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PCA-DEA Model for Efficiency Assessment of Transportation Company

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Abstract: The road mode of transportation holds a leading position in the world and its upward trend is still noticeable. The aim of this research is to determine the efficiency of the observed transportation company, i.e. efficiency of its business throughout the analyzed period of years, which in this case is from 2018 to 2022. Specifically, in this paper, it has been observed a transportation company located in Bosnia and Herzegovina, which is engaged in road internal and international transportation. An integrated PCA-DEA model was used for efficiency analysis. Six input and four output parameters were defined. Due to the small number of decision-making units, PCA (Principal component analysis) based on 70% of the information of all data collected was first applied, and the number of input-output parameters was reduced to 2 to 1. After that, DEA (Data Envelopment Analysis) was applied to obtain final efficiency values. The results show that the previous year (2022) is the most efficient under the considered conditions and circumstances, and that the company is on the right track, as it increases its efficiency.

Keywords: Transportation; Principal component analysis; Data Envelopment Analysis; Efficiency

1. Introduction

The interaction of transportation and the economy can be shown through many relations, but there are four main ones: transportation sectors are large consumers of the production of other sectors, transportation has a strong impact on socio-political aspects of development, transportation enables a reproduction process to take place, and transportation is an important factor in increasing specialized and social division of labor. As such, it is subject to constant analysis and monitoring with the aim of increasing the efficiency of performed operations on the one hand and rationalizing all resources on the other. In the conditions of high competition on the market and the fact that a large number of logistics providers operate in Bosnia and Herzegovina, the analyses must be more frequent, and the results aligned with contemporary trends.

The aim of this research and paper is to determine the efficiency of the observed company, i.e. efficiency of its business throughout the analyzed period of years, which in this case is from 2018 to 2022. In addition, it is also possible to draw conclusions about which parameters the company should take into account in order to be even more successful in its business. In particular, this paper examines a transportation company, which is engaged in road internal and international transportation. The PCA-DEA method was used for efficiency analysis. Six input and four output parameters were defined. Defined input parameters are: total number of vehicles, number of drivers, number of operating hours, vehicle maintenance costs, fuel costs per total kilometers traveled and transport staff costs. Also, the following output parameters have been defined: total number of deliveries, total quantity transported, total number of kilometers traveled and profit.

Section 2 is dedicated to the literature review, i.e. an overview of the application of the DEA model and the PCA-DEA integrated model, where it is shown in which spheres it is possible to apply the mentioned models, as well as with which multi-criteria decision-making methods the calculation was made. Section 3 shows the methodology used in the paper, while Section 4 includes the way in which data was collected from the company,

the period observed, and explaining all the elements, for both input and output parameters individually. In addition, this section of the paper shows the analysis of the company using all the parameters mentioned above. First, it is described the company and what type of transportation it deals with, to which countries it exports goods, and from which countries return routes are made. Throughout eight graphs, the relation of all parameters by observed years is shown, explaining the minimum and the maximum values. After mentioning and explaining everything, Section 5 presents the results of applying the PCA-DEA model, based on 70% of the information of all data collected. For this reason, the number of inputs and outputs was reduced from 6-4 to 2-1 since it was the only way to satisfy the rule on the number of parameters and DMUs (Decision Making Units).

2. Background

Further, it will be mentioned some of the papers in which the same or similar models as in this paper were used, namely the DEA model, i.e. integrated PCA-DEA model, used to measure the efficiency of transportation companies.

In the paper of Andrejić and Kilibarda [1], it was proposed a model for measuring the efficiency of connected logistics systems based on the DEA method and game theory. The model is applied on a real example. The results obtained show the exceptional convenience of applying the presented model. In this paper, delivery accuracy is included as one of the indicators of the quality of services provided. Regardless of all the shortcomings, this method with all its advantages represents an excellent basis for the development of tools for measuring the efficiency of complex systems with a large number of participants. The paper of Yu and Lin [2] provides a multi-active DEA model of network data, which represents production and consumption technology in a unified framework. Since the DEA analysis of a multi-activity network models the reality of railway operations, further insight can be gained from estimated results and thereby strategies to improve operational performance can be suggested. The doctoral dissertation of Blagojević [3] presented the theoretical basis of the DEA method for measuring efficiency, showing the DEA models used in the dissertation for the realization of research goals, i.e. model development. The scientific contribution of the paper is reflected in a novel approach to the assessment of the efficiency and effectiveness of railway operators, which included the development of a DEA model for the assessment of the efficiency of railway operators, which was tested and verified on a case study analyzing 21 railway operators from EU countries, Central and Eastern European countries and Bosnia and Herzegovina. The paper of Ćiraković et al. [4] presents a non-parametric analysis of the efficiency of the bus subsystem of the public transport of passengers in the city of Belgrade, based on a sample of five small, three medium and two large companies. It was shown that the entire bus transport subsystem has a low level of total efficiency, only 0.66%. Small and medium-sized companies are at a disadvantage compared to large companies, when it comes to economies of scale in the production of transport services. These results should indicate the necessity of organizational and technological redesign of the transportation system and bus companies. The purpose of the paper of Baran [5] is to determine the efficiency of road freight transport in Poland and other European Union countries based on the DEA method. The calculated DEA model uses the following variables: number of employees, turnover of road transport undertakings and the volume of road transport of goods. The highest efficiency of the transport sector was achieved by five countries (Germany, Netherlands, Luxembourg, Austria, Slovakia).

The purpose of the paper of Adler and Golany [6] is to present the combined use of PCA and DEA with the aim of improving the discrimination power in DEA, which often fails when there are too many inputs and outputs compared to the number of decision-making units. The original DEA models suggest that 73% and 100% of centers are constantly or variably efficient, due to the nature of the data and the fact that eight variables were identified to describe the 22 centers. A study by Chan et al. [7] evaluates an iron ore port in Bohai Bay, China, using iron ore logistics data in the ports as data sources. PCA is used to extract the principal components of the original indicators, which are then taken as inputs and outputs of the DEA model. Furthermore, the findings of this paper provide theoretical and decision-making bases for improving the efficiency of port logistics. Moreover, the findings of this paper provide theoretical and decision-making bases for improving the efficiency of port logistics. The research of Miškić [8] is devoted to the analysis of the efficiency of two transportation companies using the integrated PCA-DEA model and MCDM methods. The research was conducted on a sample of two transportation companies from Bosnia and Herzegovina, where data from 2013 to 2020 were used for the purposes of the paper. The ranking was performed using the MARCOS method. The paper proved that the PCA-DEA approach in combination with MCDM methods was a very useful tool for determining the individual efficiency of transportation companies. The study of Deng et al. [9] developed a comprehensive evaluation index system to evaluate the performance of Chinese logistics. PCA was applied to reduce the dimensions of the indicators, and then Slacks-Based Measure-Data Envelopment Analysis (SBM-DEA) was used to measure and evaluate logistics performance with and without carbon emission restrictions in 30 municipalities in China and analyze the overall level and spatial efficiency characteristics of China's logistics industry. In order to increase the success of transport projects, it is necessary to develop adequate models for performance management. Elements of these models are key performance indicators (KPIs), which measure the success of projects. In the paper of Ivanović et al. [10], it is

proposed a hybrid model for measuring the efficiency of public-private partnership transport infrastructure projects using key performance indicators that are defined in accordance with the estimated impact of stakeholders. The authors proposed the application of ANP and PCA approaches. The developed hybrid PCA-DEA model was applied to the example of the efficiency assessment of the airport in Sarajevo for the year 2017. The paper of Andrejić and Kilibarda [11] proposes a new methodology for measuring global logistics efficiency that integrates international and domestic indicators into a single measure of efficiency. PCA-DEA was used in this paper. The main goal of the paper of Stević et al. [12] is to develop an integrated model for determining the efficiency of representative transport companies over a period of eight years. It has been developed an original model that includes the integration of DEA, PCA, CRITIC (Criteria Importance Through Inter Criteria Correlation), Entropy and MARCOS (Measurement Alternatives and Ranking according to Compromise Solution) methods to determine the final efficiency of transport companies based on 10 input data - output parameters.

3. Methodology

Further in the paper, the applied methodology consisting of DEA and PCA is shown, where the formulas and explanations of the labels are given.

3.1 DEA Model

The scientific basis for efficiency measurement was proposed in 1957 by M. J. Farrell who, for measuring technical efficiency, took several inputs that participated in the creation of one output and defined the efficiency limit taking into account the best practice from a set of analyzed units. After two decades (in 1978), his ideas were expanded by Charnes, Cooper and Rhodes who presented a quantitative model for evaluating the relative efficiency of units (DMUs) in which it is possible to include multiple inputs and multiple outputs, while determining extreme output points in their most favorable ratio with respect to available inputs [13]. Over the years, the DEA method has become an important operational tool for efficiency analysis in private and public sectors. The DEA method has been constantly evolving since its origin. According to Cooper, the primary concept of measuring the effectiveness of decision-making units (DMUs) is formalized in a mathematical model of fractional linear programming that can be transformed into linear programming [14].

CCR is the most basic model of DEA. The DEA CCR input oriented model (min) is as follows:

$$DEA_{input} = min \sum_{i=1}^{m} w_i x_{i-input} \tag{1}$$

With following restrictions:

$$\begin{gathered} \sum_{i=1}^{m} w_i x_{ij} - \sum_{i=m+1}^{m+s} w_i y_{ij} \geq 0, \quad j = 1, \dots, n \\ \sum_{i=m+1}^{m+s} w_i y_{i-output} = 1 \\ w_i \geq 0, \qquad i = 1, \dots, m+s \end{gathered} \tag{2}$$

The DMU consists of m input parameters for each alternative x_{ij}, while s represents the output parameters for each alternative y_{ij}, taking into account the weights of parameters denoted by w_i. Also, n represents the total number of DMUs. The DEA CCR output oriented model (max) is as follows:

$$DEA_{output} = max \sum_{i=m+1}^{m+s} w_i y_{i-output} \tag{3}$$

With following restrictions:

$$-\left(\sum_{i=1}^{m} w_i x_{ij}\right) + \sum_{i=m+1}^{m+s} w_i y_{ij} \leq 0, \quad j = 1, \dots, n \tag{4}$$

$$\sum_{i=1}^{m} w_i y_{i-input} = 1$$

$$w_i \geq 0, \quad i = 1, \ldots, m + s$$

3.2 PCA Model

PCA aims to reduce dimensionality and transform multiple indicators into several synthetic indicators [7]. The wider application of this technique, due to its complex calculation, has begun with greater computer capabilities.

4. Analysis of the Transportation Company

The company, as already mentioned, is engaged in transport within the borders of Bosnia and Herzegovina, as well as outside the borders, mainly exporting to Italy, Slovenia, Croatia, Serbia, Austria and Germany, while in previous years there were also exports to Slovakia, the Czech Republic, Hungary, Poland. There are also return tours from all mentioned countries. The reason for the cessation of exports to the last four given countries was mainly the consequences of the Coronavirus, which had the greatest impact on fuel prices, which further affected the transportation process itself and the calculation of transportation costs. The following figures provides graphical representations of all parameters for all years.

Figure 1 shows the ratio of the number of vehicles and the number of drivers in the period from 2018 to 2022, available for each of the mentioned years. In 2018, the company had 14 vehicles at its disposal, while the number of drivers employed was 11. Then in 2019, the company had the same number of drivers and vehicles, i.e., 14, while in 2020, it had one more vehicle available than the number of drivers employed, i.e., 15 vehicles and 14 drivers. In 2021 and 2022, the company had the same number of vehicles, i.e., 17, while in 2021 it had one driver less than in 2022, i.e., 13.

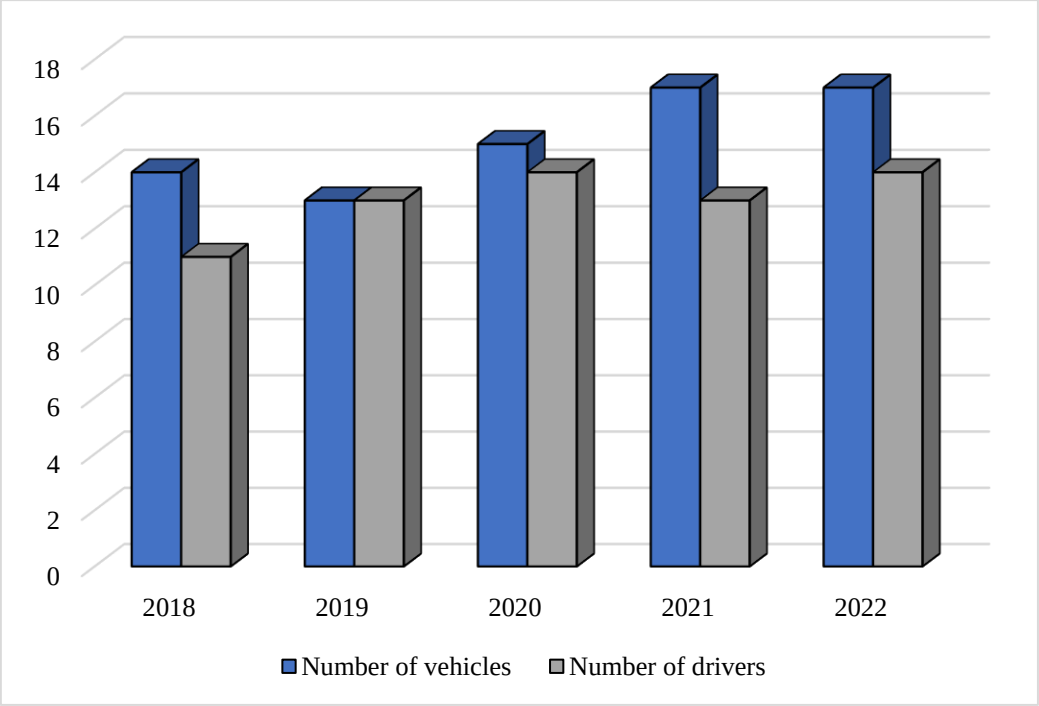

Figure 1. Graphic representation of the number of vehicles and drivers

Figure 2 shows the number of operating hours and quantity transported for the observed period of five years. As can be seen, the years 2018, 2019 and 2020 have almost approximate values for both parameters, for the number of operating hours: 25300 (2018), 28080 (2019) and 32230 (2020), and quantity transported: 21249 (2018), 28759 (2019) and 31523 (2020). The number of operating hours is also approximate for 2021 (29950) and 2022 (33320), while the quantity transported is significantly different from previous years, with values of 56215 (2021) and 61015 (2020).

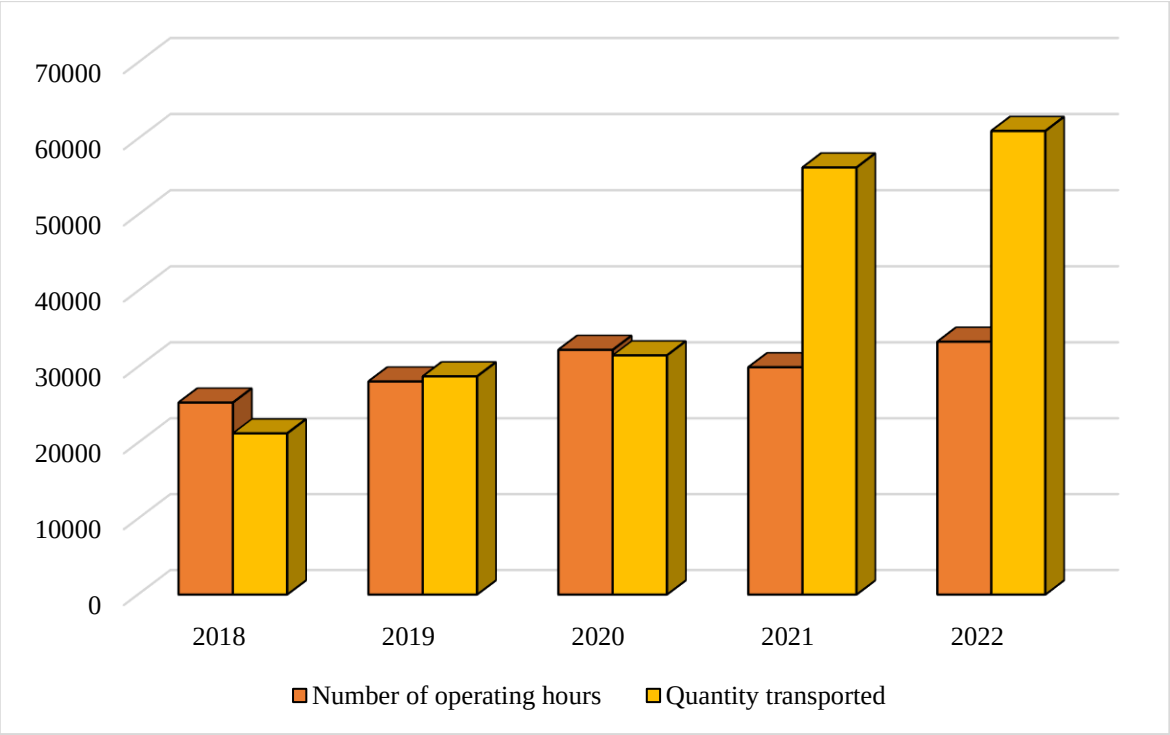

Figure 2. Number of operating hours and quantity transported

When it comes to the number of kilometers traveled (Figure 3), the year 2018 has the highest value, which is 1393740 km, followed by the year 2022 with a value of 1203026 km. Then in 2021, 2020 and 2019, the values were 1100652, 1048075 and 955386, respectively.

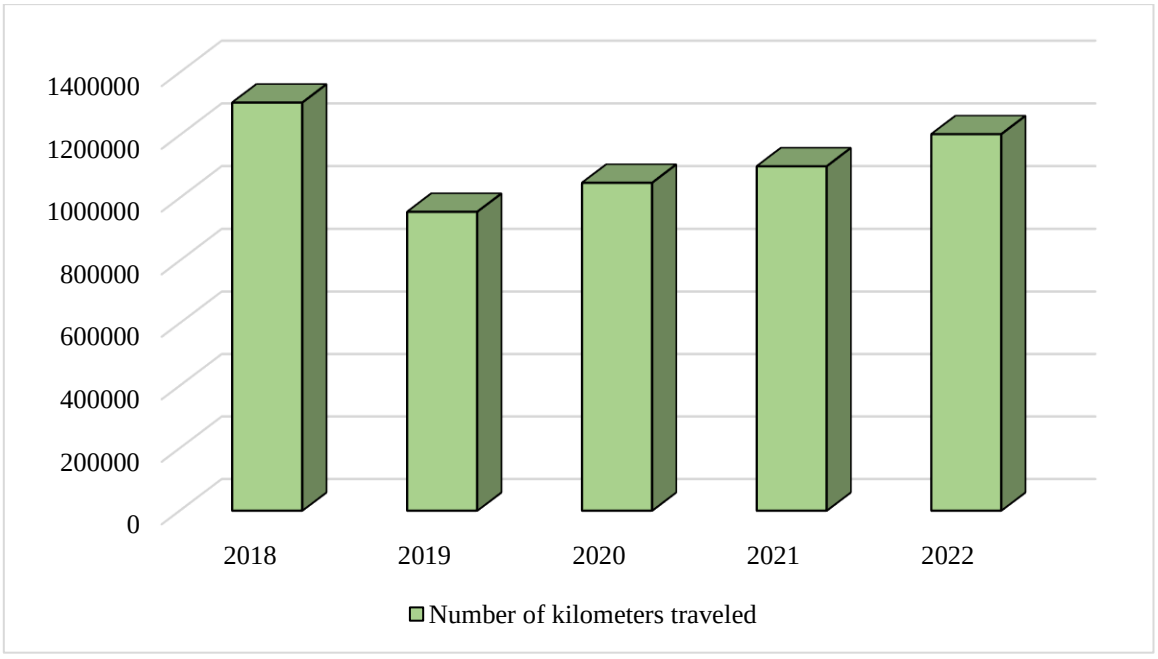

Figure 3. Number of kilometers traveled

From Figure 4, it can be seen that the largest number of deliveries was achieved in 2022, i.e., 1149, then in 2021 with the number of deliveries of 1062. The other three years have slightly lower values, 789 for 2020, 720 for 2019 and 698 for 2018. The large increase in the number of deliveries is due to the conclusion of permanent deals and contracts with certain manufacturers and also the recipients of goods, which had a significant positive impact on transportation, as well as the planning of tours.

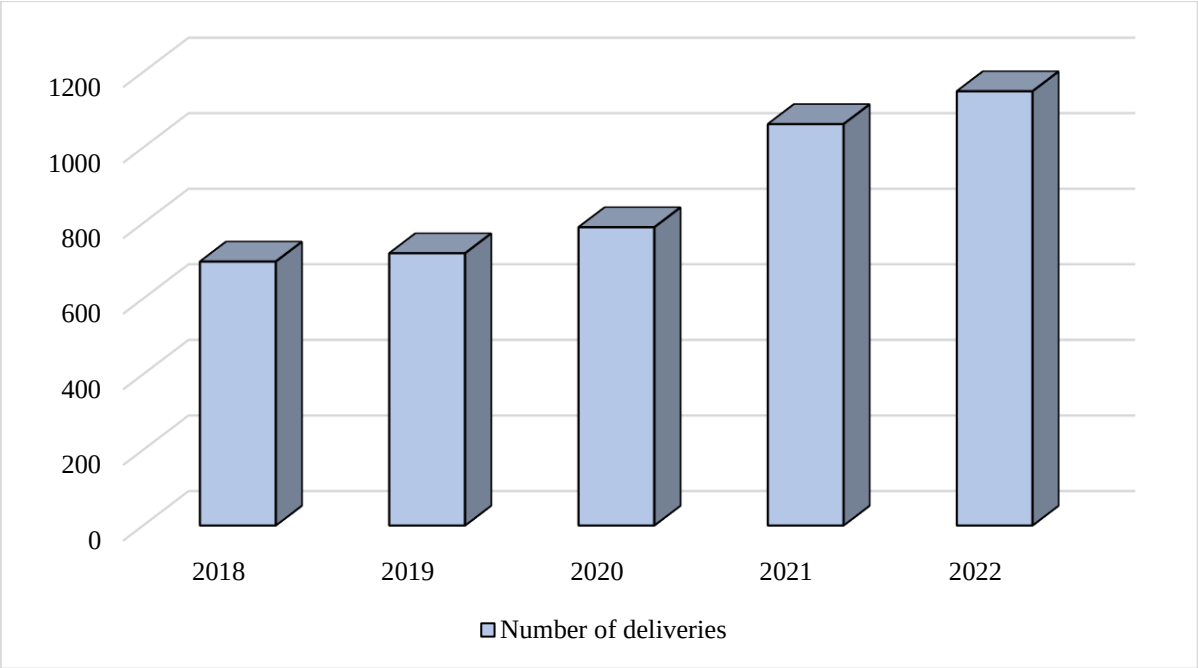

Figure 4. Number of deliveries

The next parameter that is analyzed is the maintenance costs for the vehicles that the company had at its disposal in the given years (Figure 5). These costs refer to all regular and also extraordinary costs of all vehicles in the company's fleet. Thus, the results show that the company invested the most money in 2022, in the amount of BAM 68,872, then slightly less in 2020, in the amount of BAM 66,598, and in 2021, in the amount of BAM 61,815, while 2018 and 2019 are with slightly lower costs, in the amounts of BAM 52,305 and BAM 59,841.

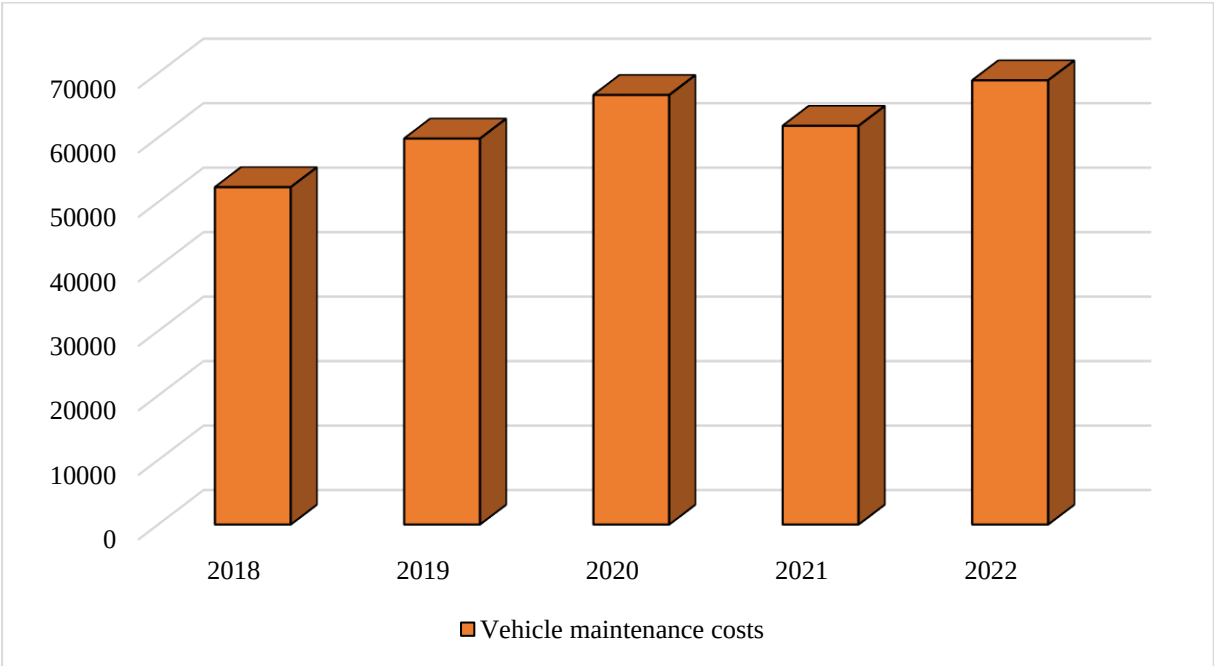

Figure 5. Vehicle maintenance costs

Based on the diagram in Figure 6, it can be concluded that the costs per total kilometers traveled are the highest at the beginning of the observed period, i.e., in 2018 with a value of 0.74. The following figures refer to 2019 and 2022, with values of 0.52 and 0.51. In 2020, fuel costs per kilometers traveled amounted to 0.67, while they were the lowest in 2021 with a value of 0.46.

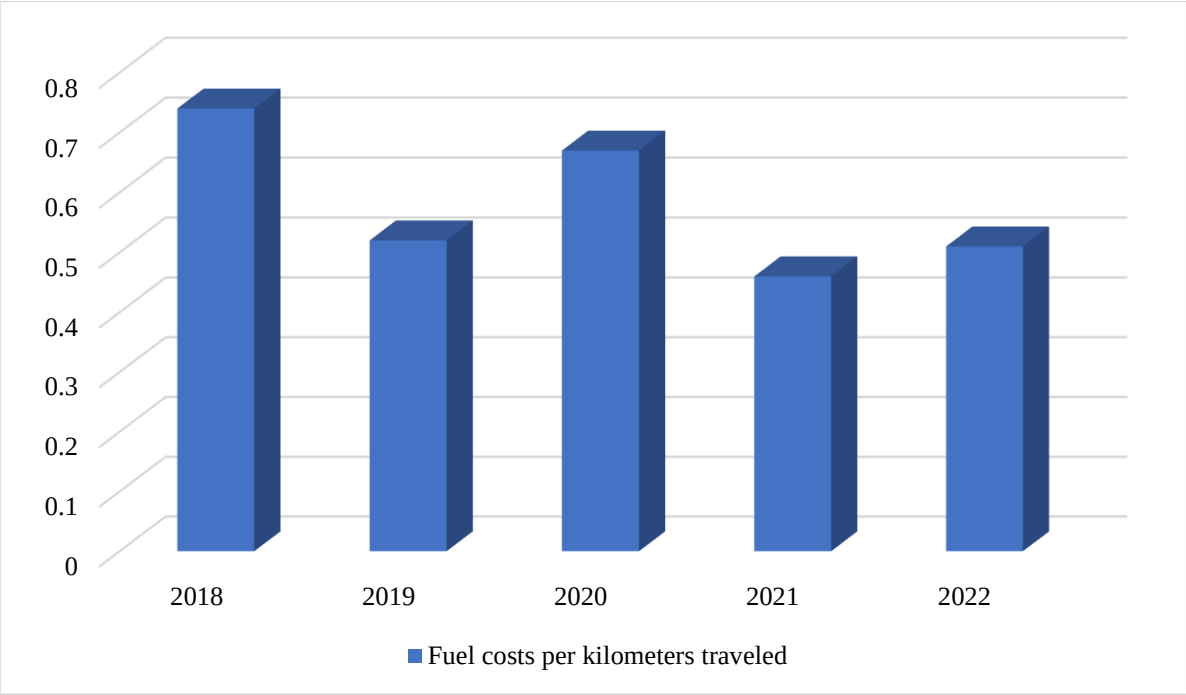

Figure 6. Fuel costs per kilometers traveled

As already mentioned, transport staff costs (Figure 7), in addition to salaries, also refer to the costs of certain contributions for all dispatchers and drivers for all months for the observed period of five years. Therefore, the company had the highest costs in 2020 with the amount of BAM 354,000, then in 2022 with the amount of BAM 307,500, followed by 2021 with the amount of BAM 300,000. In 2018 and 2019, the company had slightly lower costs than BAM 300,000, more precisely BAM 288,000 and BAM 297,500.

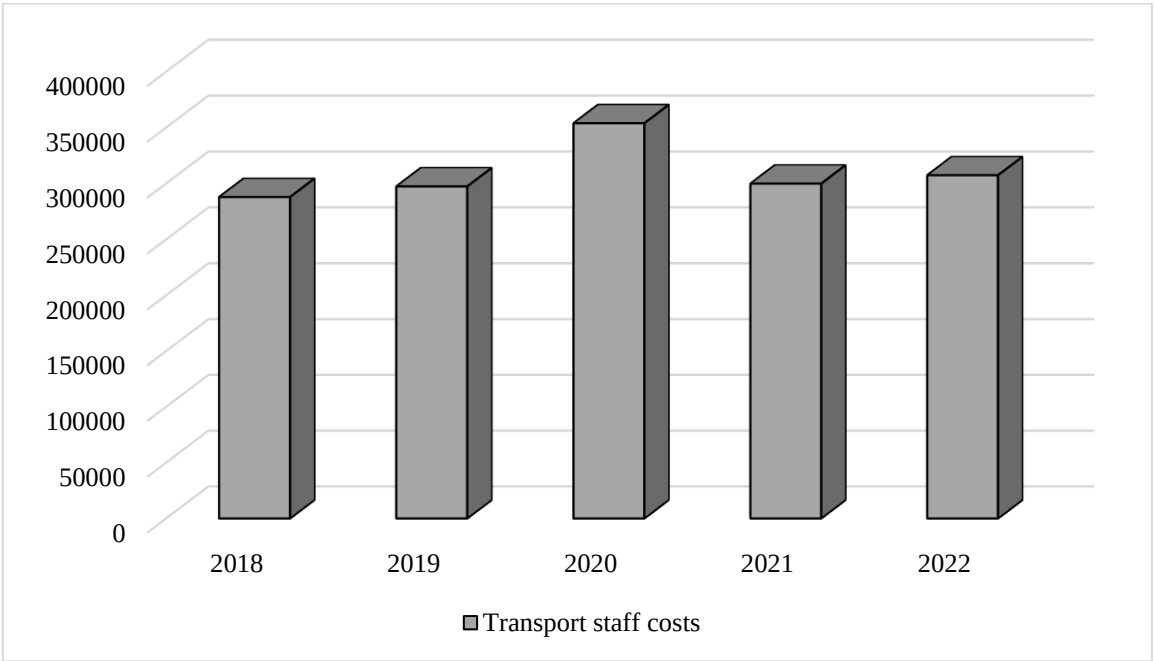

Figure 7. Transport staff costs

Figure 8 clearly shows the difference in profit in the observed period, where the company made significantly less profit in the first three than in the last two years, with the following values: BAM 16,445 for 2019; BAM 17,942 for 2020; BAM 18,123 for 2021; BAM 63,777 for 2021 and the highest profit of BAM 87,202 in 2022.

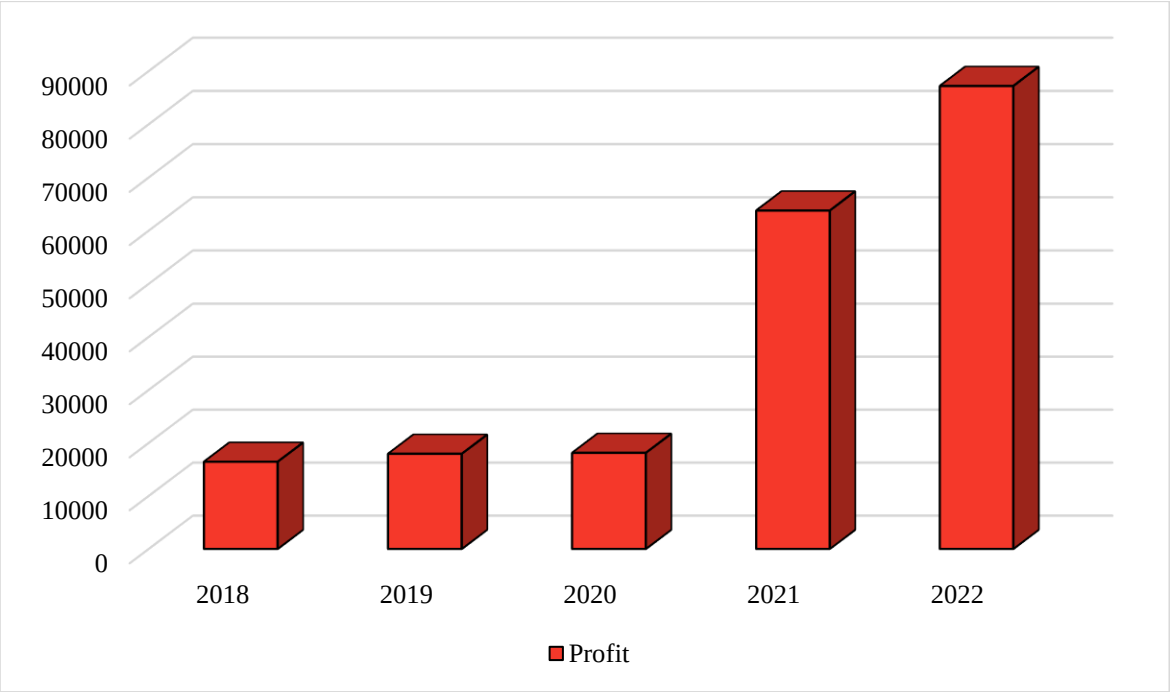

Figure 8. Profit

5. PCA-DEA Model for Determining the Efficiency of the Company

In this paper, the PCA-DEA model was used to determine the efficiency, where 70% of the information from all the data collected was used. For this reason, the number of inputs and outputs was reduced from 6-4 to 2-1 since that was the only way to satisfy the rule on the number of parameters and DMUs. Table 1 shows the data collected from the analyzed company, in the period from 2018 to 2022.

Table 1. Input and output parameters for the observed period

	2018	**2019**	**2020**	**2021**	**2022**
Number of drivers	14	13	15	17	17
Number of vehicles	11	13	14	13	14
Number of operating hours	25300	28080	32250	29950	33320
Vehicle maintenance costs	52305	59841	66598	61815	68872
Fuel costs per kilometers traveled	0.74	0.52	0.76	0.46	0.51
Transport staff costs	28800	297500	354000	300000	307500
Total number of deliveries	698	720	789	1062	1149
Quantity transported	21240	28750	31523	56215	61015
Number of kilometers traveled	1303740	955386	1048075	1100652	1203026
Profit	16445	17942	18123	63777	87202

The values obtained by calculating the efficiency using the excel solver for the PCA-DEA 2-1 model are as follows (Table 2):

Table 2. DMUs and scores 2-1

DMU	**Score**
DMU_1	0.650
DMU_2	0.591
DMU_3	0.567
DMU_4	0.949
DMU_5	1

where:

DMU1 - 2018
DMU2 - 2019

DMU3 - 2020
DMU4 - 2021
DMU5 - 2022.

Based on Table 2 and the calculation of model 2-1 (two input components and one output component) of the PCA-DEA method, it can be seen in which years the company operated efficiently. Business efficiency is successful if the DMU result is 1. In the observed company, that value was only achieved in 2022.

6. Conclusion

For the purposes of this paper, it was performed an analysis of the performance of a company, which is engaged in internal and international transportation. The first part of the analysis was related to the collection of data on the performance of the mentioned company in the past five years. Based on the data collected, input and output parameters were determined. The number of operating hours means the hours spent in the realization of transportation during a given year. The vehicle maintenance costs refer to all regular and also extraordinary costs of all vehicles in the company in a given year. The ratio of total fuel costs to total kilometers traveled represents the parameter of fuel costs per total kilometers traveled. The transport staff costs include the salaries of dispatchers and drivers during the entire 12 months for a given year, paid contributions, etc. The output parameters include: the total number of deliveries, quantity transported, number of kilometers traveled and profit. The total number of deliveries refers to all deliveries made in a given year in the company. Quantity transported as an output parameter refers to the total quantity of goods, expressed in tons, transported by the company during a given year. The number of kilometers traveled implies the total number of kilometers traveled by the company's vehicles during transportation. Profit represents the ratio, i.e., the difference between income and expenditure.

The graphics show all the parameters for which the data was collected, and the following can be concluded from the above: the company had the most vehicles (17) and drivers (14) in 2022; it had the fewest operating hours in 2018 (25,300) and the most in 2022 (33,320); vehicle maintenance costs were the lowest in 2018 (52305) and the highest in 2022 (68812); fuel costs per kilometers traveled were the lowest in 2021 (0.46), and the highest in 2018 (0.74); transport staff costs were the lowest in 2018 (BAM 288,000), and the highest in 2020 (BAM 354,000); the total number of deliveries was the lowest in 2018 (698), and the highest in 2022 (1149); quantity transported was the smallest in 2018 (21240), and the largest in 2022 (61015) and the last parameter, profit, was the lowest in 2018 (BAM 26,445), and the highest in 2022 (BAM 87,202).

After applying the PCA-DEA method in the observed company, which is engaged in internal and international transport, the results obtained show that for the analyzed period from 2018 to 2022, the company operated efficiently only in 2022 since, during the calculation, its DMU had a value of 1, which, in this model, proves its efficiency.

Data Availability

The data supporting our research results are included within the article or supplementary material.

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Conflicts of Interest

The authors declare no conflict of interest.

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