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Application of a Performance Evaluation Model to the Paper and Paper Products Printing Sector: The DEA-AHP Hybrid Algorithm

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ABSTRACT

The paper and paper products printing sector plays a crucial role in generating income, creating employment opportunities, and supporting exports and various industries. Measuring the efficiency of companies operating in this sector is important in identifying areas for improvement and enhancing overall performance. In this study, a two-stage DEA (data envelopment analysis)-AHP (analytic hierarchy process) approach is proposed to analyze the efficiency of twelve paper and paper products printing companies traded on Borsa Istanbul. The modified DEA method is employed to make pairwise comparisons of the companies. Total assets, total equity, and the number of employees are selected as inputs, while revenue and net profit are considered as outputs. The AHP method prioritizes the companies by considering the outputs of the mathematical models constructed via DEA. The proposed framework presents a different view because it contributes to identifying the most efficient company, benchmarking company performance, and determining areas for improvement.

Anahtar Kelimeler: Analytic Hierarchy Process, Data Envelopment Analysis, Efficiency Measurement, Forest Products Industry

JEL Classification: C61, L73

Bir Performans Değerlendirme Modelinin Kâğıt ve Kâğıt Ürünleri Basım Sektörüne Uygulanması: VZA-AHP Hibrit Algoritması

ÖZ

Kâğıt ve kâğıt ürünleri basım sektörü, gelir elde etmede, istihdam oluşturmada ve ihracatın ve çeşitli endüstrilerin desteklenmesinde önemli bir rol oynamaktadır. Bu sektörde faaliyet gösteren şirketlerin etkinliğinin ölçülmesi iyileştirme için alanların belirlenmesinde ve genel performansın artırılmasında önemlidir. Bu çalışmada, Borsa İstanbul'da işlem gören on iki kâğıt ve kâğıt ürünleri basım şirketinin etkinliğini analiz etmek için iki aşamalı bir VZA (veri zarflama analizi)-AHP (analitik hiyerarşi prosesi) yaklaşımı önerilmektedir. Şirketlerin ikili karşılaştırmasını yapmak için modifiye VZA yöntemi kullanılmıştır. Girdi olarak toplam varlıklar, toplam özkaynaklar ve personel sayısı, çıktı olarak ise hasılat ve net dönem kârı seçilmiştir. AHP yöntemi, VZA aracılığıyla oluşturulan matematiksel modellerin çıktılarını dikkate alarak şirketleri önceliklendirmektedir. Önerilen çerçeve en etkin şirketin belirlenmesine, şirket performansının karşılaştırılmasına ve iyileştirilecek alanların belirlenmesine katkıda bulunarak farklı bir bakış açısı sunmaktadır.

Anahtar Kelimeler: Analitik Hiyerarşi Prosesi, Veri Zarflama Analizi, Etkinlik Ölçümü, Orman Ürünleri Endüstrisi

JEL Sınıflandırması: C61, L73

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1. INTRODUCTION

The forest products industry sector processes primary and secondary products obtained from forests into semi-finished or final products. One industry type that directly uses wood as a raw material within the primary manufacturing industry group of this sector is the paper and paper products industry sector. This sector is crucial for the Turkish economy owing to its relationship with other sectors, its contribution to employment, and its impact on exports. According to a report published by the Istanbul Chamber of Industry on the paper and paper products manufacturing industry, the sector has experienced significant growth. The report reveals that the export value experienced a significant increase from $1.22 billion in 2010 to $1.98 billion in 2017. Similarly, the import value rose from $2.82 billion in 2010 to $2.91 billion in 2017. The report also highlights that the sector plays a crucial role in establishing macroeconomic stability by employing approximately 70,000 people (Demirtaş & Orçun, 2022).

The increasing competition and the race to have the largest share of global markets have imposed the necessity for companies to renew themselves, effectively utilize their resources, and produce high-quality products. While companies strive to elevate their performance in this competitive race, they must also adapt to changing trends and maintain their effectiveness even during market fluctuations (Akyüz et al., 2015). The efficient utilization of production resources is important to remain competitive, retain current market share, and succeed in new markets. Performance evaluation enables companies to assess the effectiveness of their resource utilization and determine the extent to which they are accomplishing their objectives. Throughout the performance evaluation process, decision-makers generally measure and interpret the efficiency of companies. Efficiency measurements help to identify inefficiencies, optimize resources, increase competitiveness, improve customer satisfaction, and monitor progress (Gunasekaran et al., 2005). Companies that measure their efficiency regularly and take corrective actions can improve their operations and achieve their goals more effectively. To identify effective strategies for improving efficiency, it is essential to assess the current situation of each company and rank decision-making units from best to worst. This can be accomplished through the utilization of a decision support tool (Fukuyama et al., 2023).

Various problems related to performance evaluation in the paper and paper-related industries have been addressed in the literature. Hailu (2003) examined the pollution abatement and productivity performance of the Canadian pulp and paper industry using distance functions. Hseu and Shang (2005) focused on the productivity change of the pulp and paper industry in OECD countries through a non-parametric Malmquist approach. Khanduja et al. (2009) utilized the genetic algorithm to analyze the performance of the screening unit of a paper plant. Ray (2011) emphasized that companies should aim to increase their assets and reduce their liabilities to strengthen their financial status. İslamoğlu and Çelik (2015) pointed out that the capital-to-asset ratio and net profit margin strongly and positively influence performance indicators. Yu et al. (2016) evaluated the eco-efficiency of the Chinese pulp and paper industry through data envelopment analysis (DEA) models. Toppinen et al. (2017) conducted a Delphi study to examine the current situation of the European pulp and paper industry in terms of its potential for future value creation. Hussain and Bernard (2017) analyzed whether there was productivity convergence among eight regional pulp and paper industries in the United States and Canada. Üçüncü et al. (2018) evaluated the financial performance of seven Turkish paper companies via the TOPSIS method. Tsai and Lai (2018) proposed a mathematical programming model that integrates the theory of constraints, activity-based costing methods, and green manufacturing technologies to enhance the competitiveness of the paper industry. Senthilkannan and Parameshwaran (2019) prioritized various product defects in the paper industry and suggested appropriate lean tools for process improvement. Haider et al. (2019) assessed the energy efficiency of the Indian paper industry through radial and non-radial variants of the DEA. Mourtzis et al. (2019) developed an augmented reality-based application to evaluate the performance of potential warehouse layouts in the papermaking industry. Singh et al. (2020) determined suitable fibrous raw materials via different TOPSIS approaches. Shahi and Dia (2020) utilized the bootstrap DEA method for the performance evaluation of pulp and paper mills in Ontario.

There are several parametric and non-parametric methods available for efficiency measurements. Non-parametric methods do not require making assumptions about the behavior or structure of decision-making units. Hence, these methods offer more flexibility and are better suited for production environments with multiple inputs and outputs (W. Yang & Li, 2018). The DEA method is the most commonly used non-parametric efficiency measurement tool. It is rooted in the research studies conducted by Debreu (1951) and Farrell (1957). The method was consolidated by Charnes et al. (1978). The DEA method allows for the simultaneous evaluation of multiple inputs and outputs without the need for an analytical functional structure. This modeling capability is one of the most important features of the method. In the DEA method, there is no requirement for inputs and outputs to be expressed in the same unit. Through DEA analysis, efficient and inefficient decision-making units are distinguished, and reference points are established for inefficient units. DEA outputs provide a roadmap to decision-makers for achieving efficient production and developing forward-looking strategic policies (Zemtsov & Kotsemir, 2019).

DEA models attribute a value of 1 to efficient decision-making units. Hence, efficient units are not prioritized over one another. This disadvantage of the DEA method can be overcome by employing multicriteria decision-making methods. The analytic hierarchy process (AHP) is one such method that can be utilized for this purpose (Rouyendegh et al., 2019). The AHP method was created by Saaty (1980). In this method, criteria and alternatives are evaluated based on the experiences, thoughts, and intuitions of decision-makers. The AHP employs a hierarchical structure to organize decision problems and determine the most suitable solution through pairwise comparisons. This hierarchical approach simplifies complex decision-making situations and aids in their resolution. Both qualitative and quantitative factors can be considered in decision-making. These features and benefits of the AHP position it favorably compared to many other multicriteria decision-making methods (Singer & Özşahin, 2023).

To observe deviations between a company's plans and goals and assess its position compared to competing companies, performance evaluations should be made at the end of a specific period of activity. Conducting such evaluations provides information about the financial status of companies and serves as a guiding tool for future strategic decisions. Determining priority coefficients for decision-making units and understanding their positions are crucial for making accurate decisions. In this study, an integrated DEA and AHP methodology is suggested to evaluate the efficiency of twelve companies operating in the paper and paper products printing sector in Borsa Istanbul. The DEA method is modified to obtain a precise efficiency ranking index for each company. The pairwise comparisons of the companies are performed using the modified DEA method. The resulting matrix is analyzed according to the calculation procedure of the AHP method to obtain a ranking order. To the best of the author's knowledge, this study is the first endeavor that calculates precise efficiency ranking indexes for paper and paper products printing companies via the DEA and AHP methods.

2. MATERIALS AND METHODS

2.1. Data Envelopment Analysis

The DEA is a non-parametric decision support tool used to estimate the relative efficiency of a series of decision-making units. This method examines complex and/or unknown relationships between inputs and outputs based on the principles of linear programming. It performs performance evaluations by measuring the distance of each decision-making unit from an efficiency frontier. The fundamental principle in the DEA is that all decision-making units have similar objectives and produce identical outputs using identical inputs. The DEA method consists of four main stages: first, collecting data for inputs and outputs, which are used to evaluate decision-making units; second, formulating a DEA model for data analysis; third, measuring the efficiency of decision-making units; fourth, interpreting model results to reach a final decision (Rostamzadeh et al., 2021). DEA-based procedures can be summarized as shown in Figure 1. Table 1 presents some remarkable studies that have utilized the DEA method.

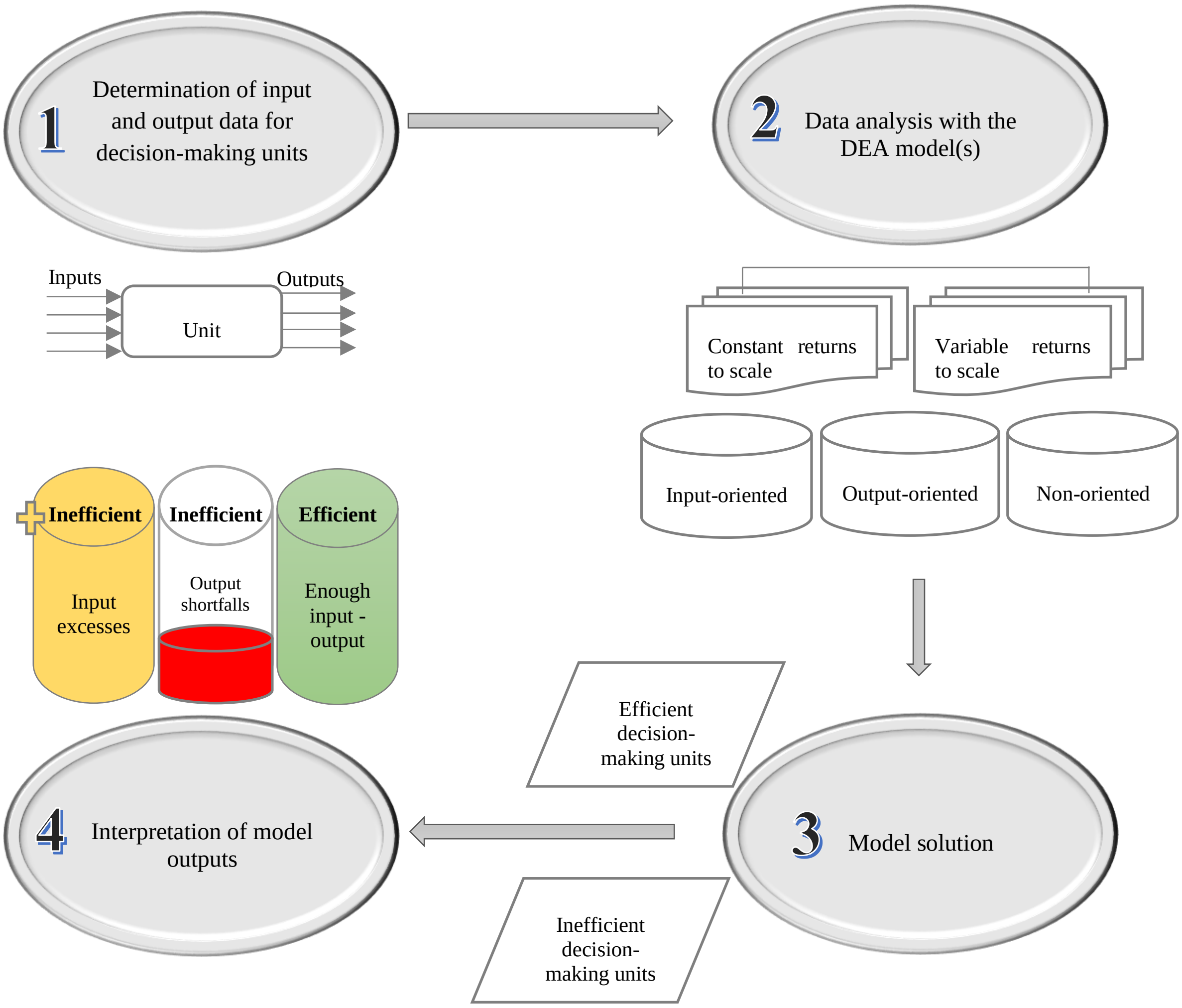


Figure 1: A Summary of DEA-Based Procedures

Table 1: Remarkable Studies Utilizing the DEA Method

Author(s)	Subject	Author(s)	Subject
Chen (2002)	Bank efficiency measurement	Soltani et al. (2021)	Water quality assessment
Sueyoshi & Goto (2009)	Bankruptcy assessment	Sueyoshi et al. (2021)	Environment-health measurement
Moreno and Lozano (2014)	Team performance assessment	Şensöğüt et al. (2021)	Occupational accident analysis
Akyüz et al. (2015)	Efficiency measurement in the furniture and panel sector	Amin et al. (2022)	Audit risk evaluation
Li et al. (2018)	Regional sustainable development	Hamdi et al. (2022)	Portfolio selection
Yang & Li (2018)	Industrial waste gas control	Liu et al. (2022)	Information technology and performance
Rouyendegh et al. (2019)	Hospital efficiency measurement	Nguyen et al. (2022)	Evaluation of maritime transportation systems
Zemtsov & Kotsemir (2019)	Regional innovation system assessment	Qi et al. (2022)	Construction safety performance evaluation
Fancello et al. (2020)	Road safety assessment	Yen & Li (2022)	Air route evaluation
Goswami & Ghadge (2020)	Supplier selection	Wu & Lin (2022)	Comparison of tourist destinations
Lee et al. (2020)	ERP system evaluation	Wang et al. (2022)	Solar plant site selection
Ersoy (2021)	Comparison of distance education departments	Alam et al. (2023)	Benchmarking of academic departments
Jomthanachai et al. (2021)	Risk management	Fukuyama et al. (2023)	Estimation of input market power

The DEA is generally divided into two main groups: constant returns to scale and variable returns to scale, depending on the scale, and into three subgroups: input-oriented, output-oriented, and non-oriented. Input-oriented models investigate the most appropriate input combination to produce a certain output composition in the most efficient way, while output-oriented models focus on obtaining the most appropriate output with a certain input combination. The classical DEA model can be formulated as follows (Fancello et al., 2020):

$$Max.Z_{pq} = \frac{\sum_{r=1}^{t} u_{rp} y_{rq}}{\sum_{i=1}^{m} v_{ip} x_{iq}} \quad (1)$$

subject to:

$$q = 1,2,\ldots,n \quad (2)$$

$$0 \leq \frac{\sum_{r=1}^{t} u_{rp} y_{rq}}{\sum_{i=1}^{m} v_{ip} x_{iq}} \leq 1 \quad q = 1,\ldots,n \quad (3)$$

$$u_{rp} \geq \in r = 1,\ldots,t \quad (4)$$

$$v_{ip} \geq \in i = 1,\ldots,m \quad (5)$$

where

n	number of units being evaluated;
t	number of outputs;
m	number of inputs;
u_{rp}	weight attached to output r for unit p;
v_{ip}	weight attached to input i for unit p;
y_{rp}	value of output r for unit p;
x_{ip}	value of input i for unit p;
z_{pq}	relative efficiency of unit q when evaluated using the weights associated with unit p;
$\in$	infinitesimal constant.

Equation (1) aims to maximize the efficiency of unit p. Equation (2) defines the efficiency of units q with respect to the weights chosen for p. Equation (3) restricts efficiency scores to lie between 0 and 1. Lastly, Equations (4) and (5) are non-negativity restrictions on outputs and inputs, respectively (Fancello et al., 2020).

The performance of decision-making units is determined by encoding and executing DEA models in a program. The DEA method indicates the efficiency of decision-making units via values in the range of [0-1]. Decision-making units with efficiency scores below 1 are labeled as inefficient. At the end of the DEA process, potential improvement actions are determined (Li et al., 2018).

2.2. Analytic Hierarchy Process

The AHP is used to effectively handle complex decision-making situations. It involves calculating weight values for evaluation criteria and determining the priority ranking of alternatives based on these criteria. The first step of the AHP method is problem structuring. After constructing a hierarchical structure for decision elements, decision-makers make pairwise comparisons to obtain priority vectors. In the final step, prioritization processes are utilized to arrive at a conclusive decision (Figure 2) (Soba & Altıntaş, 2019). AHP modeling can be effectively used to address various decision problems. Table 2 presents some notable studies that have utilized the AHP method.

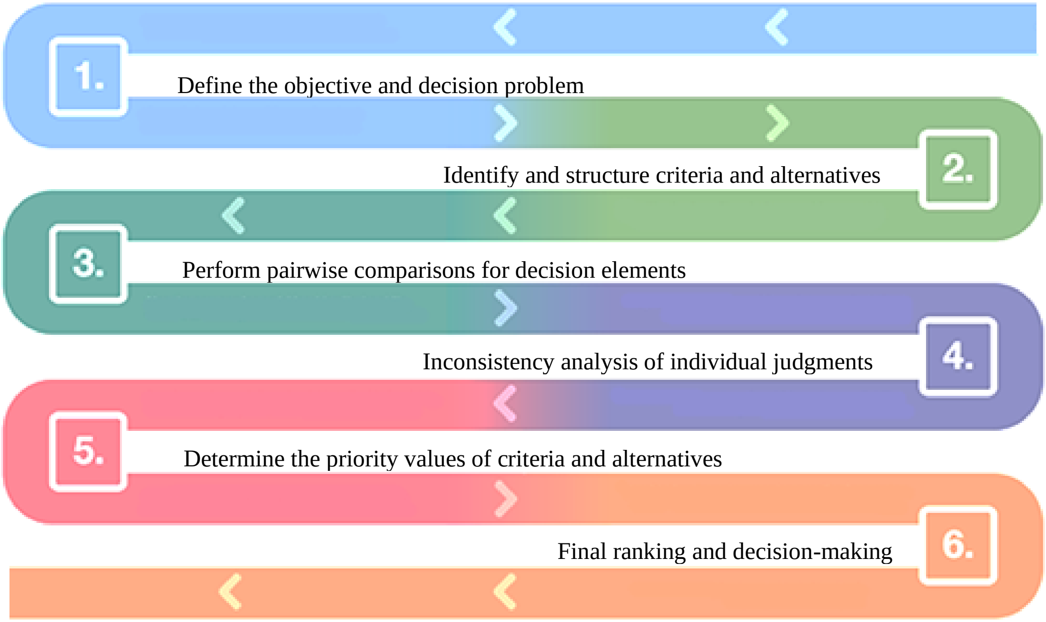


Figure 2: A Summary of AHP-Based Procedures

Table 2: Remarkable Studies Utilizing the AHP Method

Author(s)	**Subject**	**Author(s)**	**Subject**
Bhattacharya et al. (2005)	Industrial robot selection	Sulthonuddin & Herdiansyah (2021)	Industrial wastewater management
Yang et al. (2009)	Manufacturing evaluation system	Unver & Ergenc (2021)	Prioritization of forest logging activities
Kengpol et al. (2012)	Multimodal transportation routing	Zhang et al. (2021)	Performance evaluation of wave energy converters
Durão et al. (2018)	Internet of Things process selection	Ahmadi et al. (2022)	Virtual machine selection
Myeong et al. (2018)	Smart city development	Awad & Jung (2022)	Sustainable urban regeneration
Singer & Özşahin (2018)	Surface roughness evaluation	Bhaskar & Khan (2022)	Dental material selection
Özşahin et al. (2019)	Softwood species selection	Durak et al. (2022)	Technopark selection
Şahin et al. (2019)	Hospital site selection	Gao et al. (2022)	Disease vulnerability assessment
Leccese et al. (2020)	Lighting quality assessment	Jun et al. (2022)	Virtual road safety audit
Pang et al. (2020)	Product quality analysis	Panchal & Shrivastava (2022)	Landslide hazard assessment
Caner & Aydin (2021)	Shipyard site selection	Soltysova et al. (2022)	Manufacturing cell design
Marović et al. (2021)	Contractor selection	Wang et al. (2022)	Internal auditor selection
Omair et al. (2021)	Sustainable supplier selection	Singer & Özşahin (2023)	Wooden outdoor furniture selection

The AHP hierarchy facilitates pairwise comparisons of decision elements at any level. Decision-makers use a scale of 1-9 to assign numerical values to pairwise comparisons. Preference ratings (a_{ij}) are then transferred to pairwise comparison matrices (D) (Özşahin et al., 2019). To obtain the priority values of decision elements, each column of matrix D is divided by the sum of its numbers. Then the arithmetic mean of each matrix row is calculated. This process allows decision-makers to prioritize decision elements from best to worst (Dos Santos et al., 2019).

$$D = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}_{n\times n} ; a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}} \tag{6}$$

3. APPLICATION

3.1. Decision-making Framework

The paper and paper products printing sector encompasses a diverse range of companies. These companies must demonstrate strong performance to meet their fundamental economic requirements. Decision-makers generally place great importance on efficiency measurement as a means of improving company performance. Through efficiency analysis, companies can assess their resource utilization efficiency, compare their performance with other sector companies, and identify strategies to enhance their competitiveness. This study aims to analyze the financial statement information of twelve paper and paper products printing companies traded on Borsa Istanbul. A DEA-AHP approach is suggested to evaluate the efficiency of the considered companies. The DEA method is modified to enable pairwise comparisons of the companies. The outputs of the modified DEA method are then input into the AHP method. The efficiency score of each company is revealed using the calculation procedure of the AHP method. The proposed decision-making framework is illustrated in Figure 3. The steps of the integrated DEA and AHP methodology are explained below (Rouyendegh, 2009; Rouyendegh et al., 2019).

Step 1: The pairwise comparisons of decision elements (k and $\grave{k} = 1,\dots,n$) are performed using the DEA method to obtain comparison results ($e_{k,\grave{k}}$).

$$e_{k,\grave{k}} = max \sum_{r=1}^{t} u_r y_{rk} \tag{7}$$

subject to:

$$\sum_{i=1}^{m} v_i x_{rk} = 1 \tag{8}$$

$$\sum_{r=1}^{s} u_r y_{rk} - \sum_{i=1}^{m} v_i x_{rk} \leq 0 \tag{9}$$

$$\sum_{r=1}^{s} u_r y_{r\grave{k}} - \sum_{i=1}^{m} v_i x_{r\grave{k}} \leq 0 \tag{10}$$

$$u_r \geq 0, r = 1,\dots,t \tag{11}$$

$$v_i \geq 0, i = 1,\dots,m \tag{12}$$

Step 2: Matrix components are determined.

$$a_{k,\grave{k}} = \frac{e_{k,\grave{k}}}{e_{\grave{k},k}} \quad (13)$$

Step 3: A normalized matrix is obtained.

$$\dot{a}_{k,\grave{k}} = \frac{a_{k,\grave{k}}}{\sum_{k=1}^{n} a_{k,\grave{k}}} \quad (14)$$

Step 4: Column vector elements are revealed.

$$\ddot{a}_{k,\grave{k}} = \sum_{k=1}^{n} \dot{a}_{k,\grave{k}} \quad (15)$$

Step 5: The column vector is normalized to obtain priority values.

$$\dddot{a}_{k,\grave{k}} = \frac{\ddot{a}_{k}}{\sum_{k=1}^{n} \ddot{a}_{k}} \quad (16)$$

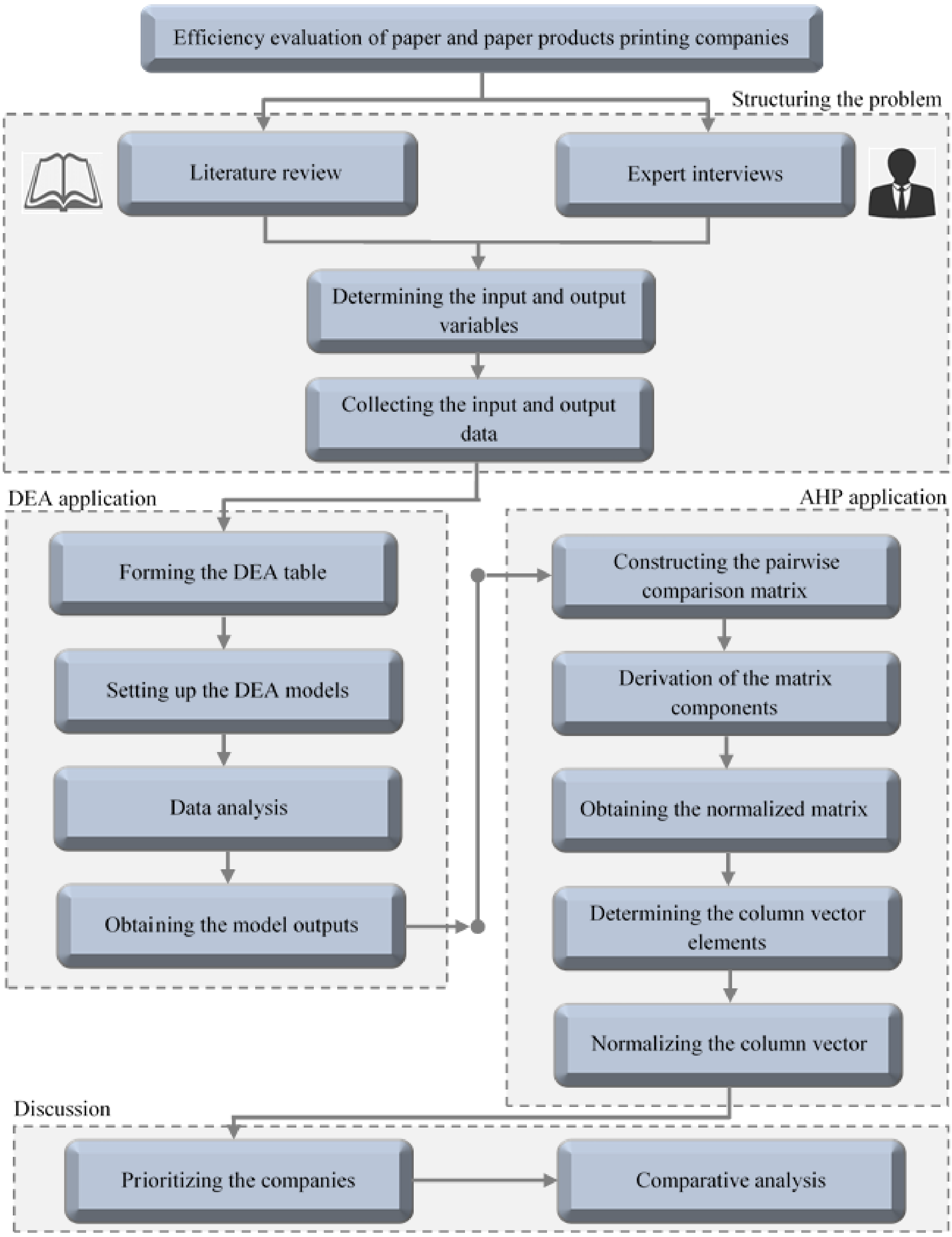


Figure 3: The Decision-making Framework

Firstly, decision elements are identified through literature research and expert interviews. Then a multicriteria decision analysis is carried out using the DEA-AHP approach to evaluate the performance of twelve paper and paper products printing companies in Borsa Istanbul. The companies included in this evaluation are listed below.

- Alkim Kâğıt Sanayi ve Ticaret A.Ş. – (ALKA)
- Kaplamin Ambalaj Sanayi ve Ticaret A.Ş. – (KAPLM)
- Kartonsan Karton Sanayi ve Ticaret A.Ş. – (KARTN)
- Mondi Turkey Oluklu Mukavva Kâğıt ve Ambalaj Sanayi A.Ş. – (MNDTR)

- Viking Kâğıt ve Selüloz A.Ş. – (VKING)
- Europap Tezol Kâğıt Sanayi ve Ticaret A.Ş. – (TEZOL)
- Konya Kâğıt Sanayi ve Ticaret A.Ş. – (KONKA)
- Prizma Pres Matbaacılık Yayıncılık Sanayi ve Ticaret A.Ş. – (PRZMA)
- Saray Matbaacılık Kağıtçılık Kırtasiyecilik Ticaret ve Sanayi A.Ş. – (SAMAT)
- Bak Ambalaj Sanayi ve Ticaret A.Ş. – (BAKAB)
- Duran Doğan Basım ve Ambalaj Sanayi A.Ş. – (DURDO)
- Barem Ambalaj Sanayi ve Ticaret A.Ş. – (BARMA)

Three inputs and two outputs are selected for the evaluation of the identified companies. Total assets, total equity, and number of employees are considered as input variables. The output variables of the decision model are revenue and net profit. The decision elements considered in the study are visually presented in Figure 4.

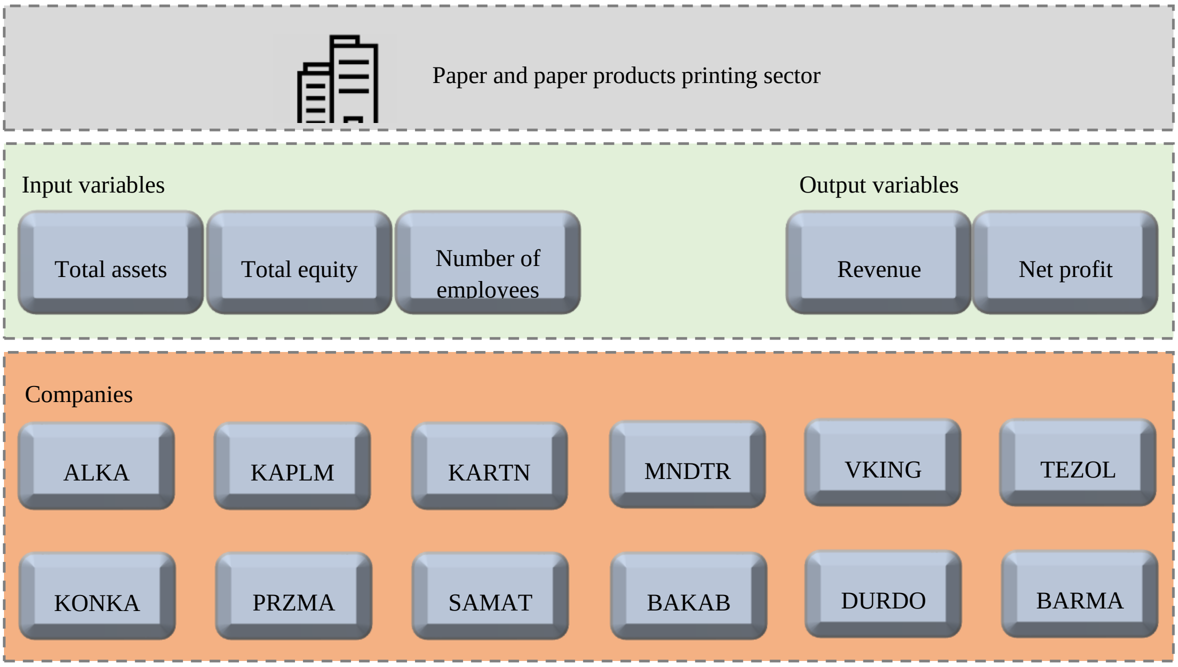


Figure 4: The Decision Elements Considered in the Study

A dataset is created by compiling data published by the Public Disclosure Platform (PDP) (URL-1, 2023) in 2022. The data are normalized using min-max normalization [Equation (17)] within the range of 0.1 to 0.9. This process standardizes the current data from a wide range to a smaller range, equalizes the significance of the variables (Al-Refaie et al., 2019), and ensures that the net profit variable satisfies the positivity condition. The data used in the study are provided in Table 3.

$$X_N = 0.1 + \frac{0.8(X - X_{min})}{(X_{max} - X_{min})} \quad (17)$$

where X_N is the normalized value, X is the real value, and X_{min} and X_{max} represent the minimum and maximum values of the data, respectively.

Table 3: The Input and Output Data

Company	Original data					Normalized data				
	Input			Output		Input			Output	
	Total assets	Total equity	Number of employees	Revenue	Net profit	Total assets	Total equity	Number of employees	Revenue	Net profit
ALKA	971762550	726918075	211	1844707692	476809036	0.2369	0.3082	0.1850	0.2776	0.5330
KAPLM	840545310	379964163	243	972121363	74877688	0.2147	0.2027	0.2007	0.1909	0.2484
KARTN	1799742153	1408353275	301	3364356706	705466741	0.3773	0.5154	0.2292	0.4285	0.6949
MNDTR	4881561957	1995668981	1666	8110333108	864779884	0.9000	0.6939	0.9000	0.9000	0.8077
VKING	1143740528	180052473	204	770150689	-134702605	0.2661	0.1420	0.1816	0.1708	0.1000
TEZOL	2046064310	1363372146	637	2396434448	728368243	0.4191	0.5017	0.3943	0.3324	0.7111
KONKA	3014682311	2673423619	458	1923605168	995192497	0.5834	0.9000	0.3064	0.2854	0.9000
PRZMA	183662291	118630542	38	57105008	18661597	0.1033	0.1233	0.1000	0.1000	0.2086
SAMAT	164467177	42065815	109	335569252	13172893	0.1000	0.1000	0.1349	0.1277	0.2047
BAKAB	1938170220	636103868	692	1956371516	162710461	0.4008	0.2806	0.4214	0.2887	0.3106
DURDO	1089137498	476429996	333	1241670494	269324756	0.2568	0.2321	0.2450	0.2177	0.3861
BARMA	1367295190	833133310	824	1469595897	258808554	0.3040	0.3405	0.4862	0.2403	0.3786

3.2. Pairwise Comparisons with DEA

The traditional DEA method evaluates each decision-making unit simultaneously with all others. This process yields efficiency scores. These scores are used to perform a descending order ranking, where the decision-making unit with the highest efficiency score is placed in the first position. However, assigning a score of 1 to all efficient decision-making units hinders the ranking of these units among themselves. To address this limitation, this study integrates the DEA and AHP methods to create precise efficiency ranking indexes.

The disaggregation power of the DEA method depends on the number of decision-making units, inputs, and outputs. In DEA applications, the following two constraints are generally taken into account: (i) the total number of inputs and outputs should be at least one less than the number of decision-making units, and (ii) the number of decision-making units should be at least twice the number of variables. This study includes twelve decision-making units and five decision variables. The number of decision elements considered in the decision model does not violate the aforementioned constraints. Therefore, linear programming models are developed to evaluate the performance of the companies. The weights assigned to the outputs and the inputs are based on the numerical values of the output and input variables, respectively.

The companies are evaluated based on the input and output variables. A total of 144 (12 × 12) mathematical models are established to compare the companies. These models are solved using the GAMS 24.1.3 optimization software. The comparison results are presented in Table 4. The pairwise comparison matrix demonstrates the dominance level of one company in relation to another. The matrix is analyzed to obtain the priority vector of the companies.

Table 4: The Pairwise Comparison Matrix Obtained Using the DEA Method

Company	ALKA	KAPLM	KARTN	MNDTR	VKING	TEZOL	KONKA	PRZMA	SAMAT	BAKAB	DURDO	BARMA
ALKA	1	1	1	1	1	1	1	1	1	1	1	1
KAPLM	1	1	1	1	1	1	1	1	1	1	1	1
KARTN	1	1	1	1	1	1	1	1	1	1	1	1
MNDTR	1	1	1	1	1	1	1	1	1	1	1	1
VKING	1	1	1	0.9409	1	1	1	1	0.9941	1	1	1
TEZOL	0.8196	1	1	1	1	1	1	0.8645	1	1	1	1
KONKA	1	1	0.9691	1	1	1	1	1	1	1	1	1
PRZMA	0.9785	1	1	1	1	1	1	1	1	1	1	1
SAMAT	1	1	1	1	1	1	1	1	1	1	1	1
BAKAB	1	1	1	0.9510	1	1	1	1	0.8058	1	1	1
DURDO	1	1	1	1	1	1	1	1	1	1	1	1
BARMA	0.7837	1	0.8488	1	1	1	1	0.8700	0.6192	1	0.9327	1

3.3. Determination of Efficiency Scores with AHP

The AHP method is based on pairwise comparisons of decision elements. In this method, the priority values of decision elements are derived by modeling the judgments of one or more decision-makers. Although the AHP method takes input from decision-makers, it does not fully reflect individuals' thinking styles. Most decisions are significantly influenced by imprecise judgments. In this study, AHP modeling is conducted using the financial and personnel data of the identified companies. The collected data are analyzed using the DEA method to create an efficiency decision matrix. This matrix is inputted into the AHP method to obtain a priority ranking.

The initial decision matrix (Table 4) comprises the outputs of the DEA mathematical models formed according to Equations (7)-(12). Therefore, with the help of Equation (13), the matrix components are determined for the AHP analysis. The reciprocal property ensures that the importance of one unit in relation to another is reflected accurately. The resulting matrix is shown in Table 5.

Table 5: The Matrix Components

Company	ALKA	KAPLM	KARTN	MNDTR	VKING	TEZOL	KONKA	PRZMA	SAMAT	BAKAB	DURDO	BARMA
ALKA	1	1	1	1	1	1.2201	1	1.0220	1	1	1	1.2761
KAPLM	1	1	1	1	1	1	1	1	1	1	1	1
KARTN	1	1	1	1	1	1	1.0319	1	1	1	1	1.1781
MNDTR	1	1	1	1	1.0629	1	1	1	1	1.0515	1	1
VKING	1	1	1	0.9409	1	1	1	1	0.9941	1	1	1
TEZOL	0.8196	1	1	1	1	1	1	0.8645	1	1	1	1
KONKA	1	1	0.9691	1	1	1	1	1	1	1	1	1
PRZMA	0.9785	1	1	1	1	1.1568	1	1	1	1	1	1.1494
SAMAT	1	1	1	1	1.0059	1	1	1	1	1.2409	1	1.6149
BAKAB	1	1	1	0.9510	1	1	1	1	0.8058	1	1	1
DURDO	1	1	1	1	1	1	1	1	1	1	1	1.0722
BARMA	0.7837	1	0.8488	1	1	1	1	0.8700	0.6192	1	0.9327	1

In the next step, Equations (14)-(16) are applied to Table 5 to determine the sequence of the companies. Figure 5 graphically presents the efficiency score and ranking position of each company.

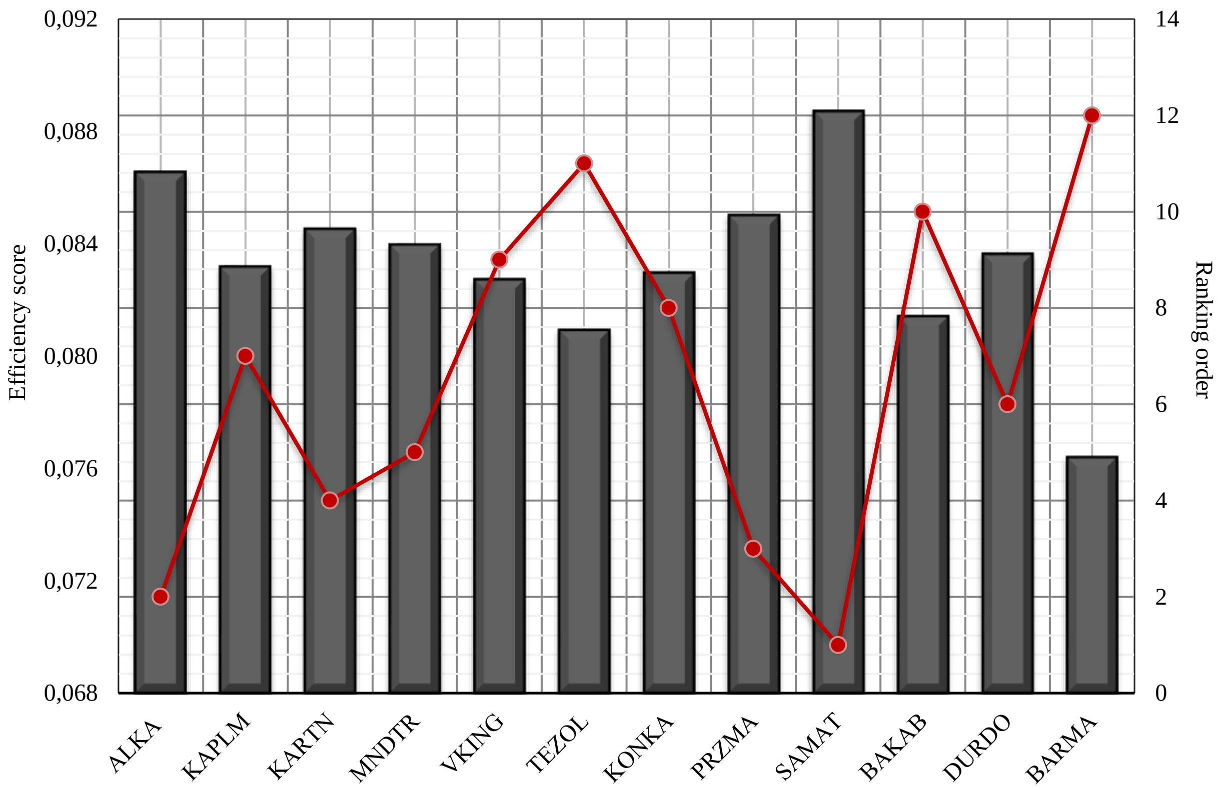


Figure 5: The DEA-AHP Outputs

The efficiency scores indicate how well each company is utilizing its resources to generate its outputs relative to the other companies in the analysis. A higher efficiency score suggests better performance. The obtained results can be interpreted as follows:

- ALKA: ALKA has an efficiency score of 0.0866. It ranks second in terms of efficiency. This implies that ALKA is effectively utilizing its resources to generate its outputs and is one of the most efficient companies in the sector.
- KAPLM: KAPLM has an efficiency score of 0.0832 and ranks seventh in terms of efficiency. Although its efficiency score is lower compared to the above-mentioned company, it still performs better than five other companies in the sector.
- KARTN: KARTN has an efficiency score of 0.0845 and ranks fourth in terms of efficiency. It lags behind SAMAT, ALKA, and PRZMA in terms of efficiency.
- MNDTR: With an efficiency score of 0.0840, MNDTR holds the fifth-ranking position. It is performing at a similar level to KARTN.
- VKING: This company has an efficiency score of 0.0827 and ranks ninth in terms of efficiency. It performs better than BAKAB, TEZOL, and BARMA but lags behind eight other companies.
- TEZOL: TEZOL has an efficiency score of 0.0809 and ranks eleventh in terms of efficiency. It performs better than only one other company (BARMA) in the sector.
- KONKA: With an efficiency score of 0.0830, KONKA holds the eighth-ranking position.

- PRZMA: This company has an efficiency score of 0.0850 and holds the third-ranking position. It performs well but not as efficiently as SAMAT or ALKA.
- SAMAT: With an efficiency score of 0.0887, SAMAT holds the first-ranking position. It is the most efficient company among all the analyzed companies, indicating strong performance and competitiveness.
- BAKAB: This company has an efficiency score of 0.0814 and holds the tenth-ranking position. It performs better than two other companies but lags behind nine other companies.
- DURDO: With an efficiency score of 0.0836, DURDO holds the sixth-ranking position. It performs relatively well, although not as efficiently as the top-ranking companies.
- BARMA: BARMA has an efficiency score of 0.0764. It ranks twelfth and last in terms of efficiency, indicating that it has the lowest resource utilization and performance compared to the other companies.

To enhance competitiveness and improve performance, the companies with lower efficiency scores should focus on identifying and addressing inefficiencies in their resource utilization and operational processes. They can benchmark against the most efficient companies (such as ALKA and SAMAT) to understand best practices and implement strategies that can lead to improved performance. This could involve optimizing production processes, streamlining operations, improving supply chain management, adopting new technologies, and enhancing overall resource efficiency.

3.4. Comparative Analysis

3.4.1. Comparison with the traditional DEA method

The DEA method measures the efficiency of homogeneous decision-making units. In this method, efficiency scores are determined by using a set of inputs and outputs to make performance comparisons between decision-making units. Once decision elements are finalized, the choice of which DEA model to use is determined. The output-oriented DEA model is preferred because it aims to provide as much output as possible with existing inputs. The selected DEA model uses total assets, total equity, and number of employees as inputs and revenue and net profit as outputs. The efficiency scores obtained for the companies by running the DEA model are presented in Figure 6.

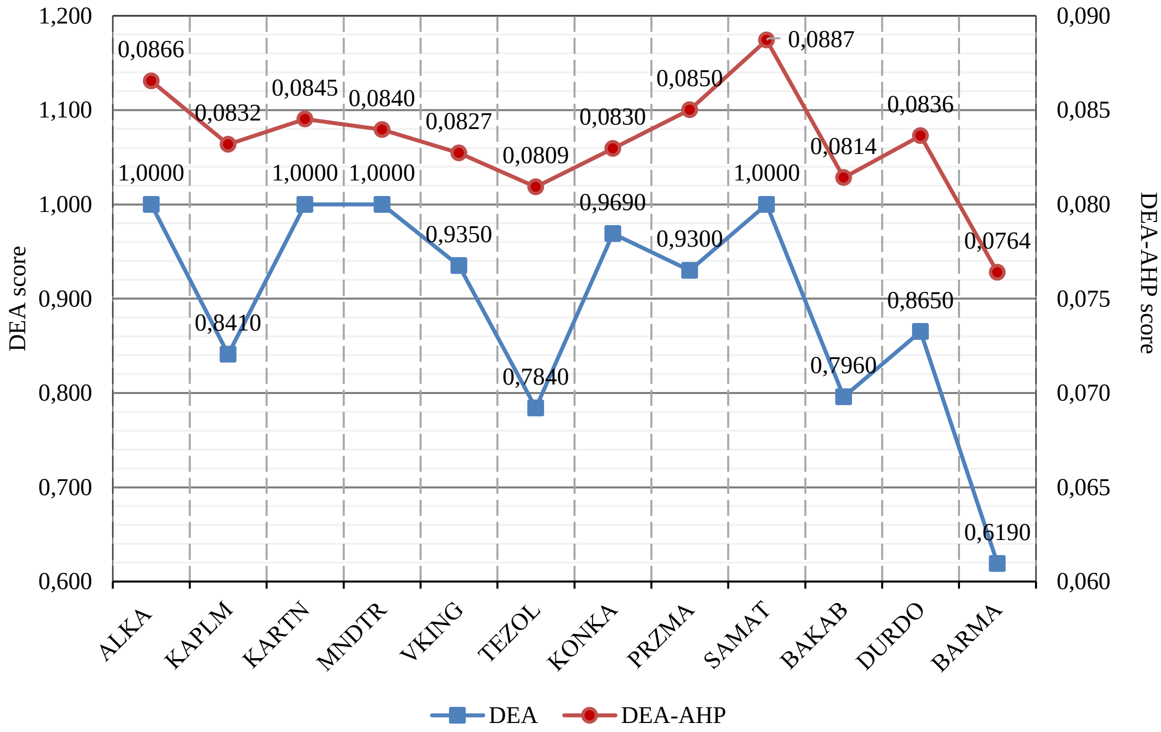
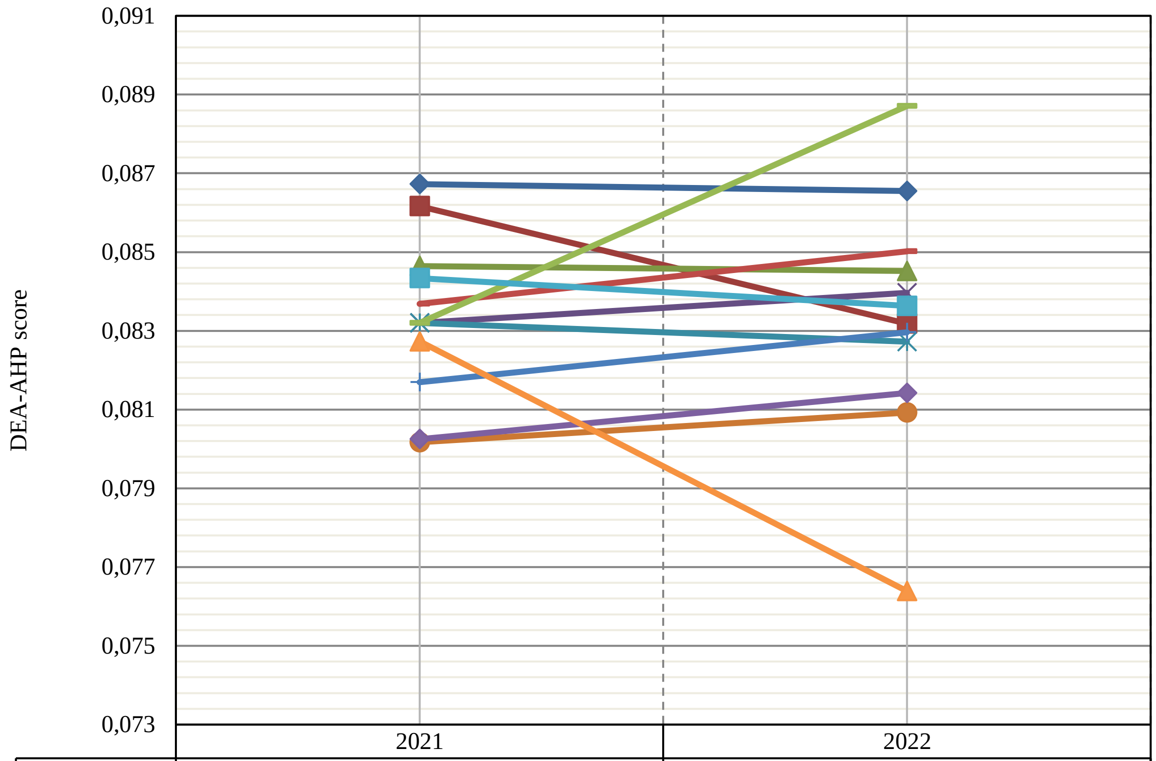


Figure 6: The Comparison between the Outputs of the DEA and DEA-AHP Methods

When using the traditional DEA method, several companies are found to have the same ranking position, indicating that they are considered equally efficient according to this method. The companies with the same efficiency score are ALKA, KARTN, MNDTR, and SAMAT. The traditional DEA method is useful for identifying efficient decision-making units based on efficiency scores. However, it lacks the ability to differentiate between equally efficient units. Therefore, it may not provide a detailed understanding of the relative performance of units. The DEA-AHP approach provides a more detailed analysis by considering the efficiency scores derived through the application of two different methods. The DEA-AHP approach provides more distinct rankings among the companies. The higher disaggregation capability of the DEA-AHP approach allows for a finer distinction between the efficiency scores of the companies. This means that the DEA-AHP approach can identify smaller differences in the relative efficiencies of the companies compared to the traditional DEA method.

3.4.2. Performing DEA-AHP for the previous year

When companies compare their performance internally, they utilize performance results from previous years and take into account changes shown over the years. By examining past performance, it is possible to identify and address any weaknesses and make more informed decisions about the future. The input and output data from the previous year are used to determine the efficiency and priority ranking of the companies for the year 2021. Figure 7 displays the results obtained by the DEA-AHP approach.



	2021	2022
ALKA	0,0867	0,0866
KAPLM	0,0862	0,0832
KARTN	0,0846	0,0845
MNDTR	0,0832	0,0840
VKING	0,0832	0,0827
TEZOL	0,0802	0,0809
KONKA	0,0817	0,0830
PRZMA	0,0837	0,0850
SAMAT	0,0832	0,0887
BAKAB	0,0802	0,0814
DURDO	0,0843	0,0836
BARMA	0,0827	0,0764

Figure 7: The Comparison of the DEA-AHP Scores for the Years 2021 And 2022

The analysis of the efficiency score results reveals a mixed performance among the paper and paper products printing companies. Some companies demonstrate improvements or maintain relatively stable efficiency levels, such as ALKA, KAPLM, VKING, and BARMA. On the other hand, companies like SAMAT, KONKA, BAKAB, and TEZOL experienced declines in their efficiency scores. The comparison of the efficiency scores provides insights into the performance of each company. It indicates areas where the companies have shown improvements, maintained stability, or experienced declines in their efficiency.

Companies with declining efficiency scores should identify the underlying causes and implement strategies to rectify them. On the other hand, companies that demonstrate improvements can analyze factors contributing to their success and use them as benchmarks for further enhancements. Consequently, this study highlights the importance of continuously monitoring and enhancing operational efficiency to strengthen competitiveness in the sector.

4. CONCLUSION

The paper and paper products printing sector plays a crucial role in generating income, creating employment opportunities, and supporting exports and various industries. Therefore, it is essential to comprehend the strengths and weaknesses of companies operating in this sector. Performance measurements serve as valuable tools for evaluating a company's operational efficiency and profitability. In this study, a two-stage decision-making methodology is proposed to evaluate the efficiency of twelve companies operating in the paper and paper products printing sector in Borsa Istanbul. In the first stage, the DEA method is utilized to make pairwise comparisons of the companies. Total assets, total equity, and number of employees are selected as inputs, while revenue and net profit are considered as outputs. The collected data are analyzed using the DEA method to form an efficiency decision matrix. In the second stage, the calculation procedure of the AHP method is applied to the resulting matrix for the ranking of the companies.

The originality and value of the current study can be elucidated as follows: (i) the efficiency evaluation problem of paper and paper products printing companies is formulated as a complex multicriteria decision-making problem; (ii) the AHP method is integrated with the DEA method to conduct a more detailed and comprehensive multicriteria analysis; (iii) five key performance variables are determined based on literature research and expert interviews; (iv) the performance of twelve paper and paper products printing companies in Turkey is compared, and precise efficiency ranking indexes are determined for the companies; (v) comparative analyses are conducted to shed light on performance variations among the companies; (vi) this study is the first attempt to use the hybrid DEA-AHP approach for examining the performance of paper and paper products printing companies; (vii) the proposed framework can be used by any company to improve its strategies; and (viii) the study provides a novel and valuable guide to decision-makers. In future research, the proposed framework can be used to compare different companies. The study can be expanded by using different input and output variables. Additionally, the problem can be solved using different decision support tools, and their results can be compared with the findings of this study.

Research and Publication Ethics Statement

This study was prepared in accordance with scientific research and publication ethics rules.

Researchers' Contribution Rate Statement

The author(s) planned the study, collected the data, and performed the analyses. The author(s) wrote, read, and approved the article.

Conflict of Interest Statement

The author(s) has no conflicts of interest to declare.

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