Mugla Journal of Science and Technology

INVESTIGATION OF PAPERS ACCORDING TO OPTICAL AND PHYSICAL PROPERTIES USING MULTI-CRITERIA DECISION-MAKING METHOD

Ufuk YILMAZ, Forest Industry Engineering, Kahramanmaraş Sütçü İmam University, Kahramanmaraş, kufu27@hotmail.com
(https://orcid.org/ 0000-0001-8240-1294)

Received: 20.10.2022, Accepted: 14.12.2022 Research Article
*Corresponding author DOI: 10.22531/muglajsci.1192273

Abstract

In this study, using the multi-criteria decision-making mechanism PROMETHEE method, a decision-making mechanism is created for the most suitable paper selection according to some optical and physical properties of the papers. Within the scope of the study, 80 g/m² high grade papers obtained from 5 different companies are used. The optical and physical properties of these papers are measured in the laboratory environment and the most suitable paper is selected by using the multi-criteria decision-making method. By using this method, the situations where the decision makers are undecided in the selection of paper became meaningful. By using this method, the most suitable paper can be selected in cases where there is uncertainty in both the paper and printing sector, and this method can be used by all companies that appeal to this sector. This study, which may attract the attention of many companies for the paper industry, has the potential to shed light on the studies in the field of decision making.
Keywords: Multi criteria decision making, PROMETHEE method, paper, optical properties, physical properties

KAĞITLARIN ÇOK KRİTERLİ KARAR VERME YÖNTEMİ KULLANILARAK OPTİK VE FİZİKSEL ÖZELLİKLERİNE GÖRE İNCELENMESİ

Özet

Bu çalışmada çok kriterli karar verme mekanizması PROMETHEE yöntemi kullanılarak kağıtların bazı optik ve fiziksel özelliklerine göre en uygun kağıt seçimi için bir karar verme mekanizması oluşturulmuştur. Çalışma kapsamında 5 farklı firmadan temin edilen 80 g/m² I. Hamur kağıtlar kullanılmıştır. Bu kağıtların optik ve fiziksel özellikleri laboratuvar ortamında ölçülmüş ve çok kriterli karar verme yöntemi kullanılarak en uygun kağıt seçimi yapılmıştır. Bu yöntem kullanılarak kağıt seçiminde karar vericilerin kararsız kaldığı durumlar anlamlı hale gelmiştir. Bu yöntem kullanılarak hem kağıt hem matbaacılık sektöründe kararsız kalınan durumlarda en uygun kağıt seçimi yapılabilir ve bu sektöre hitap eden tüm şirketler tarafından bu yöntem kullanılabilir. Kağıt sektörü için bir çok şirketin ilgisini çekebilecek olan bu çalışma karar verme alanındaki çalışmalara ışık tutabilecek potansiyele sahiptir.
Anahtar Kelimeler: Çok kriterli karar verme, PROMETHEE yöntemi, kağıt, optik özellikler, fiziksel özellikler

Cite

Yılmaz, U., (2022). "Investigation of Papers According to Optical and Physical Properties Using Multi-Criteria Decision-Making Method", Mugla Journal of Science and Technology, 8(2), 77-81.

1. Introduction

Fuzzy logic was defined by Zadeh [1]. The purpose of multi-criteria decision making is to determine the optimum alternative based on certain criteria. [2-3]. Researchers investigate MCDM problems and fuzzy logic in detail [4-5-6-7-8-9-10]. The optical and physical properties of the papers are the factors that make the paper quality. These factors are the features that both paper manufacturers and paper users should know and pay attention to. Produced papers are constantly checked for ink-paper compatibility during production or printing. Paper selection in the printing industry is made according to physical properties such as weight, breaking length, burst index, tearing index, air permeability, as well as optical properties such as whiteness, brightness, yellowness and opacity. The quality of paper products is not only about their performance, but also about their visuality. Optical properties of paper such as brightness, whiteness, brightness and opacity affect visual perception and attractiveness. From a practical point of view, it is important to quantify these optical properties with repeatable and reliable measurement methods and to correlate these measured values with the properties of the paper's structure and components [11].

In this article, it is aimed to identify the optimum paper by using the intuitionistic fuzzy PROMETHEE according to the optical and physical properties of office papers obtained from 5 different companies.

2. Materials and Methods

Definition 1: (A3,6) Let $X \neq \emptyset$. An intuitionistic fuzzy set A in X;

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in X\}, \quad (1.1)$$

$$\mu_A(x), \nu_A(x), \pi_A(x): X \to [0,1] \quad (1.2)$$

Intuitionistic fuzzy value (IFV) described [12] as follows: $\tilde{a} = (\mu_{\tilde{a}}, \nu_{\tilde{a}}, \pi_{\tilde{a}})$ and where $\mu_{\tilde{a}}, \nu_{\tilde{a}}, \pi_{\tilde{a}} \in [0,1]$.

Definition 2: For IFVs $\tilde{a}$ and $\tilde{b}$ the following operations was described [12; 13]:

$$(1)\tilde{a} \oplus \tilde{b} = \left(\mu_{\tilde{a}} + \mu_{\tilde{b}} - \mu_{\tilde{a}}\mu_{\tilde{b}}, \nu_{\tilde{a}}\nu_{\tilde{b}}\right)$$

$$(2)\tilde{a} \otimes \tilde{b} = \left(\mu_{\tilde{a}}\mu_{\tilde{b}}, \nu_{\tilde{a}} + \nu_{\tilde{b}} - \nu_{\tilde{a}}\nu_{\tilde{b}}\right)$$

$$(3)\bigoplus_{j=1}^{m} \tilde{a}_j = \left(1 - \prod_{j=1}^{m}(1-\mu_j), \prod_{j=1}^{m}\nu_j\right)$$

$$(4)\bigotimes_{j=1}^{m} \tilde{a}_j = \left(\prod_{j=1}^{m}\mu_j, \prod_{j=1}^{m}(1-\nu_j)\right)$$

The following function was utilized to compare IFVs [14]: $\rho(\alpha) = 0.5(1+\pi_\alpha)(1-\mu_\alpha)$

The $\rho(\alpha)$ value decreases, value of preferred α increases.

Linguistic terms, one of the many methods used to determine criterion weights was utilized to express ideas of decision makers in this paper [15-16]. As indicated in the Table 1 below, the weights of the criteria will be determined by linguistic terms.

Table 1. Linguistic Terms for Rating Criterion

Linguistic Terms	IFNs
Very Important	(0.9,0.1)
Important	(0.75,0.2)
Medium	(0.5,0.45)
Unimportant	(0.35,0.6)
Very Unimportant	(0.1,0.9)

Gaussian criterion type was used in this paper.

Definition 3: [17] Gaussian criterion type;

$$P(d) = \begin{cases} 0, & d \leq 0 \\ 1 - e^{\frac{-x^2}{2\sigma^2}} & d \geq 0 \end{cases}$$

Evaluate the alternatives $x_i (i = 1,2,\dots,n)$ with respect to the criteria $c_j (j = 1,2,\dots,m)$ and determine the deviations based on pairwise comparisons:

$$d_j(x,y) = c_j(x) - c_j(y)$$

Definition 4: (12) An intuitionistic fuzzy preference relation R is represented by a matrix $R = (r_{ik})_{n\times n}$ where $r_{ik} = \langle (x_i,x_k), \mu(x_i,x_k), \nu(x_i,x_k)\rangle$ for all $i,k = 1,2,\dots,n$. For convenience, we let $r_{ik} = (\mu_{ik}, \nu_{ik})$ where μ_{ik} denotes the degree to which the object x_i is preferred to the object x_k, ν_{ik} indicates the degree to which the object x_i is not preferred to the object x_k.

$$\mu_{ik}, \nu_{ik} \in [0,1],\ \mu_{ik} + \nu_{ik} \leq 1,$$

$$\mu_{ik} = \nu_{ki},\ \mu_{ki} = \nu_{ik}$$

$$\pi_{ik} = 1 - \mu_{ik} - \nu_{ik},$$

for $\forall\, i,k = 1,2,\dots,n$.

The preference matrix looks like this [16]:

$$U^{(j)} = (\mu_{ik}^{(j)})_{n\times n} = \begin{bmatrix} - & \mu_{12}^{(j)} & \cdots & \mu_{1n}^{(j)} \\ \mu_{21}^{(j)} & - & \cdots & \mu_{2n}^{(j)} \\ \vdots & \vdots & - & \vdots \\ \mu_{n1}^{(j)} & \mu_{n2}^{(j)} & \cdots & - \end{bmatrix}$$

The intuitionistic fuzzy preference relation matrix looks like this:

$$R^{(j)} = (r_{ik}^{(j)})_{n\times n} = \begin{bmatrix} - & (\mu_{12}^{(j)}, \nu_{12}^{(j)}) & \cdots & (\mu_{1n}^{(j)}, \nu_{1n}^{(j)}) \\ (\mu_{21}^{(j)}, \nu_{21}^{(j)}) & - & \cdots & (\mu_{2n}^{(j)}, \nu_{2n}^{(j)}) \\ \vdots & \vdots & - & \vdots \\ (\mu_{n1}^{(j)}, \nu_{n1}^{(j)}) & (\mu_{n2}^{(j)}, \nu_{n2}^{(j)}) & \cdots & - \end{bmatrix}$$

IFWA operator was used in this paper [12-13]. The all intuitionistic fuzzy preference index of the alternative x_i to x_k on all criteria can be derived as:

$$r(x_i, x_k) = r_{ik} = \bigoplus_{j=1}^{m}\left(\tilde{w}_j \otimes r_{ik}^{(j)}\right)$$

where $r(x_i,x_k) = r_{ik}$ shows the degree to which the alternative x_i is preferred to the alternative x_k all criteria.

$$\tilde{w}_j \otimes r_{ik}^{(j)} = \left(\mu_{ik}^{(j)}\mu_{\tilde{w}j}, \nu_{ik}^{(j)} + \nu_{\tilde{w}j} - \nu_{ik}^{(j)}\nu_{\tilde{w}j}\right)$$

Overall intuitionistic fuzzy preference relationship looks like this:

$$R = (r_{ik})_{n\times n} = \begin{bmatrix} - & (\mu_{12}, \nu_{12}) & \cdots & (\mu_{1n}, \nu_{1n}) \\ (\mu_{21}, \nu_{21}) & - & \cdots & (\mu_{2n}, \nu_{2n}) \\ \vdots & \vdots & - & \vdots \\ (\mu_{n1}, \nu_{n1}) & (\mu_{n2}, \nu_{n2}) & \cdots & - \end{bmatrix}$$

Two different rankings are obtained among the alternatives:

(1) The intuitionistic fuzzy positive outranking flow:

$$\tilde{\varphi}^{+}(x_i) = \frac{1}{n-1}\bigoplus_{k=1,k\neq i}^{n} r(x_i,x_k) = \frac{1}{n-1}\bigoplus_{k=1,k\neq i}^{n} r_{ik}$$

(2) The intuitionistic fuzzy negative outranking flow:

$$\tilde{\varphi}^{-}(x_i) = \frac{1}{n-1}\bigoplus_{k=1,k\neq i}^{n} r(x_k,x_i) = \frac{1}{n-1}\bigoplus_{k=1,k\neq i}^{n} r_{ki}$$

As a result, the net ranking is obtained by the following formula:

$$\rho(\varphi(x_i)) = \rho(\tilde{\varphi}^{+}(x_i)) - \rho(\tilde{\varphi}^{-}(x_i))$$

3. Evaluation of Paper By Decision Making Mechanism

In this study, the physical and optical properties of papers are investigated by using the intuitionistic fuzzy-based PROMETHEE method. Thanks to intuitionistic fuzzy sets, it is easier for the decision maker to express his ideas. Data are obtained by performing optical and physical tests on papers. Afterwards, these data are evaluated in the decision-making mechanism thanks to the intuitionistic fuzzy values. A total of 5 papers are examined. In this study, there are 2 main criteria, a total of 8 sub-criteria. The papers in the study are evaluated on 8 criteria. The set of alternatives is $\{S_1, S_2, S_3, S_4, S_5\}$ and the set fo criteria is $\{P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8\}$. The criteria are stated below.

3.1. Optical properties

As stated earlier, the noticed value of paper materials adhere to their appearance. Properties such as gloss, whiteness, brightness and opacity are often used to measure the visual quality of paper. Below are some basic parameters of the optical properties of the papers mentioned above.

3.1.1. P_1 – Whiteness

According to Ganz, whiteness; "It is a property of colors with high light reflection and low purity located in a relatively narrow region of the color space along the dominant wavelengths of about 470 nm and 570 nm" [18]. Whiteness is a colorimetric parameter that can vary depending on lighting conditions. The whiteness of papers is controlled by bleaching cellulose fibers, coating and adding filler-optical bleaching materials.

3.1.2. P_2 – Brightness

Luminance is defined as the reflection of blue light with a spectral distribution that peaks at 457 nm compared to a perfectly reflective, perfectly diffusing surface. There are two common methods of brightness measurement. As first seen in Figure 1, this process can be done with a 45 ºC angle and fixed illuminator in accordance with the TAPPI Method T 452 standard. TAPPI Method T 452 [19].

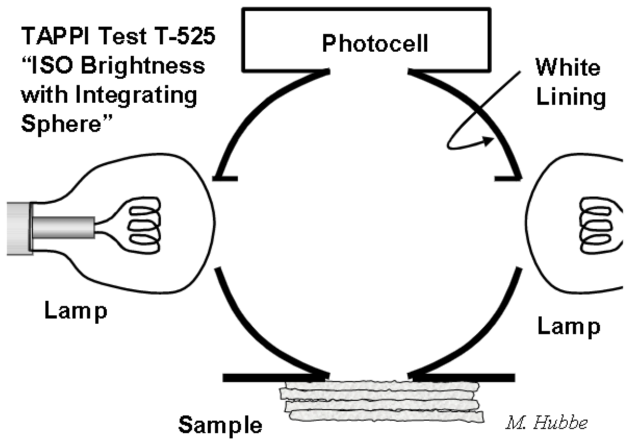

Figure 1. Basic configuration of paper brightness according to TAPPI Method T 452

Alternatively, gloss can be evaluated by the diffused illumination principle, which perceive light that is normally reflected on the material surface, as demonstrated in Standard ISO 2470 and T 571 [19].

3.1.3. P_3 – Yellowness

Yellowness (ASTM E313) is a number obtained from spectrophotometric data that calculates the color change of a paper sample from clear or yellow to white. The most common reason for measuring this value is to be able to detect color changes caused by an actual external exposure to or modified from a material. Papers made from wood pulp contain lignin. Lignin can be defined as the substance that gives hardness to wood. This substance oxidizes with air and turns brown-yellow. For example, the paper known as newsprint contains a lot of lignin and tends to turn yellow quickly.

3.1.4. P_4 – CIE whiteness

The CIE whiteness value may be 100 for the most accurate measurement, but with the addition of optical whitening agents (OBA) added to increase the reflectivity into the paper, ultraviolet rays return to the visible spectrum and the value range can vary between 100 and 170 [20].

3.1.5. P_5 –Opacity

We can treat opacity as a simple measure of paper's covering ability. The transparency (permeability) of the paper is quantified using reflection measurement methods, although it is related to its quality. Two of the most common of these measurement methods are TAPPI 425 and ISO 2471.

3.2. Physical properties of paper

3.2.1. P_6 –Burst index

Strength of paper materials tells about the property of the material to bear the stress when an external pressure is applied to it [21]. Burst strength is related to tensile strength and fiber orientation. It is a test of the ability of the paper to resist bursting when placed under the pressure of a diaphragm. In the Mullen test, the specimen paper is clamped with a ring over a collapsed diaphragm, which is then filled with oil, until the paper burst. The measurement is related as the pressure applied to the diaphragm at the moment of bursting [22]. The higher the burst index of the paper, the higher the possibility of using the paper for packaging. For many industries, burst index is a sought-after value in papers.

3.2.2. P_7 – Breaking length

Breaking length is the strength of the sample paper against breaking when a load extending parallel to the paper is applied. A piece of paper cut into strips is placed in a device with a test gripper, with one movable edge and one fixed. The paper resists breaking as the movable gripper starts to move. This is called the breaking length. It varies from 500m to 14000m depending on the type of paper.

3.2.3. P_8 – Tear index

Tear resistance paper can be defined as the average force required to continue tearing in the first cut. The tear index is obtained by dividing the tear strength by the weight.

The optical and physical properties obtained for each paper as a result of the tests performed on the papers are given in Table 2.

In this study, all papers are evaluated according to each criterion using the Gaussian criterion type. All steps are calculated one by one using the intuitionistic fuzzy PROMETHEE method and according to the results obtained, the positive, negative and net flow values of the alternatives are given in Table 4 and shown in Figure 2.

According to the net outranking values below, the optimum paper is C_4 sample. When evaluated according to all the characteristics of the papers, the optimum paper order is as follows: C_4, C_5, C_3, C_2, C_1.

Table 2. Findings of optical and physical properties obtained for each paper

Item	C_1	C_2	C_3	C_4	C_5
Whiteness (P_1)	77.41	81.37	80.20	85.12	81.8
Brightness (P_2)	98.36	102.93	101.91	104.87	100.55
Yellowness (P_3)	-31.34	-31.87	-33.13	-27.28	-28.23
CIE whiteness (P_4)	153.04	154.74	155.94	150.33	147.7
Opacity (P_5)	94.88	97.70	97.42	97.75	97.30
Tear index (P_6)	0.34	0.29	0.29	0.69	0.49
Burst index (P_7)	1.84	1.70	1.98	2.36	1.84
Breaking length (P_8)	2490	1652	1637	2184	2580

The importance levels of the criteria for the alternatives whose data are specified above are determined by the decision maker in Table 3.

Table 3. Weights of Criteria

Weights	Importance
w_1	*VI*
w_2	*VI*
w_3	*I*
w_4	*M*
w_5	*I*
w_6	*M*
w_7	*M*
w_8	*M*

Table 4. Positive, negative and net flow values of alternatives

Alternative	Positive Value	Negative Value	Net value
C_1	0,683	0,656	0,026
C_2	0,659	0,657	0,002
C_3	0,658	0,657	0,001
C_4	0,656	0,833	-0,177
C_5	0,657	0,657	-0,001

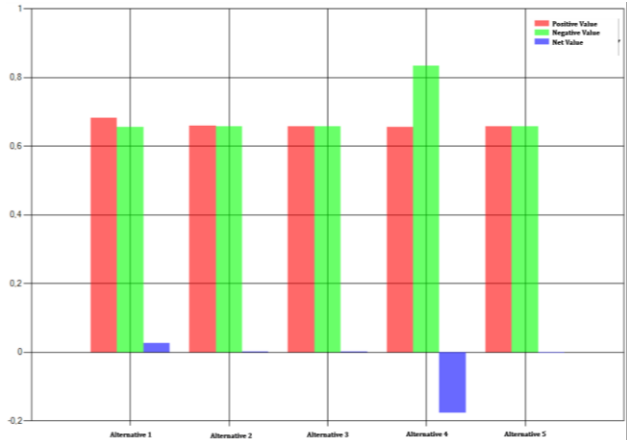

Figure 2. Graphical representation of positive, negative and net outranking values

4. Conclusion

In this study, 80 g/m^2 papers obtained from 5 different companies are examined according to both their physical and optical properties. First of all, these papers are subjected to optical and physical properties in the laboratory environment. With the obtained data, a multi-criteria decision-making mechanism is created thanks to the intuitionistic fuzzy PROMETHEE method. Thanks to the intuitionistic fuzzy values, the membership, non-membership and sensitivity degrees of the data have gained meaning. The optimum paper is determined by examining the positive, negative and net outranking flow calculations obtained according to all criteria. According to the evaluation results of the obtained data, as a result of the evaluations made by considering all optical and physical properties, it is determined that the most optimum paper is the C_4 sample. Among the remaining papers, the order from best to worst is determined as C_5, C_3, C_2, C_1. When we look at the results of the study in general, if it is necessary to make a choice without using the intuitionistic fuzzy PROMETHEE method, this choice would be a very difficult choice as well as a wrong choice. Because in general, if a selection is to be made only according to the obtained optical and physical values, it could be expected that the second optimum paper would be C_2 and the third most optimum paper would be C_3.

Any of the other multi-criteria decision-making methods can be used instead of the intuitionistic fuzzy PROMETHEE method used in this study. The purpose of using the intuitionistic fuzzy PROMETHEE method; assigning a specific weight to each of the criteria, choosing the appropriate one from different defined criteria types, changing it for each criterion, and observing both positive and negative values at the same time, enabling us to obtain net values. Different criteria types can be used instead of the Gaussian criteria type used in the study. By expanding the data of the study, different papers can be examined with multi-criteria decision-making methods. In addition to the physical and optical properties of the papers, a different study can be obtained by examining the chemical properties.

5. Acknowledgment

I would like to thank Dr. Feride TUGRUL for her assistance in mathematical calculations.

6. References

[1] Zadeh, L.A. “Fuzzy Sets”, *Information and Control*, Vol.8, pp.338-353, 1965.

[2] Tuğrul, F. "Evaluation of papers according to offset print quality: the intuitionistic fuzzy based multi criteria decision making mechanism", *Pigment & Resin Technology*, Vol. ahead-of-print No. ahead-of-print, https://doi.org/10.1108/PRT-04-2022-0059, 2022.

[3] Majumder, M. “Multi Criteria Decision Making”, *Chapter 2,* Springer, pp.35-47, 2015.

[4] Tuğrul, F., Çitil, M. and Karasolak, B., Dağlı, M. “Interpretation of Physical Conditions of Schools with Fuzzy Multi Criteria Decision Making”, *Journal of Universal Mathematics*, 3(1), 46-52, 2020.

[5] Tuğrul, F., Yılmaz, B. and Çitil, M. “Application of Ranking with Similarity Measure in Multi Criteria Decision Making”, *Konuralp Journal of Mathematics*, 7(2), 438-441, 2019a.

[6] Tuğrul, F., Çitil, M. and Balcı, S. “On The Determination Students' Aptitude Using Intuitionistic Fuzzy Logic”, *Journal of Universal Mathematics*, 2(1), 36-41, 2019b.

[7] Tuğrul, F., Yılmaz, B. and Çitil, M. “School Success Ranking in Multi Criteria Decision Making”, *Turkish Journal Mathematics and Computer Science,* 10, 1-6, 2018.

[8] Tuğrul, F., Çitil, M. and Gezercan, M. “Application of Intuitionistic Fuzzy Sets in High School Determination Via Normalized Euclidean Distance Metod”, *Notes on Intuitionistic Fuzzy Sets,* 23(1), 42-47, 2017.

[9] Tuğrul, F., and Çitil, M. “A New Perspective On Evaluation System in Education With Intuitionıstıc Fuzzy Logic and Promethee Algorithm”, *Journal of Universal Mathematics,* Vol.4 No.1 pp.13-24, DOI: 10.33773/jum.796173, 2021.

[10] Tuğrul, F. “Personnel Selection Utilizing the Decision-Making Mechanism Created with The Intuitionistic Fuzzy TOPSIS Method”, *Mugla Journal of Science and Technology,* 8(2), 16-21, 2022.

[11] Farnood, R. "Optical properties of paper: theory and practice", *In Advances in Pulp and Paper Research,* Trans. of the XIVth Fund. Res. Symp. (S.J. I’Anson, ed.), pp 273–352, FRC, Manchester, DOI: 10.15376/frc.2009.1.273 2018.

[12] Xu, Z.S. “Intuitionistic fuzzy aggregation operators”, *IEEE Transactions on Fuzzy Systems*, Vol.15, pp. 1179-1187, 2007.

[13] Xu, Z.S. and Yager, R.R. “Some geometric aggregation operators based on intuitionistic fuzzy set”, *International Journal of General Systems,* Vol. 35, pp.417-433, 2006.

[14] Szmidt, E. and Kacprzyk, J. “Amount of information and its reliability in the ranking of Atanassov’s intuitionistic fuzzy alternatives”, in: E. Rakus-Andersson, R.R. Yager, N. Ichalkaranje, L. Jain, ed. *Recent advances in decision making (Studies in Computational Intelligence)*, Berlin, Germany:Springer, pp. 7-19, 2009.

[15] Çuvalcıoğlu, G. “Some Properties of Controlled Set Theory”, *Notes on Intuitionistic Fuzzy Set*, Vol.20, No.2, pp.37-42, 2014.

[16] Liao, H. and Xu, Z.S. “Multi-criteria decision making with intuitionistic fuzzy PROMETHEE”, *Journal of Intelligent Fuzzy Systems,* Vol.27, pp.1703-1717, 2014.

[17] Brans, J.P. and Vincke, P. “A Preference Ranking Organisation Method (The PROMETHEE Method for Multiple Criteria Decision Making)”, *Management Science,* Vol.31 No.6, pp.647-656, 1985.

[18] Ganz, E. “Whiteness: Photometric Specification and Colorimetric Evaluation”, *Appl. Opt.* 15(9):2039–2058, 1976.

[19] Hubbe, M. A., Pavlak J. J. and Koukoulas A. A. “Paper’s appearance: A review,” *BioResources* 3(2), 627-665, DOI: 10.15376/biores.3.2.627-665, 2008.

[20] https://www.bosslimited.co.uk/a-stationers-guide-topaper/#:~:text=For%20a%20perfect%20reflecting%2C%20non,(mainly%20ultra%2Dviolet)%20back (Date of access: 10.10.2022)

[21] https://www.prestogroup.com/blog/formula-to-calculate-bursting-factor-and-index/ (Date of access: 10.10.2022)

[22] http://www.surrencystudios.com/Paper%20Characteristics.htm (Date of access: 10.10.2022)