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The COVID-19 pandemic's impact on the financial performance of the aviation industry

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Abstract. Extraordinary situations such as the COVID-19 crisis affect various financial indicators of companies, including profitability, indebtedness, and liquidity. This study aims to examine the impact of the pandemic on the financial performance of the global aviation industry. The methodological foundation is based on the prospect theory of Kahneman and Tversky. The sample consists of 20 internationally operating airline companies. The analysis covers two periods: the five years preceding the pandemic (2015–2019) and the two-year pandemic period (2020–2021). Fifteen financial ratios, grouped under liquidity, profitability, financial structure, and activity, were calculated and used as data. The data were first weighted using the entropy method, followed by analysis through the TOPSIS and PROMETHEE which are multi-criteria decision-making methods. Additionally, performance rankings for the pre-pandemic and pandemic periods were compared using Spearman rank correlation, revealing consistency between TOPSIS and PROMETHEE results. Both methods indicate that the pandemic generally had a negative effect on financial performance. According to TOPSIS, the most adversely affected companies were *Air China*, *British Airways*, *LATAM Airlines Group*, and *Southwest Airlines*. According to PROMETHEE, these were *Aeroflot Russian Airlines*, *Air China*, *Air France*, and *Alaska Airlines*. However, both methods also identified *Emirates* and *Delta Airlines* as companies whose financial performance improved during the pandemic. These improvements may be attributed to timely adjustments in financial strategies, enhanced operational efficiency, and agile responses to emerging opportunities. Furthermore, the findings suggest that companies with strong pre-pandemic performance did not necessarily retain their leading positions during the pandemic, highlighting the disruptive and unpredictable nature of such extraordinary events.

Keywords: airline industry; airline companies; financial performance; COVID-19; entropy.

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Влияние COVID-19 на финансовое состояние отрасли пассажирских авиаперевозок

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Аннотация. Чрезвычайные ситуации, такие как кризис COVID-19, оказывают критическое влияние на финансовые показатели компаний, в частности рентабельность, задолженность и ликвидность. Статья посвящена исследованию воздействия пандемийного кризиса на финансовое состояние индустрии пассажирских авиаперевозок. Методологическая основа представлена теорией перспектив Д. Канемана и А. Тверски. Информационную базу составили данные 20 крупнейших авиакомпаний мира. Период исследования включал два подпериода: допандемийный (2015–2019 гг.) и пандемийный (2020–2021 гг.). Для анализа показателей деятельности авиакомпаний рассчитаны 15 финансовых коэффициентов, распределенных на четыре группы: ликвидность, рентабельность, финансовая структура и оборачиваемость. Данные взвешены с помощью метода энтропии и проанализированы методами многокритериального анализа решений TOPSIS и PROMETHEE. Тест ранговой корреляции Спирмена позволил установить согласованность итогов ранжирования финансовых показателей компаний в допандемийный и пандемийный периоды. Результаты исследования подтвердили, что кризис COVID-19 негативно сказался на финансовых показателях большинства авиакомпаний, но наиболее сильное влияние испытали Air China, British Airways, LATAM Airlines Group и Southwest Airlines (согласно TOPSIS), а также «Аэрофлот», Air China, Air France и Alaska Airlines (согласно PROMETHEE). В то же время оба метода выявили улучшение средних показателей в пандемию у компаний Delta Airlines и Emirates, чей рост может объясняться оптимизацией финансовой стратегии и деятельности компаний, оперативной реакцией на возникающие возможности. Продемонстрировано, что компаниям – лидерам индустрии в допандемийный период не всегда удавалось удержать свои позиции в разгар кризиса.

Ключевые слова: отрасль пассажирских авиаперевозок; авиакомпании; финансовые показатели; COVID-19; энтропия.

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INTRODUCTION

In the modern age, where speed is the priority for transportation, the airline is a clear choice. As air travel demand has grown, so has the airline industry; global passenger traffic reached 4,988 million in 2025, reflecting decades of expansion[1]. This growth was driven by technological advances, falling real costs (e.g., jet fuel price declines and economies of scale) and rising incomes, resulting in an average long-run growth rate of about 4.4% per year [Oxley, Jain, 2015]. Over time, deregulation and globalization have transformed the sector. For example, the U.S. Airline Deregulation Act of 1978 and similar liberalization worldwide led to more competition and the birth of new carriers. Airline networks now serve virtually every continent, and hundreds of carriers operate scheduled services. The largest carriers include legacy network airlines and low-cost carriers from every region: Delta Air Lines (USA, ~62 billion US dollars revenue), United (~58 billion US dollars), and American (~54 billion US dollars) are among the biggest by revenue, followed by European groups such as Lufthansa (~43 billion US dollars) and IAG (Spain/UK, ~37 billion US dollars). Major Asian carriers likewise feature prominently (e.g., China Southern ~24.5 billion US dollars, Air China ~23.4 billion US dollars)[2]. Notably, large state-owned Middle Eastern airlines like Emirates (~37 billion US dollars) and Qatar (~22 billion US dollars) would also be the Top 10 if included. In short, the global carrier landscape is highly competitive and geographically diverse. This inevitably leads to a gradual development of the aviation industry, which has an essential place in the world economy and is highly competitive, with many major airline companies operating worldwide. Analysing these companies' financial data provides insight into their financial health and efficiency compared to peers. At the same time, financial analysis can illuminate competitiveness and sustainability. For airlines, core goals include maintaining safety, providing reliable service, and controlling costs while preserving quality. To meet these goals, carriers strive to achieve low unit costs (e.g., cost per available seat-kilometer) and high utilization (e.g., load factors), but external shocks can disrupt this balance. Historically, the industry has faced numerous crises: oil price shocks (the 1970s, the 2000s), geopolitical events (Gulf War 1990–91, 9/11/2001), health scares (SARS 2003, H1N1 2009, volcanic ash 2010, Ebola 2014, etc.), and financial downturns (2008–2009). Each caused sharp but generally short-lived downturns in traffic[3]. The 9/11 attacks alone temporarily cut U.S. demand by over 30%, and recovery took several years; similarly, the 2008 global financial crisis prompted deep but transitory declines. Industry reports confirm that global air passenger traffic has always seemed to bounce back strongly from short-term upheavals [Oxley, Jain, 2015], due to underlying long-run growth trends and falling fares. Indeed, IATA analysis finds that after shocks like SARS or 9/11, at least half of the initial passenger loss remains after two years, but by year five over 80% of the loss is recovered.

As with many other industries, the pandemic has been a challenging period that has profoundly affected the aviation industry. IATA data show that global airline revenue was about 838 billion US dollars in 2019 (with passenger services dominating), then plunged to 384 billion in 2020 under COVID-19, before rebounding to ~909 billion by 2023[4].

The onset of the COVID-19 pandemic in 2020 marked an unprecedented crisis for air transport. As global travel restrictions and lockdowns took effect, demand collapsed. IATA reports that worldwide RPK (revenue passenger-kilometers) fell by 66% in 2020 and a further 58% in 2021 compared to 2019. One study estimated the total value-chain loss at 244 billion US dollars in 2020 and 146 billion in 2021 [Jaap, Saxon, Lind, 2022]. In practical terms, airlines saw revenues halved (industry revenue down –54% in 2020) and most carriers swung to deep losses. For example, IATA industry statistics show the global airline net loss was about **–**137.7 billion US dollars in 2020, with a further loss of –40.4 billion in 2021. Even by 2022 and 2023, as traffic recovered, net losses remained large: the industry returned to small profits only by 2024. In short, 2020–2021 were the worst financial years on record for airlines[5].

These impacts were far more severe than prior crises. To put it in perspective, economists noted the COVID-19 downturn was about three times worse than the steepest part of the 2008–09 global financial crisis[6]. With such strain, airlines were forced into extraordinary measures. Many carriers cut capacity by over 90% at the height of lockdowns, grounded fleets, and halted international routes almost entirely. Workforce measures included large layoffs and furloughs; for example, the U.S. CARES Act provided payroll aid to help keep crews employed, but still thousands of jobs were cut worldwide. Fleet restructuring occurred as older aircraft were retired early. Airlines also drew on liquidity sources: many issued debt or equity, and some used frequent-flyer programs as collateral to raise cash. Notably, the industry's total debt burden jumped dramatically – global airline debt rose from ~430 billion US dollards in 2019 to 651 billion by the end of 2020, a 51% increase. This leveraged position strained airlines further, as credit ratings fell sharply during the crisis [Jaap, Saxon, Lind, 2022].

[1] IATA. (2025). https://www.iata.org/en/iata-repository/pressroom/fact-sheets/industry-statistics/.

[2] Top publicly traded airlines by revenue. https://companiesmarketcap.com/airlines/largest-airlines-by-revenue.

[3] How the Airline Industry Survived SARS, 9/11, the Global Recession and More. https://apex.aero/articles/aftershocks-coronavirus-impact/.

[4] IATA. (2025). https://www.iata.org/en/iata-repository/pressroom/fact-sheets/industry-statistics/.

[5] Ibid.

[6] How the Airline Industry Survived SARS, 9/11, the Global Recession and More. https://apex.aero/articles/aftershocks-coronavirus-impact/.

On the cost side, certain expenses actually spiked: jet fuel prices, after crashing in 2020, rebounded 70% in 2021 and another 43% in 2022 [Jaap, Saxon, Lind, 2022], adding pressure on cash-strapped carriers. For the airlines that managed to fly cargo or pivot (e.g., shipping freight or repatriation flights), some revenue streams remained, but they were tiny relative to passenger revenue.

Scholarly analyses have documented airlines' strategic responses. Albers and Rundshagen [2020] performed a content analysis of European carriers and found that the initial response strategies focused on retrenchment (cutting costs, seeking state aid) and preserving liquidity. Over time, some carriers sought innovation (e.g., cargo flights, new ticketing policies), but the majority of effort in 2020–2021 was on survival and adapting operations to health regulations. The pandemic also led firms to become acutely sensitive to risk; many strengthened internal processes (hygiene protocols, flexible booking) and reevaluated networks. Throughout, ensuring safety (in the sense of health security) became an added cost item – airlines had to implement mandatory cleaning, testing protocols, etc., further squeezing finances. Many of them financially reported significant losses, reduced revenues, and increased operating costs due to mandatory safety measures and flight closures [Albers, Rundshagen, 2020].

It is evident that the pandemic had a detrimental impact on the airline transport industry so, the study aims to assess the annual financial performance of the Top 20 global airline companies and make comparisons between their pre-pandemic and pandemic-era performances, computed financial ratios from the companies' statements and evaluated their economic performances using TOPSIS and PROMETHEE techniques. Then the results are compared for both pre-pandemic and pandemic periods with Spearman analysis.

THEORETICAL FRAMEWORK

The airline industry has long been recognized as one of the most volatile and capital-intensive sectors of the global economy. Profitability and financial performance are shaped by numerous factors such as fuel costs, labor expenses, regulatory conditions, market competition, and demand fluctuations [Doganis, 2019]. Prior literature demonstrates that efficiency and performance measurement in aviation require multidimensional evaluation because simple profitability indicators may obscure deeper structural strengths or weaknesses [Barros, Peypoch, 2009].

In particular, scholars emphasize the importance of comparative analysis among leading carriers to benchmark efficiency, competitiveness, and resilience [Kottas, Madas, 2018]. As the pandemic drastically reshaped market conditions, comparative financial performance assessment allows researchers to identify which airlines adapted better, preserved liquidity, and sustained operational efficiency under crisis conditions.

Evaluating airline financial performance is inherently a multi-criteria problem. Airlines operate in diverse contexts and are assessed not only on profitability but also on cost efficiency, debt management, liquidity, and asset utilization. No single indicator fully captures financial performance. As a result, multi-criteria decision-making (MCDM) methods are widely used in academic studies of corporate finance and efficiency [Zavadskas, Turskis, Kildienė, 2014].

MCDM techniques allow decision-makers to combine multiple financial ratios and performance indicators into an integrated evaluation framework. Unlike traditional ratio analysis, MCDM recognizes trade-offs: for example, an airline may show high revenue growth but simultaneously weak solvency. Such trade-offs are crucial in comparative benchmarking.

Among the many MCDM methods, TOPSIS and PROMETHEE have gained prominence due to their ability to handle conflicting criteria, incorporate decision-makers' preferences, and provide clear rankings of alternatives [Behzadian et al., 2012].

TOPSIS, developed by Hwang and Yoon [1981], is based on a simple but powerful principle: the best alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. Prior research has applied TOPSIS in the finance domains, showing its robustness in ranking firms under uncertainty. Thus, it is theoretically justified to apply TOPSIS in the airline sector to capture performance variations. PROMETHEE, proposed by Brans and Vincke [1985], is another widely used outranking method in MCDM. Unlike TOPSIS, which is based on distance measures, PROMETHEE applies pairwise comparisons of alternatives across criteria to establish preference flows. It allows more flexibility in handling qualitative judgments and non-compensatory preferences. By adopting a dual-method MCDM approach (TOPSIS and PROMETHEE), this study contributes to the theoretical advancement of performance evaluation in volatile industries.

There are limited studies in the literature on measuring the financial performance of airline companies. Wang [2008] used the Fuzzy TOPSIS method to analyse the financial performance of three selected airlines in Taiwan. In the study conducted using liquidity ratios, financial structure ratios, activity ratios, and profitability ratios between 2001 and 2005, the existing 21 criteria were reduced to 12 using expert opinion by the grey relationship analysis method. According to the results China Airlines performed the highest.

Barros and Wanke [2015] used TOPSIS, artificial neural networks, and DEAP methods to measure the financial efficiency of African airlines. With the criteria of the number of employees, the total number of aircraft, operating costs, revenue per paid passenger-kilometre, and revenue per kilometre, the efficiency of 29 airlines between 2010 and 2013 were evaluated. As a result, it was determined from the artificial neural network analysis that efficiency can be increased by improving operational processes.

Wanke, Barros and Chen [2015] evaluated the financial performance data of 35 airlines operating in Asia between 2006 and 2012 using TOPSIS and Markov Chain Monte Carlo methods. In order to analyse the performance of the airline companies, 11 criteria, such as operating cost, depreciation, salary, employees, aircraft, total assets, fixed assets, revenues, EBIT, the number of passengers, and revenue per passenger mile were taken as the basis. As a result, it is revealed that while the efficiency of the enterprises is positively affected by privatization and low-cost competition, fuel prices hurt airline them.

Teker, Teker and Guner [2016] aim to analyse the Top 20 airlines in the world's financial performance between 2011 and 2014. To quantify the financial performance of airlines on a unique basis, a hormonic index is proposed that considers performance categories such as profitability, operating efficiency, and liquidity. They suggest that the measuring of financial performance based on total revenue or profitability is insufficient and might be improved by integrating other variables.

Cetin and Altan [2019] analysed financial activities of three airlines at Esenboga Airport by using TOPSIS and AHP techniques. In the study conducted on Turkish Airlines, Pegasus Airlines, and Sun Express Airlines, the dominant criteria are cost for the AHP method and the size and newness of the aircraft for Fuzzy TOPSIS. According to the research results, Turkish Airlines was the alternative decision unit with the best performance.

Dube and Nhamo [2020] look at possible recovery routes for the world's aviation sector after the COVID-19 pandemic's extreme adverse effects. The study, which used archival and secondary data primarily from Flightradar24, ICAO, IATA, and EUROCONTROL, discovered that the pandemic had a significant negative impact on international aviation, leading to rating downgrades, bankruptcy, and liquidation of several airlines and airports because of extreme cash burn brought on by travel restrictions.

To assess airlines' competitiveness by comparing their operational and financial results to predetermined standards [Bae, Gupta, Mau, 2021] tested FAHP, TOPSIS, and a hybrid FAHP-TOPSIS approach. The hybrid method uses FAHP to calculate influential weights of the TOPSIS criteria. The research investigates the correlation between financial and operational performance standards, offering valuable perspectives for airlines to create an assessment framework that facilitates an understanding of their operational proficiencies and limitations. The hybrid FAHP-TOPSIS model's results validate the usefulness of adding fuzzy values to significant weight criterion.

The effects of the COVID-19 pandemic on the U.S. air transportation system between March and August 2020 are examined in research by [Bauranov et al., 2021]. The network maintained its stability and resistance to disruption even in the face of sharp drops in both flight and passenger numbers. Despite the closure of 24% of airports, there was only a 5.1% decrease in network efficiency, meaning most airlines still served most destinations.

Using data from previously released studies, the study of [Nguyen, Nguyen, Bui, 2022] examines how the COVID-19 pandemic has affected several facets of the aviation and tourism industries. The authors determine the COVID-19 pandemic's effects on aviation and tourism by analysing earlier records. After that, the study will present strategies to improve the tourism sector's ability to adjust to the pandemic scenario.

Keles [2023] made an efficiency comparison of nine largest airline companies in Europe before and after the pandemic. Between 2019 and 2020, the number of seats, kilometres, employees, and aircraft supplied were used as inputs, and the number of passengers was used as output. According to the results, Aegean Airlines was a fully efficient airline before and after the pandemic.

In conclusion, these presented studies demonstrate that there are few studies in the literature examining the impact of COVID-19 on the financial performance of major airlines in the periods of pre- and post-COVID-19. Another feature of this study is that it uses two different MCDM methods, ensuring robustness of the results.

MATERIALS AND METHODS

This study aims to measure the financial performance of airline companies with two different multi-criteria decision-making methods for two periods determined as before and during the COVID-19 pandemic and to test the existence of performance change according to both methods.

The data were obtained from the annual reports of the Top 20 airlines, ranked on the American internet news site Business Insider, based on the information reported by the London-based Official Airline Guides company that provides aviation data. For this ranking, the number of seats offered to customers during 2018 was considered[1].

The financial ratios were calculated using the selected companies' balance sheets and income statements between 2015 and 2021. Fifteen financial ratios categorized into four groups such as liquidity, financial structure, activity, and profitability ratios constituted the criteria of the study. On the other hand, the 20 airline companies determined constituted the alternatives of the study. The years between 2015 and 2019 were the pre-pandemic period, and those between 2020 and 2021 were the pandemic.

The criteria are given in Table 1, and the alternatives are in Table 2.

[1] The 20 biggest airlines in the world, ranked. https://www.businessinsider.com/biggest-airlines-world-oag-2019-3#20-alaska-airlines-1,2019.

Table 1 – Financial ratios (criteria) to assess the airlines' performance
Таблица 1 – Финансовые коэффициенты (критерии) оценки деятельности авиакомпаний

No.	Name of the financial ratios	Category of the financial ratios	Formula of financial ratios
C1	Current ratio	Liquidity	Current assets / Short-term liabilities
C2	Acid-test ratio	Liquidity	(Current assets – Stocks) / Short-term liabilities
C3	Cash ratio	Liquidity	Cash and cash equivalents / Short-term liabilities
C4	Financial leverage ratio	Financial structure	Liabilities (total liabilities) / Total assets
C5	Shareholders' equity ratio	Financial structure	Shareholders' equity / Total assets
C6	Financing rate	Financial structure	Equity / Total liabilities
C7	Ratio of short-term liabilities to total debt	Financial structure	Short-term liabilities / Total liabilities
C8	Receivables turnover rate	Activity	Net sales / Trade receivables
C9	Current asset turnover ratio	Activity	Net sales / Current assets
C10	Fixed asset turnover ratio	Activity	Net sales / Fixed assets
C11	Equity turnover ratio	Activity	Net sales / Equity
C12	Asset turnover ratio	Activity	Net sales / Total assets
C13	Net profit margin	Profitability	Net profit / Net sales
C14	Operating profit margin	Profitability	Operating profit / Net sales
C15	Earnings before interest and tax / Assets	Profitability	EBIT / Total assets

Table 2 – Airline companies (alternatives) of the sample
Таблица 2 – Авиакомпании выборки

No.	Airline companies	IATA codes	No.	Airline companies	IATA codes
A1	All Nippon Airways (ANA)	ANA	A11	Delta Air Lines	DAL
A2	Aeroflot Russian Airlines	AFL	A12	EasyJet	EJU
A3	Air Canada	ACA	A13	Emirates	UAE
A4	Air China	CCA	A14	IndiGo	IGO
A5	Air France	AFR	A15	LATAM Airlines Group	LAN
A6	Alaska Airlines	ASA	A16	Lufthansa	DLH
A7	American Airlines	AAL	A17	Ryanair	RYR
A8	British Airways	BAW	A18	Southwest Airlines	SWA
A9	China Eastern Airlines	CES	A19	Turkish Airlines	THY
A10	China Southern Airlines	CSN	A20	United Airlines	UAL

Source: The 20 biggest airlines in the world, ranked. https://www.businessinsider.com/biggest-airlines-world-oag-2019-3#20-alaska-airlines-1,2019.

TOPSIS and PROMETHEE methods were applied from multi-criteria decision-making methods and the entropy method to weigh the criteria in the study. Excel program was used for the entropy and the TOPSIS methods, and the Visual PROMETHEE program was used for the PROMETHEE method. The ranking results were evaluated by Spearman rank correlation.

Decision-makers decide by considering how their decisions' positive and negative consequences will affect their current situation. By selecting the criteria, they determine what they want or should avoid. They try to establish the most suitable alternative for its criteria. Criteria weights differ according to the decision problem, and criteria may have different degrees of importance in different conditions and situations. While the decision-maker creates the criteria of the problem, they also determine the criteria weights.

The TOPSIS method generally ranks alternatives from the closest to the positive ideal solution to the farthest one based on their relative proximity to different criteria. TOPSIS can be used as a decision-making tool in many fields, such as finance, economics, accounting, production, marketing, and quality control [Subasi, 2011]. TOPSIS method is a method consisting of 8 steps.

Step 1: Setting objectives and defining evaluation criteria. In decision problems, alternatives and criteria should be defined and determined to reach a solution. The decision matrix is formed after the alternatives and criteria are established, and the next step proceeds.

Step 2: Creating the decision matrix. The first decision matrix (a_{ij}) is formed by placing the evaluation criteria for decision-making problems in columns and the alternatives in rows to rank their superiority. As shown in Table 3, m is the number of decision points, and n is the number of criteria in the decision matrix [Ersoy, 2016].

Table 3 – Structure of the decision matrix
Таблица 3 – Структура матрицы решений

Alternatives	Criteria		
	y_1	y_2	$y_3 \dots y_n$
a_1	a_{11}	a_{12}	$a_{13} \dots a_{1n}$
a_2	a_{21}	a_{22}	$a_{23} \dots a_{2n}$
…	…	…	…
…	…	…	…
a_m	a_{m1}	a_{m2}	$a_{m3} \dots a_{mn}$

Note: $a_1, a_2, \dots, a_m$ are alternatives; $y_1, y_2, \dots, y_n$ are criteria.

Accordingly, the decision matrix is created:

$$a_{ij} = \begin{bmatrix} a_{11} & a_{21} & a_{31} & \dots & a_{m1} \\ a_{12} & a_{22} & a_{31} & \dots & a_{m2} \\ a_{13} & a_{23} & a_{33} & \dots & a_{m3} \\ \dots & \dots & \dots & \dots & \dots \\ a_{1n} & a_{2n} & a_{3n} & \dots & a_{mn} \end{bmatrix}, \tag{1}$$

where $i = 1, \dots m$ is the number of alternatives; $j = 1, \dots n$ is the number of criteria.

Step 3: Constructing the normalized decision matrix. The normalization process enables comparing the criteria by removing the different scales in which the data are located. Each criterion value in the decision matrix is normalized by the values in the column to which they belong (a_{ij}). The normalized matrix (R) is obtained by taking the square root of the sum of squares [Zelvi, 2019].

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}; i = 1, \dots, m; j = 1, \dots, n. \tag{2}$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & . & \dots & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}. \tag{3}$$

Step 4: Creating the weighted standard decision matrix. The decision-maker weights the decision matrix normalized in Step 2. In the weighting process, a 10-point scale can be used, or the decision matrix can be formed by weighting with the entropy method. The set of weights $W = (W_1, W_2, \dots, W_n)^T$, $\sum_{i=1}^{n} W_i = 1$ (the sum of the weights must be equal to 1) is applied by the decision-maker to the decision matrix. This matrix is the one in which the column elements of the R matrix correspond to W_j multiplied by the weight value. The weighted decision matrix is called V [Oztel, 2016].

$$V_{ij} = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1j} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2j} & \dots & v_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{i1} & v_{i2} & \dots & v_{ij} & \dots & v_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \dots & v_{mj} & \dots & v_{mn} \end{bmatrix} mxn =$$

$$= \begin{bmatrix} W_1 r_{11} & W_2 r_{12} & \dots & W_j r_{1j} & \dots & W_n r_{1n} \\ W_1 r_{21} & W_2 r_{22} & \dots & W_j r_{2j} & \dots & W_n r_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ W_1 r_{i1} & W_2 r_{i2} & \dots & W_j r_{ij} & \dots & W_n r_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ W_1 r_{m1} & W_2 r_{m2} & \dots & W_j r_{mj} & \dots & W_n r_{mn} \end{bmatrix} mxn. \tag{4}$$

The initial a_{ij} matrix is normalized R_{ij} matrix. In Step 3, R_{ij} multiplying each value in the normalized decision matrix by the criteria weight V_{ij} weighted decision matrix was found. The formula obtains the decision matrix $V_{ij} = R_{ij}\ W_j$ shown in Equation (4).

Step 5: Determination of positive ideal (A^+) and negative ideal (A^-) solution. In the third step of the analysis, the weighted decision matrix (V_{ij}) is constructed by determining the maximum and minimum values within each column of the evaluation matrix. This procedure enables the differentiation between benefit-oriented and cost-oriented criteria. Specifically, for benefit-oriented factors, the highest values are considered to establish the positive ideal solution (A^+), whereas for cost-oriented factors, the lowest values are utilized to define the negative ideal solution (A^-). Through this distinction, the method ensures that the ideal solutions accurately reflect the most favourable outcomes for each criterion type. The mathematical formulation of both the positive and negative ideal solutions is provided in Equation (5) [Oral, Kipkip, 2019].

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\} \text{ (maximum values).}$$
$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \text{ (minimum values).} \tag{5}$$

Step 6: Calculation of discrimination measures between alternatives. In the TOPSIS method, the Euclidian distance is used to find the deviations of alternatives from the positive and negative ideal points. After finding the ideal solutions in terms of benefits and costs with the help of the formulae given in Step 4, the following formulae are used to find the deviation distance values S^+ (ideal separation) and S^- (ideal negative separation), which are the deviation distance values to the largest and smallest ideal solution points [Uzun, 2015].

The following formula calculates the distance to the ideal separation point:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_i - v_j^+)^2}, i = 1, \dots, m. \tag{6}$$

The following formula calculates the distance to the ideal negative separation point:

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, i = 1, \dots, m. \tag{7}$$

Step 7: Calculation of relative proximity to the ideal solution (C^+). To find the relative closeness value for each alternative, Equation (8) is calculated [Zelvi, 2019].

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+}, 0 \le C_i^+ \le 1. \quad (8)$$

Step 8: Ranking of alternatives. Relative closeness to the positive ideal solution (C^+) is ranked and the problem is solved by selecting the alternative with the highest value in the ranking.

The PROMETHEE method provides an advantage to the decision maker in terms of being able to select a criterion specific to each evaluation while making a decision. In addition, it allows the evaluation of the criteria differently through preference functions. Thus, it provides the opportunity to quickly make a correct decision. Preference functions are of 6 types: Ordinary (Type 1), U-Type (Type 2), V-Type (Type 3), Levelled (Type 4), Linear-Linear (Type 5), and Gaussian (Type 6). The researcher chooses the most appropriate preference function according to the study.

Things to be considered when selecting preference functions are as follows:

1) Ordinary (Type I) preference function is the most appropriate to be selected for the criterion if the decision maker has no preference for the relevant criterion;

2) U-Type (Type II) function should be used if the decision maker wants to use a preference for decision options that have more values than the value he/she has set for the underlying criterion;

3) V-Type (Type III) should be used if the decision maker who wants to use his/her preference towards decision points with above-average values does not want to ignore the values below [Kaygisiz, 2019];

4) if a specific range of values will determine the decision maker's preference for an evaluation factor, the Levelled (Type IV) preference function should be selected as the preference function [Ekin, Okutkan, 2021];

5) suppose the decision maker needs to use his/her preference for a criterion according to the decision options with a value above the average. In that case, the Linear (Type V) preference function should be preferred [Ertikin, 2019];

6) if the deviation of the relevant evaluation factor from the mean will be decisive in the decision maker's preference, the preference function to be selected should be a Gaussian preference function [Sahin, 2014].

The analysis with the PROMETHEE method is carried out in 7 steps:

Step 1: Preparation of the decision matrix.

Step 2: Determination of the preference functions of the criteria.

Step 3: Determination of joint preference functions.

Step 4: Determination of preference indices.

Step 5: Determination of positive and negative superiority values.

Step 6: Determination of partial priorities with PROMETHEE I.

Step 7: Determination of clear priorities with PROMETHEE II.

RESULTS

The findings obtained from the study are presented under three headings as TOPSIS, PROMETHEE and Spearman findings. A sample table for the year 2015 data is given for each of the application steps presented in the method section of the study.

Results of the TOPSIS Method

Creation and standardisation of the decision matrix. Table 4 shows the alternatives consisting of the relevant companies and the criteria consisting of financial ratios only[1] for 2015 sample. A decision matrix was formed with these figures.

After the decision matrix is formed, each criterion's standard deviation and average values between 2015 and 2021 are found, and standardization is performed. Each firm's smallest values between 2015 and 2021 are selected for standardization, and the standardization transformation is completed by adding this value and all alternative values.

The normalized decision matrix. Normalized decision matrices are formed by taking the square root of the sum of the squares of the values in the column to which each criterion value in the matrix belongs. Table 5 shows the normalized decision matrix for 2015.

Creation of weighted normalized decision matrix with the entropy method. The steps of the weighting process with the entropy method are as follows. A matrix is created with the financial ratios of each company for each year. Then, standard deviation and mean values are calculated for each criterion. In the standardization phase, this calculated standard deviation and mean values are used for each criterion, and a matrix for all years is formed in this way.

New values are obtained by summing each criterion value in this matrix with the smallest value of the matrix. Then, these values are divided by the column total value of the same criterion, and *p*-values are found. Each of these values is multiplied by its logarithm and summed and multiplied by –1/LN (total number of years) to find the *e*-values of each column. Then, *d*-values are found by 1 – *e* operation. Each *d*-value is divided by the sum of all *d*-values to find the criteria weights. Table 6 shows the criteria weights of all the alternatives calculated by the entropy method.

Weighted normalized decision matrices are created by multiplying the calculated criteria weights with the normalized decision matrices created in the previous step. The weighted normalized decision matrix for 2015 is presented in Table 7.

Determination of positive ideal (A^+) and negative ideal (A^-) solution. To reach the positive ideal and negative ideal solution, the minimum and maximum values are reached by summing all alternative values of the column

[1] Since the article would take up too much space, only tables for a single year are presented in the study. Tables for other years can be present by the authors.

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Table 4 – Decision matrix for 2015 data
Таблица 4 – Матрица решений для данных за 2015 г.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
A1	1,04	0,94	0,07	0,65	0,35	0,54	0,29	10,90	2,47	1,06	2,13	0,74	0,02	0,05	0,03
A2	0,75	0,71	0,17	1,12	–0,12	–0,10	0,57	6,24	3,11	2,28	–11,49	1,32	–0,02	0,11	–0,01
A3	1,08	1,03	0,15	1,00	0,00	0,00	0,29	21,17	3,36	1,54	346,70	1,06	0,02	0,11	0,02
A4	0,40	0,37	0,14	0,69	0,31	0,45	0,24	35,40	5,45	0,57	1,65	0,52	0,07	0,14	0,04
A5	0,63	0,58	0,26	0,99	0,01	0,01	0,51	14,00	3,45	1,65	95,45	1,12	0,01	0,04	0,01
A6	0,92	0,89	0,04	0,63	0,37	0,59	0,28	23,77	3,37	1,15	2,32	0,86	0,15	0,23	0,20
A7	0,89	0,83	0,03	0,81	0,19	0,24	0,27	25,77	3,47	1,07	4,24	0,82	0,20	0,15	0,09
A8	0,60	0,57	0,15	0,70	0,30	0,43	0,37	20,02	3,33	0,95	2,47	0,74	0,22	0,11	0,17
A9	0,31	0,28	0,12	0,80	0,20	0,25	0,38	28,73	4,30	0,57	2,49	0,50	0,05	0,13	0,03
A10	0,22	0,19	0,07	0,73	0,27	0,36	0,35	41,45	7,91	0,65	2,25	0,60	0,04	0,12	0,03
A11	0,52	0,50	0,11	0,80	0,20	0,26	0,33	18,86	4,50	0,92	3,75	0,77	0,11	0,19	0,14
A12	0,72	0,72	0,37	0,53	0,47	0,87	0,37	24,09	3,66	1,32	2,08	0,97	0,12	0,15	0,14
A13	0,80	0,75	0,24	0,75	0,25	0,34	0,31	9,81	3,13	1,04	3,07	0,78	0,06	0,07	0,04
A14	1,07	1,03	0,68	0,96	0,04	0,04	0,27	147,90	4,52	1,88	34,04	1,33	0,09	0,97	0,17
A15	0,50	0,46	0,13	0,84	0,16	0,19	0,31	8,95	3,45	0,64	3,32	0,54	–0,02	0,05	–0,02
A16	0,72	0,66	0,09	0,82	0,18	0,22	0,38	3,63	3,59	1,36	5,48	0,99	0,05	0,05	0,06
A17	1,72	1,72	0,35	0,67	0,33	0,50	0,28	90,71	0,99	0,88	1,40	0,46	0,15	0,18	0,08
A18	0,54	0,50	0,21	0,66	0,35	0,53	0,35	47,25	4,93	1,15	2,69	0,93	0,11	0,21	0,16
A19	0,81	0,76	0,23	0,70	0,30	0,42	0,24	25,76	3,35	0,80	2,17	0,64	0,10	0,10	0,09
A20	0,63	0,57	0,24	0,78	0,22	0,28	0,30	33,30	4,84	1,15	4,22	0,93	0,19	0,14	0,10

Table 5 – Normalized decision matrix for 2015 data
Таблица 5 – Нормализованная матрица решений для данных за 2015 г.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
A1	0,28	0,28	0,27	0,47	0,23	0,23	0,53	0,31	0,34	0,41	0,45	0,39	0,39	0,40	0,38
A2	0,28	0,30	0,27	0,50	0,20	0,20	0,58	0,35	0,32	0,38	0,27	0,39	0,38	0,44	0,31
A3	0,27	0,25	0,21	0,55	0,12	0,13	0,50	0,43	0,49	0,52	0,47	0,52	0,42	0,46	0,40
A4	0,66	0,65	0,49	0,40	0,28	0,27	0,00	0,49	0,40	0,44	0,58	0,43	0,45	0,47	0,45
A5	0,18	0,19	0,18	0,34	0,36	0,35	0,64	0,49	0,47	0,31	0,69	0,49	0,40	0,44	0,43
A6	0,47	0,46	0,24	0,18	0,52	0,53	0,40	0,43	0,39	0,58	0,51	0,53	0,45	0,45	0,55
A7	0,02	0,03	0,63	0,28	0,42	0,41	0,66	0,28	0,68	0,50	0,35	0,53	0,51	0,45	0,49
A8	0,30	0,30	0,08	0,28	0,41	0,40	0,31	0,53	0,45	0,42	0,43	0,45	0,47	0,43	0,50
A9	0,58	0,57	0,54	0,55	0,10	0,10	0,62	0,10	0,00	0,50	0,64	0,47	0,46	0,49	0,46
A10	0,23	0,22	0,26	0,40	0,29	0,28	0,54	0,17	0,47	0,48	0,52	0,48	0,45	0,50	0,46
A11	0,32	0,32	0,25	0,30	0,40	0,39	0,46	0,32	0,35	0,47	0,29	0,45	0,42	0,43	0,46
A12	0,72	0,72	0,37	0,53	0,47	0,87	0,37	24,09	3,66	1,63	2,08	0,97	0,12	0,15	0,14
A13	0,80	0,75	0,24	0,75	0,25	0,34	0,31	9,81	3,13	1,08	3,07	0,78	0,06	0,07	0,04
A14	1,07	1,03	0,68	0,96	0,04	0,04	0,27	147,93	4,52	2,94	3,41	1,33	0,09	0,97	0,17
A15	0,50	0,46	0,13	0,84	0,16	0,19	0,31	8,95	3,45	0,89	3,32	0,54	–18,35	46,05	–19,73
A16	0,72	0,66	0,09	0,82	0,18	0,22	0,38	3,63	3,59	14,75	5,48	0,99	0,05	0,05	0,06
A17	1,72	1,71	0,35	0,67	0,33	0,50	0,28	90,79	0,99	1,03	1,40	0,46	0,15	0,18	0,08
A18	0,24	0,24	0,25	0,35	0,35	0,34	0,54	0,55	0,50	0,47	0,53	0,47	0,41	0,44	0,47
A19	0,40	0,38	0,10	0,20	0,48	0,49	0,16	0,51	0,57	0,49	0,50	0,50	0,51	0,41	0,60
A20	0,29	0,29	0,29	0,25	0,45	0,45	0,46	0,48	0,43	0,47	0,40	0,46	0,51	0,45	0,47

Table 6 – Criterion weights of all the alternatives calculated by the entropy method
Таблица 6 – Веса альтернатив по критериям, рассчитанные методом энтропии

	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14	w15
A1	0,09	0,09	0,10	0,08	0,07	0,07	0,05	0,06	0,06	0,05	0,05	0,05	0,05	0,05	0,05
A2	0,07	0,07	0,10	0,10	0,06	0,07	0,06	0,06	0,06	0,06	0,08	0,06	0,05	0,05	0,06
A3	0,11	0,11	0,12	0,11	0,07	0,07	0,04	0,04	0,04	0,04	0,10	0,04	0,04	0,04	0,04
A4	0,08	0,07	0,10	0,12	0,06	0,06	0,12	0,06	0,04	0,05	0,05	0,05	0,05	0,05	0,05
A5	0,10	0,10	0,10	0,10	0,05	0,05	0,06	0,05	0,05	0,09	0,07	0,05	0,05	0,05	0,05
A6	0,10	0,10	0,09	0,10	0,05	0,05	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
A7	0,09	0,09	0,06	0,10	0,05	0,05	0,08	0,10	0,08	0,05	0,09	0,05	0,05	0,04	0,05
A8	0,05	0,05	0,11	0,12	0,05	0,05	0,11	0,07	0,07	0,05	0,09	0,05	0,04	0,04	0,05
A9	0,10	0,10	0,11	0,12	0,06	0,06	0,09	0,12	0,08	0,03	0,04	0,03	0,03	0,03	0,03
A10	0,10	0,10	0,10	0,10	0,07	0,07	0,06	0,10	0,05	0,04	0,04	0,04	0,04	0,04	0,04
A11	0,09	0,09	0,10	0,10	0,05	0,05	0,05	0,09	0,06	0,05	0,09	0,05	0,05	0,05	0,05
A12	0,09	0,09	0,10	0,11	0,05	0,05	0,09	0,08	0,06	0,05	0,05	0,05	0,05	0,05	0,05
A13	0,05	0,05	0,07	0,11	0,05	0,05	0,05	0,10	0,11	0,05	0,08	0,05	0,05	0,05	0,05
A14	0,07	0,07	0,07	0,09	0,06	0,06	0,10	0,07	0,07	0,06	0,09	0,05	0,05	0,05	0,05
A15	0,05	0,05	0,08	0,11	0,05	0,05	0,11	0,11	0,11	0,05	0,05	0,05	0,05	0,05	0,05
A16	0,08	0,08	0,10	0,10	0,05	0,05	0,08	0,09	0,07	0,05	0,09	0,05	0,04	0,04	0,04
A17	0,06	0,06	0,09	0,08	0,08	0,08	0,09	0,07	0,07	0,05	0,05	0,05	0,05	0,05	0,05
A18	0,10	0,10	0,10	0,10	0,05	0,05	0,06	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05
A19	0,05	0,05	0,09	0,11	0,05	0,05	0,11	0,06	0,09	0,05	0,05	0,05	0,06	0,08	0,07
A20	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,09	0,06	0,05	0,06	0,05	0,05	0,05	0,05

Table 7 – Weighted normalized decision matrix for 2015 data
Таблица 7 – Взвешенная нормализованная матрица решений для данных за 2015 г.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
A1	,026	,026	,026	,039	,017	,017	,028	,020	,021	,021	,024	,020	,020	,020	,019
A2	,020	,021	,027	,051	,013	,013	,037	,020	,018	,023	,021	,022	,018	,022	,018
A3	,030	,029	,024	,061	,008	,009	,020	,016	,020	,022	,046	,022	,015	,017	,015
A4	,050	,048	,048	,049	,016	,016	,000	,030	,018	,021	,030	,021	,021	,022	,021
A5	,017	,018	,018	,034	,018	,017	,039	,024	,023	,027	,047	,024	,020	,021	,021
A6	,046	,045	,022	,018	,027	,028	,039	,021	,020	,031	,025	,027	,022	,023	,029
A7	,002	,003	,040	,027	,020	,020	,050	,027	,052	,023	,032	,025	,024	,020	,023
A8	,016	,015	,009	,032	,020	,021	,033	,035	,034	,019	,037	,021	,021	,019	,016
A9	,056	,057	,060	,064	,006	,006	,057	,011	,000	,014	,025	,013	,013	,013	,013
A10	,023	,022	,026	,039	,020	,020	,035	,016	,021	,021	,022	,020	,019	,021	,020
A11	,030	,030	,024	,029	,018	,018	,023	,031	,020	,021	,027	,020	,019	,020	,021
A12	,063	,063	,037	,057	,024	,046	,033	1,876	,223	,078	,101	,046	,005	,007	,007
A13	,044	,041	,018	,080	,013	,018	,017	1,021	,329	,056	,240	,040	,003	,004	,002
A14	,070	,068	,046	,089	,002	,003	,027	1,562	,305	,169	,299	,061	,004	,052	,009
A15	,024	,023	,010	,095	,007	,009	,034	1,028	,369	,042	,163	,026	–,874	2,157	–,947
A16	,058	,055	,009	,081	,009	,011	,030	,318	,236	,677	,484	,045	,002	,002	,003
A17	,106	,105	,034	,054	,027	,040	,025	6,337	,070	,052	,077	,025	,007	,009	,004
A18	,024	,025	,026	,036	,018	,018	,030	,036	,031	,023	,027	,023	,020	,022	,023
A19	,020	,019	,009	,022	,022	,023	,017	,031	,051	,024	,024	,025	,031	,032	,041
A20	,029	,030	,029	,026	,021	,021	,022	,044	,024	,023	,025	,022	,025	,021	,023

containing each criterion. Table 8 shows the ideal benefits (F) and cost (M) solutions.

After reaching the deviation values from the positive and negative ideal solution points, positive and negative ideal separation criteria values were found to find the deviation values to the maximum and minimum ideal solution points. Table 9 shows the values of ideal and negative ideal separation criteria according to years.

Table 8 – Determination of positive and negative ideal solutions
Таблица 8 – Определение позитивных и негативных идеальных решений

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
		F	F	F	M	F	F	M	F	F	F	F	F	F	F	F
A1	A⁺	,065	,065	,067	,051	,037	,038	,028	,034	,031	,022	,026	,023	,022	,021	,023
	A⁻	,025	,026	,026	,016	,007	,008	,003	,003	,001	,000	,001	,000	,000	,000	,000
A2	A⁺	,042	,042	,051	,053	,036	,038	,037	,030	,031	,032	,055	,031	,023	,023	,035
	A⁻	,013	,013	,008	,014	,012	,012	,011	,001	,005	,010	,021	,008	,000	,000	,005
A3	A⁺	,076	,076	,076	,061	,039	,040	,021	,017	,020	,022	,071	,022	,017	,017	,019
	A⁻	,016	,018	,021	,010	,008	,008	,000	,001	,002	,003	,023	,003	,000	,000	,001
A4	A⁺	,050	,048	,064	,080	,032	,036	,060	,033	,021	,025	,030	,025	,021	,022	,022
	A⁻	,004	,003	,014	,014	,002	,003	,000	,001	,000	,003	,000	,004	,003	,002	,003
A5	A⁺	,056	,057	,056	,060	,025	,027	,039	,024	,023	,061	,047	,024	,022	,021	,023
	A⁻	,017	,018	,018	,018	,005	,005	,011	,002	,005	,022	,016	,005	,000	,001	,002
A6	A⁺	,052	,052	,065	,063	,027	,028	,061	,023	,027	,031	,025	,027	,022	,023	,029
	A⁻	,013	,013	,022	,018	,003	,004	,017	,004	,005	,004	,003	,004	,000	,000	,002
A7	A⁺	,042	,042	,040	,056	,025	,026	,050	,061	,052	,023	,062	,025	,024	,020	,023
	A⁻	,002	,003	,013	,017	,006	,006	,016	,018	,015	,002	,020	,003	,001	,000	,001
A8	A⁺	,028	,028	,071	,078	,026	,029	,079	,035	,042	,022	,051	,022	,021	,020	,024
	A⁻	,003	,003	,009	,019	,001	,002	,026	,004	,003	,000	,011	,001	,000	,000	,004
A9	A⁺	,063	,067	,072	,067	,029	,029	,057	,081	,051	,014	,025	,013	,013	,013	,015
	A⁻	,014	,015	,012	,015	,004	,004	,003	,011	,000	,000	,001	,000	,000	,000	,001
A10	A⁺	,063	,063	,066	,050	,048	,048	,035	,058	,023	,021	,022	,020	,020	,021	,021
	A⁻	,015	,015	,015	,000	,012	,012	,004	,011	,004	,003	,003	,003	,003	,003	,004
A11	A⁺	,061	,061	,060	,058	,021	,021	,028	,052	,036	,021	,062	,021	,019	,020	,021
	A⁻	,020	,020	,022	,023	,005	,005	,002	,007	,011	,003	,024	,003	,000	,000	,001
A12	A⁺	,136	,136	,059	,082	,025	,051	,041	1,876	,223	,078	,104	,046	,005	,007	,007
	A⁻	,059	,059	,013	,054	,011	,015	,025	,495	,065	,023	,027	,007	–,029	–,033	–,006
A13	A⁺	,046	,042	,023	,093	,015	,039	,017	2,091	,441	,062	,302	,040	,005	,005	,003
	A⁻	,031	,028	,009	,039	,007	,008	,013	,492	,178	,030	,117	,010	–,004	–,027	–,001
A14	A⁺	,156	,155	,074	,092	,021	,032	,043	1,562	,305	,454	,796	,061	,006	,052	,012
	A⁻	,070	,068	,039	,061	,002	,003	,027	2,443	,037	,102	,194	,017	–,017	,050	–,001
A15	A⁺	,031	,030	,017	,131	,010	,014	,058	1,320	,369	,047	,163	,027	1,026	3,591	,955
	A⁻	,010	,009	,006	,087	–,024	–,017	,034	,951	,265	,040	–,079	,012	–,874	–,054	–,947
A16	A⁺	,075	,072	,015	,096	,013	,018	,033	,550	2,124	,747	,484	,045	,003	,004	,004
	A⁻	,006	,001	,000	,073	,002	,002	,025	,129	,096	,187	,313	,016	–,021	–,023	–,010
A17	A⁺	,604	,603	,044	,055	,032	,052	,034	8,768	,121	,052	,100	,031	,012	,011	,008
	A⁻	,057	,057	,034	,049	,026	,038	,023	2,236	,007	,022	,077	,017	–,003	–,002	–,005
A18	A⁺	,060	,060	,061	,061	,028	,030	,030	,036	,031	,023	,027	,023	,023	,022	,023
	A⁻	,024	,025	,026	,016	,005	,006	,006	,010	,010	,001	,004	,004	,000	,000	,001
A19	A⁺	,026	,028	,053	,073	,022	,023	,061	,033	,051	,024	,024	,025	,031	,043	,041
	A⁻	,002	,002	,009	,022	,000	,000	,016	,002	,012	,002	,002	,002	,001	,008	,005
A20	A⁺	,060	,060	,061	,062	,022	,022	,023	,044	,029	,023	,034	,022	,025	,021	,023
	A⁻	,024	,024	,024	,025	,004	,004	,001	,000	,007	,004	,002	,004	,001	,000	,002

Table 9 – Finding the discrimination measures between the alternatives
Таблица 9 – Определение мер дискриминации между альтернативами

		2015	2016	2017	2018	2019	2020	2021
A1	S^+	0,085	0,078	0,069	0,069	0,073	0,066	0,090
	S^-	0,059	0,068	0,075	0,074	0,079	0,086	0,074
A2	S^+	0,081	0,040	0,040	0,055	0,074	0,097	0,083
	S^-	0,049	0,087	0,096	0,073	0,069	0,048	0,056
A3	S^+	0,112	0,117	0,104	0,084	0,108	0,094	0,080
	S^-	0,053	0,051	0,076	0,092	0,065	0,066	0,113
A4	S^+	0,047	0,072	0,090	0,073	0,064	0,121	0,117
	S^-	0,118	0,084	0,097	0,104	0,086	0,037	0,065
A5	S^+	0,083	0,060	0,054	0,080	0,074	0,085	0,064
	S^-	0,065	0,070	0,080	0,063	0,065	0,063	0,085
A6	S^+	0,049	0,052	0,050	0,075	0,068	0,097	0,067
	S^-	0,098	0,076	0,087	0,075	0,079	0,065	0,071
A7	S^+	0,081	0,059	0,064	0,070	0,077	0,085	0,070
	S^-	0,076	0,090	0,090	0,065	0,068	0,061	0,088
A8	S^+	0,069	0,047	0,065	0,036	0,060	0,096	0,103
	S^-	0,099	0,104	0,109	0,112	0,095	0,080	0,069
A9	S^+	0,119	0,110	0,107	0,106	0,086	0,114	0,082
	S^-	0,086	0,076	0,078	0,097	0,101	0,055	0,124
A10	S^+	0,103	0,102	0,072	0,059	0,117	0,078	0,085
	S^-	0,051	0,052	0,069	0,095	0,045	0,102	0,068
A11	S^+	0,075	0,072	0,083	0,083	0,090	0,064	0,059
	S^-	0,062	0,068	0,063	0,066	0,058	0,094	0,071
A12	S^+	0,106	0,213	0,204	0,560	1,394	1,110	0,521
	S^-	1,396	1,200	1,206	0,844	0,106	0,300	0,908
A13	S^+	1,079	1,137	1,198	1,215	1,625	0,762	0,201
	S^-	0,567	0,503	0,445	0,424	0,096	0,888	1,621
A14	S^+	0,588	1,528	1,851	1,762	8,142	6,029	3,468
	S^-	8,124	6,649	6,325	6,452	0,225	2,161	4,722
A15	S^+	3,061	1,174	0,413	0,396	0,705	3,932	3,908
	S^-	2,229	3,426	4,402	4,476	4,192	1,297	1,280
A16	S^+	1,903	1,924	0,185	1,928	2,153	0,814	2,076
	S^-	0,577	0,658	2,146	0,596	0,092	1,452	0,243
A17	S^+	2,532	1,831	0,859	0,747	4,179	3,797	6,533
	S^-	4,102	4,854	6,062	6,533	2,427	2,811	0,773
A18	S^+	0,071	0,063	0,060	0,064	0,072	0,083	0,062
	S^-	0,070	0,069	0,079	0,067	0,064	0,066	0,070
A19	S^+	0,047	0,065	0,032	0,053	0,057	0,113	0,079
	S^-	0,114	0,078	0,110	0,093	0,084	0,043	0,073
A20	S^+	0,059	0,063	0,067	0,067	0,081	0,070	0,059
	S^-	0,083	0,077	0,073	0,077	0,061	0,072	0,082

Calculation of closeness to ideal solution (C^+). To reach the value of closeness to the ideal solution, the ratio of the sum of the positive and negative ideal separation criteria to the positive ideal separation criterion of each alternative should be calculated. Finding these values constitutes the final stage of the TOPSIS method. When the relative closeness values to the ideal solution are ranked, the companies are ranked according to their financial performance.

Results of the TOPSIS method. For each of the 20 airlines, the annual financial performance ranking for the 2015–2021 period obtained by the TOPSIS method is given in Table 10.

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Table 10 – Ranking of the Top 20 airlines' financial performance according to TOPSIS
Таблица 10 – Ранжирование финансовых показателей 20 крупнейших авиакомпаний методом TOPSIS

	2015		2016		2017		2018		2019		2020		2021	
	C^+	Rank	C^+	Rank	C^+	Rank	C^+	Rank	C^+	Rank	C^+	Rank	C^+	Rank
A1	0,412	7	0,466	5	0,523	2	0,516	4	0,520	3	0,566	1	0,453	6
A2	0,374	6	0,684	2	0,705	1	0,569	3	0,483	4	0,331	7	0,405	5
A3	0,322	6	0,303	7	0,423	3	0,524	2	0,377	5	0,412	4	0,587	1
A4	0,716	1	0,538	4	0,519	5	0,588	2	0,574	3	0,234	7	0,359	6
A5	0,440	6	0,537	3	0,599	1	0,442	5	0,466	4	0,426	7	0,570	2
A6	0,665	1	0,591	3	0,636	2	0,499	6	0,538	4	0,402	7	0,514	5
A7	0,485	4	0,604	1	0,584	2	0,481	5	0,471	6	0,419	7	0,556	3
A8	0,589	5	0,687	2	0,627	3	0,755	1	0,611	4	0,456	6	0,403	7
A9	0,419	5	0,410	6	0,422	4	0,479	3	0,542	2	0,328	7	0,603	1
A10	0,331	6	0,339	5	0,491	3	0,616	1	0,278	7	0,568	2	0,445	4
A11	0,454	4	0,488	3	0,434	6	0,440	5	0,392	7	0,594	1	0,544	2
A12	0,929	1	0,850	3	0,855	2	0,601	5	0,071	7	0,213	6	0,636	4
A13	0,345	3	0,307	4	0,271	5	0,259	6	0,056	7	0,538	2	0,890	1
A14	0,933	1	0,813	2	0,774	4	0,785	3	0,027	7	0,264	6	0,577	5
A15	0,421	5	0,745	4	0,914	2	0,919	1	0,856	3	0,248	6	0,247	7
A16	0,233	5	0,255	3	0,921	1	0,236	4	0,041	7	0,641	2	0,105	6
A17	0,618	4	0,726	3	0,876	2	0,897	1	0,367	6	0,425	5	0,106	7
A18	0,495	5	0,520	3	0,566	1	0,513	4	0,470	6	0,445	7	0,530	2
A19	0,707	2	0,547	5	0,775	1	0,637	3	0,597	4	0,277	7	0,479	6
A20	0,583	1	0,550	3	0,521	5	0,533	4	0,433	7	0,507	6	0,582	2

Results of the PROMETHEE method

The PROMETHEE multi-criteria decision-making method was also applied to test the robustness of TOPSIS application results. Entropy results calculated previously were used in the weighting stage. Table 11 shows the financial performance ranking results of the companies obtained by the Visual PROMETHEE program.

Results of Spearman rank correlation

The ranking results obtained by both methods in Table 10 and Table 11 are separated as pre-pandemic (P.P.) and pandemic (P) periods, the average of TOPSIS results in Table 12 and the average of PROMETHEE results in Table 13.

Using these values, the hypotheses were tested:

H1: According to TOPSIS, there is no relationship between the ranking averages of the companies in pre-pandemic (P.P.) and pandemic (P) periods.

H2: According to PROMETHEE, there is no relationship between the companies' mean ranking in P.P. and mean ranking in P.

Table 11 – Ranking of the Top 20 airlines' financial performance according to PROMETHEE
Таблица 11 – Ранжирование финансовых показателей 20 крупнейших авиакомпаний методом PROMETHEE

	2015	2016	2017	2018	2019	2020	2021
A1	6	2	4	3	5	1	7
A2	5	3	4	1	2	7	6
A3	1	2	5	3	6	7	4
A4	2	3	1	4	5	7	6
A5	1	2	4	3	5	7	6
A6	4	5	2	3	1	7	6
A7	2	4	6	5	7	3	1
A8	1	2	3	4	6	5	7
A9	7	6	5	2	1	4	3
A10	5	7	3	1	4	2	6
A11	5	4	6	3	7	1	2
A12	1	2	3	4	5	7	6
A13	3	4	5	6	7	1	2
A14	1	2	4	3	6	7	5
A15	2	5	7	6	3	1	4
A16	1	2	3	5	7	4	6
A17	4	3	2	1	6	5	7
A18	1	2	6	5	7	3	4
A19	1	2	3	4	6	5	7
A20	1	2	4	3	7	6	5

Table 12 – Mean values of the airlines' (P.P.) and (P) TOPSIS rankings
Таблица 12 – Средние значения TOPSIS-рейтинга авиалиний в допандемийный (P.P.) и пандемийный (P) периоды

Firm	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
P.P.	4,2	3,2	4,6	3,0	3,8	3,2	3,6	3,0	4,0	4,4	5,0	3,6	5,0	3,4	3,0	4,0	3,2	3,8	3,0	4,0
P	3,5	6,0	2,5	6,5	4,5	6,0	5,0	6,5	4,0	3,0	1,5	5,0	2,0	5,5	6,5	4,0	6,0	4,5	6,5	4,0

Table 13 – Mean values of the airlines' (P.P.) and (P) PROMETHEE rankings
Таблица 13 – Средние значения PROMETHEE-рейтинга авиалиний в допандемийный (P.P.) и пандемийный (P) периоды

Firm	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
P.P.	4,0	3,0	3,4	3,0	3,0	3,0	4,8	3,2	4,2	4,0	5,0	3,0	5,0	3,2	4,6	3,6	3,2	4,2	3,2	3,4
P	4,0	6,5	5,5	6,5	6,5	6,5	2,0	6,0	3,5	4,0	1,5	6,5	1,5	6,0	2,5	5,0	6,0	3,5	6,0	5,5

H3: There is no relationship between the companies' mean ranking according to TOPSIS and the companies' mean ranking according to PROMETHEE.

H4: There is no relationship between the mean ranking of firms P.P. according to TOPSIS and the mean ranking P according to PROMETHEE.

The Spearman rank correlation formula in Equation (9) is used to test the relationship between the rankings.

$$\text{Spearman R} = \frac{\text{Covariance}}{\text{XRa St. Dev.} \times \text{YRa St. Dev.}}. \qquad (9)$$

The results for four hypotheses are presented in Table 14, which shows that all the four hypotheses were rejected. So, to both TOPSIS and PROMETHEE, there is an inverse relationship between the pre-pandemic performance rankings of the companies and their performance rankings during the pandemic. In addition, there is a direct relationship between TOPSIS and PROMETHEE results in terms of pre-pandemic performance rankings and between TOPSIS and PROMETHEE results in terms of pandemic period performance rankings.

DISCUSSION AND CONCLUSION

Although the damage caused by the COVID-19 crisis to airline transport is apparent, the purpose of this study, which investigates how much the companies in the sector are financially affected by the pandemic, is to evaluate the annual financial performances of globally recognized airline companies and compare the results of the pre-pandemic and pandemic periods. Accordingly, the 2015–2019 period was determined as the pre-pandemic period and the 2020–2021 period as the pandemic period.

For this purpose, performance-determining financial ratios were first calculated from the financial statements of 20 selected global airlines. These financial ratios are weighted using the entropy method. Then, the financial performances of all the companies in the relevant period were evaluated using the multi-criteria decision-making methods such as TOPSIS and PROMETHEE. The results obtained are compared for both periods.

As a result, among the selected companies, the companies whose financial performance decreased the most during the pandemic period compared to the pre-pandemic period are Aeroflot Russian Airlines, Air China, Air France, and Alaska Airlines, according to PROMETHEE results, and Air China, British Airways, LATAM Airlines Group, and Southwest Airlines according to TOPSIS results. On the other hand, due to both methods, Delta Airlines and Emirates were found to be the companies whose financial performance increased the most during the pandemic compared to the pre-pandemic period. These companies probably implemented strategic measures to optimize their financial health, streamline their operations, and take advantage of the opportunities arising in the sector [Kiraci, Tanriverdi, Akan, 2023]. Other airline companies can learn from the performance of companies such as Delta Airlines and Emirates and take examples regarding their ability to survive in times of crisis and achieve sustainable success in the sector.

Another result of the study, five companies (All Nippon Airways, Air Canada, China Southern Airlines, Delta Airlines, Emirates) according to the average ranking performance of the TOPSIS, and six companies (American Airlines, China Eastern Airlines, Delta Airlines, Emirates,

Table 14 – The results of hypotheses testing
Таблица 14 – Результаты тестирования гипотез

Indicators	H1	H2	H3	H4
Covariance	–34,45	–34,11	19,09	19,09
XRa St. Dev.	5,87	5,84	5,87	5,87
YRa St. Dev.	5,87	5,84	5,84	5,84
R	–1	–1	0,557	0,557
P(2-tailed)	0	0	0,011	0,011

LATAM Airlines Group, Southwest Airlines), according to the average ranking performance of the PROMETHEE results, were found to have above-average financial performance during the pandemic period.

It was concluded that the pandemic negatively affected the financial performances in the aviation sector in general. Similar results are found in [Kursuncu, Secilmis, 2023; Mintah, Gulko, 2023]. It can be said that the reasons such as the decrease in demand, operational disruptions and travel restrictions encountered in the sector and financial difficulties arising from economic uncertainties are effective in the emergence of this situation.

Including only 20 companies in the study, using 15 financial ratios selected as financial performance determinants, and using two methods from multi-criteria decision-making techniques limit this study. For future studies, it is recommended that similar studies be conducted nationally or regionally, different research methods be used, and the impact of the pandemic on different modes of transport be evaluated. ■

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