric intuitionistic fuzzy entropy and its applications in multiple attribute decision making. *International Journal of Applied and Computational Mathematics*, 4, Article ID 52.

[11] Meng, L., Li, L., Xie, W., Li, Y., & Liu, Z. (2023). Time-sequential hesitant fuzzy entropy, cross entropy and correlation coefficient and their application to decision making, *Engineering Applications of Artificial Intelligence*, 123(C), Article ID 106455.

[12] Mishra, A. R., Jain, D., & Hooda, D. S. (2016). On logarithmic fuzzy measures of information and discrimination. *Journal of Information and Optimization Sciences*, 37(2), 213–231.

[13] Patel, A., Jana, S., & Mahanta, J. (2023). Intuitionistic fuzzy EM-SWARA-TOPSIS approach based on new distance measure to assess the medical waste treatment techniques. *Applied Soft Computing*, 144, Article ID 110521.

[14] Revkin, S. K., Piazza, M., Izard, V., Cohen, L., & Dehaene, S. (2008). Does subitizing reflect numerical estimation?. *Psychological Science*, 19(6), 607–614.

[15] Sönmez, S. (2011). Interactive effects of copolymers and nano-sized pigments on coated recycled paperboards in flexographic print applications. *Asian Journal Of Chemistry* 23(6), 2609–2613.

[16] Sönmez, S., Wu, Q., Gong, R., Fleming, P.D., & Pekarovicova, A. (2022). The recyclability and printability of electrophotographic printed paper. *Nordic Pulp & Paper Research Journal*, 27, 497–506.

[17] Szmidt, E., & Kacprzyk, J. (2001). Entropy for intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 118(3), 467–477.

[18] Szmidt, E., & Kacprzyk, J. (2004). Similarity measure for intuitionistic fuzzy sets and its application in supporting medical diagnostic reasoning. In: *Proceedings of the 7th International Conference "Artificial Intelligence and Soft Computing" (ICAISC'2004),*

Zakopane, Poland, 7–11 June 2004. *Lecture Notes in Computer Science*, Vol. 3070, Springer, pp. 388–393.

[19] Szmidt, E., & Kacprzyk, J. (2006). Distances between intuitionistic fuzzy sets: Straightforward approaches may not work. In: *Proceedings of the 3rd International IEEE Conference Intelligent Systems*, London, UK, 4–6 September 2006, pp. 716–721.

[20] Szmidt, E., Kacprzyk, J., & Bujnowski, P. (2004). Correlation between intuitionistic fuzzy sets: Some conceptual and numerical extensions. In: *Proceedings of the 2012 IEEE International Conference on Fuzzy Systems*, Brisbane, QLD, Australia, 10–15 June 2012, pp. 1–12.

[21] Szmidt, E., Kacprzyk, J., & Bujnowski, P. (2014). How to measure the amount of knowledge conveyed by Atanassov's intuitionistic fuzzy sets. *Information Sciences*, 257, 276–285.

[22] Şahin, C. (2012). *Evaluation of the Effect of the Efficiency of Operators on Print Quality in Offset Printing*. PhD Thesis, Gazi University, Ankara.

[23] Şahin, C., Özomay, Z., & Keskin, B. (2013). Evaluation of weighting pressure's effect on dot gain in newsprint paper. *Electronic Journal of Vocational Colleges*, 3(3), 121–128.

[24] Thao, N. X. (2021). Some new entropies and divergence measures of intuitionistic fuzzy sets based on Archimedean t-conorm and application in supplier selection. *Soft Computing*, 25, 5791–5805.

[25] Tuğrul, F. (2024). Evaluation of papers according to offset print quality: The intuitionistic fuzzy based multi criteria decision making mechanism. *Pigment & Resin Technology*, 53(1), 122–129.

[26] Verma, R., & Sharma, B. D. (2013). Exponential entropy on intuitionistic fuzzy sets. *Kybernetika*, 49(1), 114–127.

[27] Wang, J. Q., & Wang, P. (2012). Intuitionistic linguistic fuzzy multi-criteria decision-making method based on intuitionistic fuzzy entropy. *Control and Decision*, 27(11), 1694–1698.

[28] Wei, C. P., Gao, Z. H., & Guo, T. T. (2012). An intuitionistic fuzzy entropy measure based on trigonometric function. *Control and Decision*, 27(4), 571–574.

[29] Yang, G., Ren, M., & Hao, X. (2023). Multi-criteria decision-making problem based on the novel probabilistic hesitant fuzzy entropy and TODIM method. *Alexandria Engineering Journal*, 68, 437–451.

[30] Ye, J. (2010). Two effective measures of intuitionistic fuzzy entropy. *Computing*, 87, 55–62.

[31] Yılmaz, U. (2016). *Investigation of the Effect on Offset Print Quality of Physical Properties of Some Printing Papers*. MSc Thesis, Kahramanmaraş Sütçü İmam University, Kahramanmaraş.

[32] Yılmaz, U. (2022). Analysis of the color properties of papers subjected to different recycling numbers in electrophotographic (toner) printing. *Pigment & Resin Technology*, 52(2), 228–236.

[33] Yılmaz, U., Kıllı, U., Kurt, M. B., Tutuş, A., & Sönmez, S. (2022). Investigation of differently coated corrugated cardboard in terms Of electrophotographic print chroma and hue angle. *Turkish Journal of Forestry*, 23(1), 51–57.

[34] Yılmaz, U., Tutuş, A., & Sönmez, S. (2021). A research of comparing of the effects on the color properties of offset, laser and inkjet print systems on uncoated recycled papers. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 37(1), 130–136.

[35] Yılmaz, U., Tutuş, A., & Sönmez, S. (2021). Investigation of color values of inkjet and laserjet prints on recycled papers. *Journal of Graphic Engineering and Design*, 12(3), 5–12.

[36] Yılmaz, U., Tutuş, A., & Sönmez, S. (2021). Investigation of recycling repetition effect on deinkability efficiency and printing properties. *Journal of Adhesion Science and Technology*, 36(12), 1299–1313.

[37] Yılmaz, U., Tutuş, A., & Sönmez, S. (2022). Effects Of using recycled paper in inkjet printing system on colour difference. *Pigment & Resin Technology*, 51(3), 336–343.

[38] Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338—353.

[39] Zhang, H., & Yu, L. (2012). MADM method based on cross-entropy and extended TOPSIS with interval-valued intuitionistic fuzzy sets. *Knowledge-Based Systems*, 30, 115–120.

[40] Zhang, Z. (2013). Hesitant fuzzy power aggregation operators and their application to multiple attribute group decision making. *Information Science*, 234, 150–181.