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Optimising the Efficiency of Municipal Utility Vehicle Fleets Using DEA-CRITIC-MARCOS: A Sustainable Waste Management Approach

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Abstract: The efficiency of utility vehicle fleets in municipal waste management plays a crucial role in enhancing the sustainability and effectiveness of non-hazardous waste disposal systems. This research investigates the operational performance of a local utility company's vehicle fleet, with a specific focus on waste separation at the source and its implications for meeting environmental standards in Europe and beyond. The study aims to identify the most efficient vehicle within the fleet, contributing to broader goals of environmental preservation and waste reduction, with a long-term vision of achieving "zero waste". Efficiency was evaluated using Data Envelopment Analysis (DEA), where key input parameters included fuel costs, regular maintenance expenses, emergency repair costs, and the number of minor accidents or damages. The output parameter was defined as the vehicle's working hours. Following the DEA results, the Criteria Importance Through Intercriteria Correlation (CRITIC) method was employed to assign weightings to the criteria, ensuring an accurate reflection of their relative importance. The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method was then applied to rank the vehicles based on their overall efficiency. The analysis, conducted over a five-year period (2019-2023), demonstrated that Vehicle 3 (MAN T32-J-339) achieved the highest operational efficiency, particularly in 2020. These findings underscore the potential for optimising fleet performance in waste management systems, contributing to a cleaner urban environment and aligning with global sustainability objectives. The proposed model provides a robust framework for future applications in similar municipal settings, supporting the transition towards more eco-friendly waste management practices.

Keywords: Utility vehicle fleet; Efficiency; Sustainability; Waste management; Data Envelopment Analysis (DEA); Criteria Importance Through Intercriteria Correlation (CRITIC); Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS); Urban waste

1 Introduction

Developing countries face two challenges: a lack of financial resources to fund missing municipal infrastructure and municipal vehicles, and a lack of public awareness regarding waste separation at the household level and increasing recycling of secondary raw materials from waste (plastics and PET, paper and cardboard, metals, as well as glass). On the other hand, progress is evident in developed countries, which have optimal financial resources for building road infrastructure and acquiring necessary municipal equipment aligned with green and circular economies. Therefore, hybrid and partially electric vehicles are features of modern economies in Europe and around the world.

In this paper, the efficiency of the fleet of the local utility company Progres from the city of Doboj, Bosnia and Herzegovina, in relation to performing regular and extraordinary tasks - collecting and transporting non-hazardous municipal waste from the specified area – has been analyzed. Out of a total of 10 trucks used for daily waste collection and transport from urban and rural areas, four are active daily and are the subject of analysis in this study. The remaining six trucks will be disregarded because they are only used in case of specific breakdowns of the mentioned trucks. Breakdowns are promptly resolved, and there is always one additional truck available (out of the four mentioned) as a reserve option in case of unforeseen repairs or if more time is needed to restore them to service.

The collection and transportation of non-hazardous municipal waste from the city of Doboj are conducted daily (urban zone from 7 pm to 7 am the next day), while in rural areas it is only performed from Monday to Friday between 7 am and 3 pm. The trucks are MAN vehicles with Euro 4 diesel engines, ranging in age from 2001 to 2004. Unfortunately, according to local laws on municipal waste management, the utility company must finance the renewal of its fleet and municipal containers from its current income, as well as pay a fee for leasing public spaces where these containers are located. This represents a significant burden for the company, which serves the general public interest and operates in a low-accumulation sector of the economy. All trucks are technically equipped for waste collection and transportation, along a clearly defined route suitable for containers of 1.1 m^3 and 7 m^3 , as well as municipal bins of 140 and 240 liters in capacity. A notable advantage of these vehicles is the modified attachments on the trucks, designed by experts from the utility company Progres, for servicing all types of municipal containers along the transportation route, ensuring efficiency without idling. This is crucial for optimizing the use of available resources (fuel and lubricants), which poses a significant long-term challenge for Progres.

The paper sets out input (quantitative) parameters, such as vehicle age, annual fuel consumption, minor and major breakdowns on an annual basis, as well as regular and emergency maintenance. For the purposes of this study, these input parameters are examined for a five-year period, i.e., for the period 2019-2023. The role and significance of each vehicle participating in waste collection and transportation are present, along with a proposal for acquiring more modern and cost-effective vehicles, powered by environmentally friendly options – as hybrid or Euro 6 engines, supported by a financial plan for their procurement. Therefore, the aim of the paper is to indicate the current state of the vehicle fleet of the utility company Progres from the city of Doboj, which is among the 10 largest cities in Bosnia and Herzegovina, and to propose measures for the improvement and renewal of the fleet with modern and cost-effective vehicles, provided that the financial framework allows for it.

It is important to emphasize that Bosnia and Herzegovina needs to catch up with modern Europe, especially regarding accession to the Union, i.e., meet all necessary goals it entails, with a particular focus on low-carbon emissions, directly related to the procurement of modern trucks for waste collection and transportation in "green mode". Therefore, we must start thinking about this issue today because tomorrow may be too late, but with the support of the state and clear legislative regulations at the level of both entities of Bosnia and Herzegovina. Unfortunately, laws on waste management are still in effect and differ between entities, making it difficult to access grants directly related to "green" goals and environmental protection.

2 Literature Review

The policy of managing recycling and transitioning from a linear to a circular economy has been a challenge in recent decades, with a primary focus on recycling valuable secondary raw materials from waste, because the percentage of recycled materials annually is negligible in developed countries, but considerably lower in transition countries [1]. However, research has shown that EU countries face challenges in transitioning from a linear to a circular economy, both at the member state level and at a micro level. For instance, certain regions in Italy, especially island areas, lack financial resources to adopt the EU development model in terms of waste management and achieve positive outcomes in circular economy practices [2]. Recent studies within the EU have emphasized the significance of the circular economy, particularly concerning e-waste. There has been a notable increase in the number of mobile phone management strategies [3]. Based on the previous statement, it is clear that the solution to this problem is seen through reverse logistics, return strategy, and resource allocation. The goal of waste management is not only collection and disposal but primary focuses on the 3Rs and maximizing the extraction of valuable secondary raw materials from total waste, thereby recycling and creating new value.

On the other hand, research has shown that the inefficiency of the vehicle fleet and idling on the transportation route during waste collection and transport represent a significant vulnerability of the organization itself [4]. The financial burden, in addition to an inadequate and aging vehicle fleet of the utility company, leads to difficulties not only in waste management but also in addressing critical issues related to preserving human health and the environment in general [5]. According to the same author, optimizing transport routes for waste collection and transport, while adhering to the 3R directive, will lead to positive outcomes for transition countries in terms of resource efficiency and developing waste management strategies aligned with EU directives [6]. Urbanization represents a major challenge for the collection, transport, and disposal of non-hazardous municipal waste. The construction of municipal infrastructure along with defining clear transport routes that effectively support comprehensive waste management systems is an additional challenge [7]. Therefore, population growth in urban areas in the developed world, pressures from environmental associations for a healthy living environment, and the concept of "zero waste" represent additional provocative pressure on forming strategic options for comprehensive waste management in modern cities.

Green growth and development entail significant investments in infrastructure development, and wealthy countries see this as their full potential and competitive advantage—the sustainability of biodiversity, increasing the percentage of recycling in total waste, and the efficiency of municipal vehicles are the main features of this strategy [8]. On the other hand, to achieve the stated goal of wealthy countries, they must also include poor countries, i.e., developing countries, both through social and ecological development and green economy [9]. The success of the business system, and thus of local communities, depends on the management of the company, i.e., the expertise of its leaders, further reflected in the condition of the vehicle fleet, its efficiency, and operational costs. The aim is to reduce costs and innovate business processes, not just to meet formal requirements by disposing of waste [10]. Similarly, the local community plays a crucial role in the chain of the aforementioned process. Continuous monitoring of the vehicles that make up the utility company's fleet, along with periodic reporting to management on their condition, will contribute to the efficiency of business processes in terms of task speed and efficiency, and ultimately the costs of fuel, lubricants, and minor and major breakdowns, which are part of the total fleet costs [11].

Research has shown that diesel-powered utility vehicles must constantly test their fuel consumption and establish a correlation between the year of production of the utility vehicle, the type of fuel, and occasional or even continuous breakdowns throughout the year. The price and quality of fuel as well as the conditions offered by retail stores are directly related to the fuel consumption of utility vehicles and the year of their production [12].

In recent decades, fuel consumption has been the second most important factor in the operating costs of utility companies, immediately after utility vehicle crew [13]. Optimizing synthetic fuels not only contributes to savings in overall company costs but also protects the environment, which is particularly important for the ecological awareness of the local community [14, 15]. Research has shown that the greatest losses occur in the propulsion system of internal combustion engines, and the goal is to minimize the total amount of fuel consumed by the vehicle on a daily, weekly, monthly, and annual basis [16]. On the other hand, studies have also shown that an automated information system facilitates monitoring of fuel consumption in utility vehicles and leads to rationalization in the management of company operational costs [17].

Traffic represents a significant contemporary challenge, being a complex system involving a large number of diverse motor vehicles while adhering to professional standards and legal regulations with the aim of ensuring safe traffic for both vehicles and individuals involved. This complex technical and technological system primarily requires the technical reliability of vehicles participating in traffic, including the impact of minor technical faults on vehicles, in order for the entire system to function flawlessly [18, 19]. Vehicle lifecycle costs, in addition to fuel costs, which is one of the largest items, also include registration and insurance costs, as well as personal income expenses for utility vehicle crew. While we cannot influence the latter two types of costs, it is essential to emphasize the first item (fuel costs), upon which the efficiency and purpose of utility vehicles depend [20]. Choosing the optimal utility vehicle, along with efficiency in operational costs, fuel, and lubricants, poses a major challenge for transition countries. Selecting the best fleet with modern monitoring via web information systems represents the success of the company and the management that oversees it in the long term [10]. Utility companies belong to local communities and are closest to their citizens, aiming to ensure the smooth provision of this service in the public interest, safely, affordably, and by optimally combining available resources. Overall, the local community should support utility companies not only in simple waste collection and transportation but also in the development of a comprehensive municipal waste management system, creating conditions for a safe environment while minimizing greenhouse gas effects [21].

3 Methodology

In this section of the paper, Figure 1 illustrates the applied methodology, where it is clear that the criteria and alternatives of the utility company were first defined. Subsequently, the DEA method was applied to measure efficiency. Following the calculation by the DEA method, the selection of the most efficient vehicle was conducted using multi-criteria decision-making methods.

3.1 DEA

The efficiency measurement of waste collection vehicles in the given company was conducted using the DEA model. DEA models are applied in various fields to assess efficiency, aiming to achieve the most accurate results essential for optimizing specific systems depending on the defined problem.

The DEA method is utilized in productivity and efficiency analyses across different comparisons of companies, organizations, regions, and countries. The DEA method finds increasing importance in logistics [22–25]. Figure 2 illustrates two DEA CCR models [26] applied to obtain the values of alternatives, i.e., Decision Making Units (DMUs) according to the input-oriented model (min) and output-oriented model (max).

3.2 CRITIC Method

The CRITIC method [27] is a correlation method. The CRITIC method includes the following steps and calculations [28–30], schematically shown in Figure 3.

3.3 MARCOS Method

The MARCOS method is implemented through the following steps and calculations [31, 32], as shown in Figure 4.

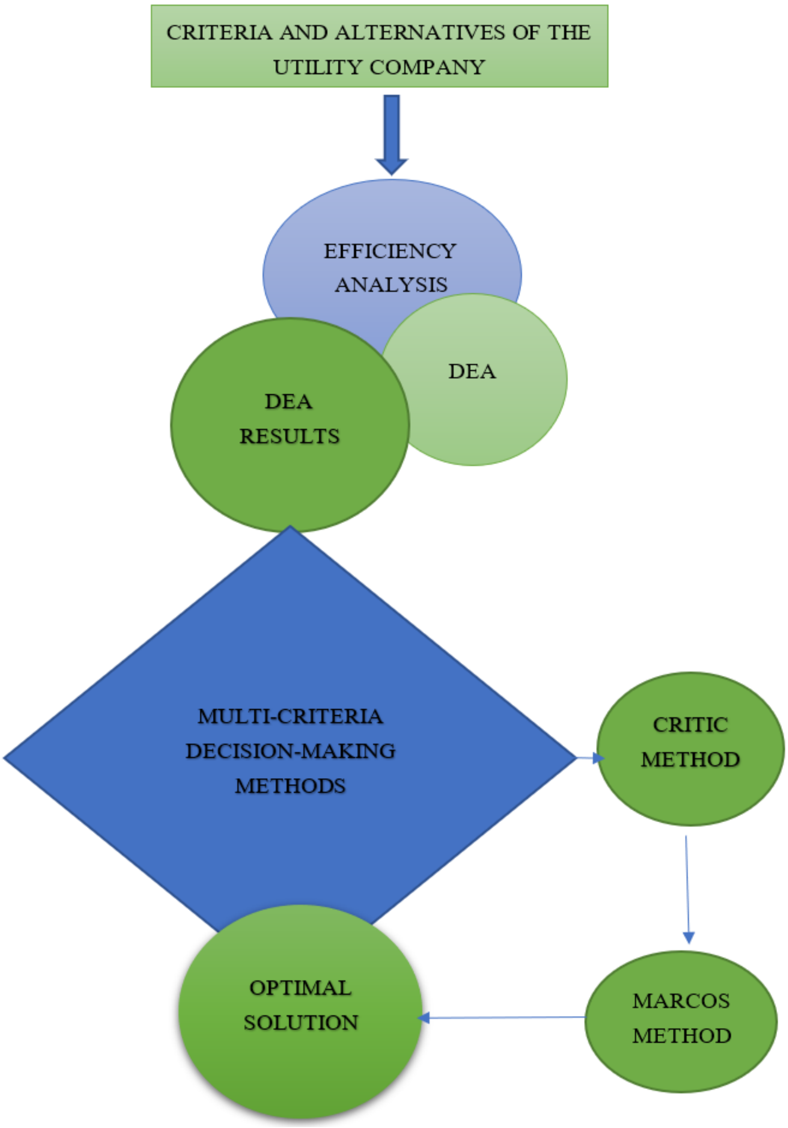

Figure 1. Applied methodology

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

$$st:$$

$$\sum_{i=1}^{m} w_i \, x_{ij} - \sum_{i=m+1}^{m+s} w_i \, y_{ij} \geq 0, \quad j = 1, \ldots, n$$

$$\sum_{i=m+1}^{m+s} w_i \, y_{i-output} = 1$$

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

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

$$st:$$

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

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

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

Figure 2. Input and output DEA CCR models

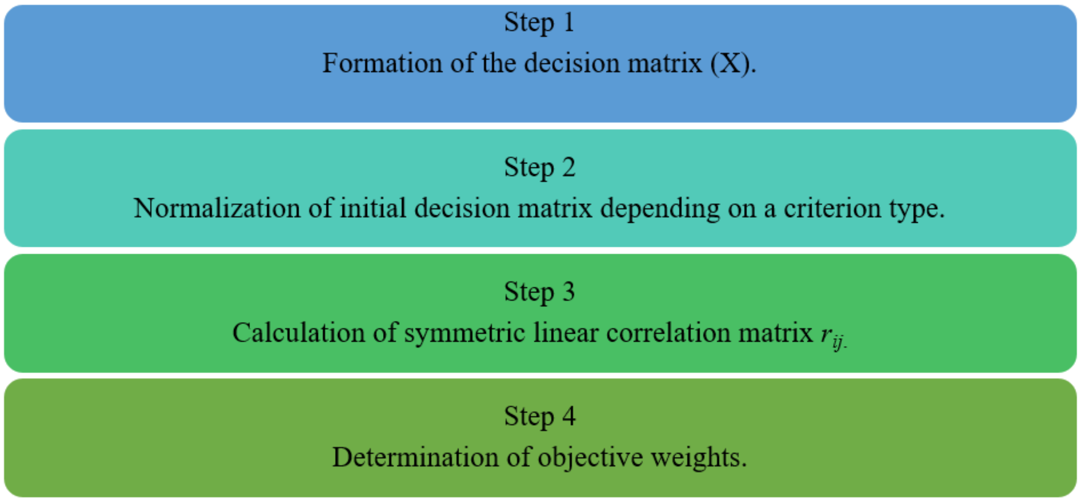

Figure 3. Steps of the CRITIC method

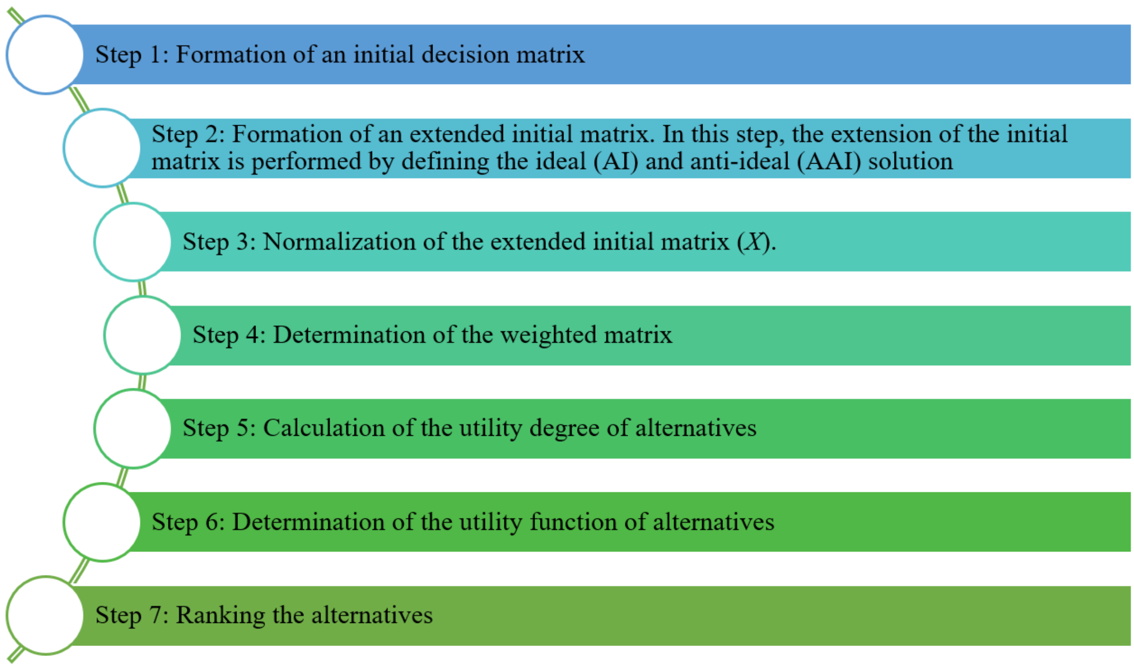

Figure 4. Steps of the MARCOS method

4 Results of DEA-MCDM

Based on the company's previous work and the vehicles in service, it has been determined that there are four alternatives, which are actually four vehicles and five criteria on which efficiency will be calculated. The criteria are:

·Fuel costs;
· Regular maintenance costs;
· Emergency maintenance costs;
· Total number of minor accidents or damages, and
· Number of working hours.

First, the DEA model is applied, followed by MCDM methods: the CRITIC method for determining the weights of the criteria, and then the MARCOS method for defining the most efficient vehicle in the company.

4.1 DEA

The data required for calculating efficiency using the DEA model are listed in Table 1. The analysis covers four specified vehicles for a period of five years (2019-2023). Input parameters include: *fuel costs, regular maintenance costs, emergency maintenance costs, and the total number of all minor accidents or damages. The output parameter in this case is the number of working hours*.

Table 1. Input and output parameters for DEA

Vehicle - DMU	Input 1	Input 2	Input 3	Input 4	Output 1
DMU1-2019	49764	992	1820	2	3960
DMU2-2019	30670	830	1415	4	2040
DMU3-2019	28546	810	1735	4	2030
DMU4-2019	29995	955	3870	3	2052
DMU1-2020	40985	870	1858	2	3780
DMU2-2020	24799	912	1722	2	2048
DMU3-2020	22213	885	950	1	2002
DMU4-2020	23515	820	1880	3	2010
DMU1-2021	51723	920	1985	3	4200
DMU2-2021	31322	875	1705	4	2056
DMU3-2021	30571	900	1820	3	2050
DMU4-2021	29812	1150	2010	1	2050
DMU1-2022	64382	950	2450	7	4320
DMU2-2022	39303	1001	1450	2	2088
DMU3-2022	37122	910	2000	3	2080
DMU4-2022	35525	910	3200	2	2072
DMU1-2023	62545	1081	2085	4	4248
DMU2-2023	37602	910	1580	2	2080
DMU3-2023	36161	890	4010	8	2052
DMU4-2023	31215	1000	7500	6	2060

Below is an example calculation of efficiency for the first vehicle DMU1-2019, using the Input CCR model [26].

$$DEA_{input-vozilo1} Min = 49764 * w1 + 992 * w2 + 1820 * w3 + 2 * w4;$$

$$49764 * w1 + 992 * w2 + 1820 * w3 + 2 * w4 - (3960 * w5) >= 0;$$

$$30670 * w1 + 830 * w2 + 1415 * w3 + 4 * w4 - (2040 * w5) >= 0;$$

$$28546 * w1 + 810 * w2 + 1735 * w3 + 4 * w4 - (2030 * w5) >= 0;$$

$$29995 * w1 + 955 * w2 + 3870 * w3 + 3 * w4 - (2052 * w5) >= 0;$$

$$40985 * w1 + 870 * w2 + 1858 * w3 + 2 * w4 - (3780 * w5) >= 0;$$

$$24799 * w1 + 912 * w2 + 1722 * w3 + 2 * w4 - (2048 * w5) >= 0;$$

$$22213 * w1 + 885 * w2 + 950 * w3 + 1 * w4 - (2002 * w5) >= 0;$$

$$23515 * w1 + 820 * w2 + 1880 * w3 + 3 * w4 - (2010 * w5) >= 0;$$

$$51723 * w1 + 920 * w2 + 1985 * w3 + 3 * w4 - (4200 * w5) >= 0;$$

$$31322 * w1 + 875 * w2 + 1705 * w3 + 4 * w4 - (2056 * w5) >= 0;$$

$$30571 * w1 + 900 * w2 + 1820 * w3 + 3 * w4 - (2050 * w5) >= 0;$$

$$29812 * w1 + 1150 * w2 + 2010 * w3 + 1 * w4 - (2050 * w5) >= 0;$$

$$64382 * w1 + 950 * w2 + 2450 * w3 + 7 * w4 - (4320 * w5) >= 0;$$

$$39303 * w1 + 1001 * w2 + 1450 * w3 + 2 * w4 - (2088 * w5) >= 0;$$

$$37122 * w1 + 910 * w2 + 2000 * w3 + 3 * w4 - (2080 * w5) >= 0;$$

$$35525 * w1 + 910 * w2 + 3200 * w3 + 2 * w4 - (2072 * w5) >= 0;$$

$$62545 * w1 + 1081 * w2 + 2085 * w3 + 4 * w4 - (4248 * w5) >= 0;$$

$$37602 * w1 + 910 * w2 + 1580 * w3 + 2 * w4 - (2082 * w5) >= 0;$$

$$36161 * w1 + 890 * w2 + 4010 * w3 + 8 * w4 - (2052 * w5) >= 0;$$

$$31215 * w1 + 1000 * w2 + 7500 * w3 + 6 * w4 - (2060 * w5) >= 0;$$

$3960 * w5 = 1;$

$w1 > 0; w2 > 0; w3 > 0; w4 > 0; w5 > 0;$

After solving this model, the objective function is 1.000.

By solving all DEA models for each vehicle, the values are obtained as shown in Figure 5, where it is clear that vehicle 1-2019, vehicle 1-2020, vehicle 3-2020, vehicle 1-2021, and vehicle 4-2021 have demonstrated efficiency. These values are integrated into the MCDM model to calculate the most efficient solution, i.e., which vehicle contributes the most to the successful operation of the company.

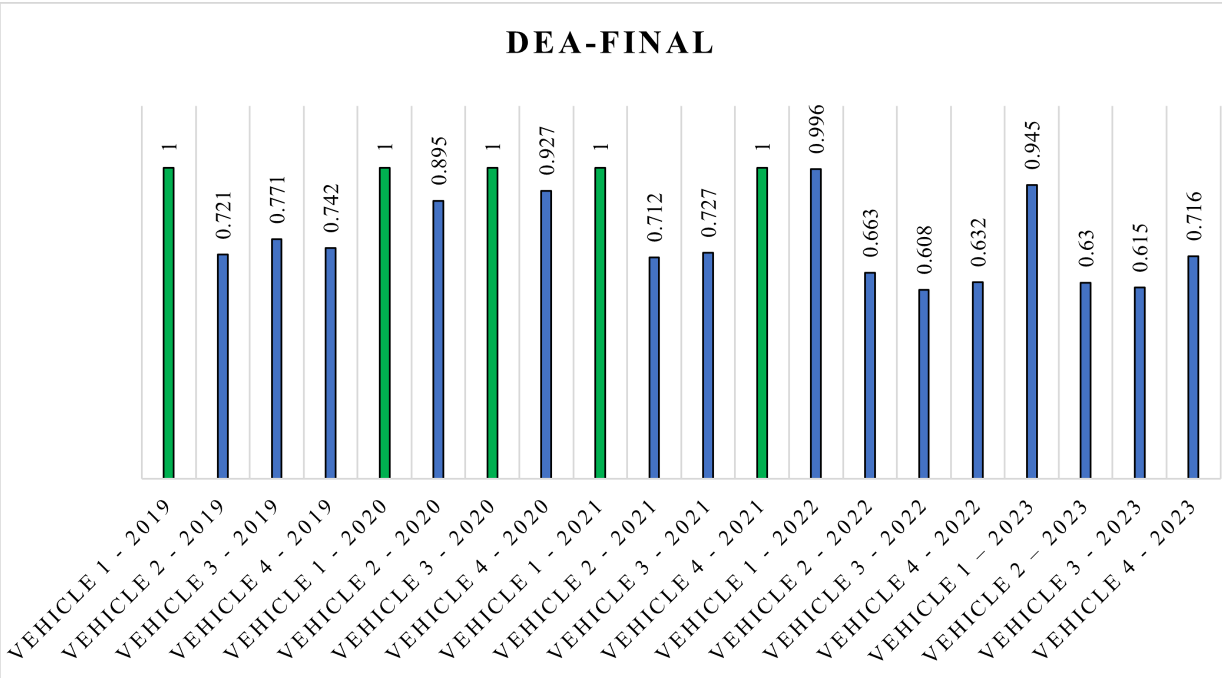

Figure 5. Results of the DEA model

4.2 Determining the Weights of the Criteria Using the CRITIC Method

Step 1. The initial matrix (X) is shown in Table 2.

Applying the remaining steps of the CRITIC method resulted in the final criterion weight values presented in Table 3.

Table 2. Initial matrix

	C1	C2	C3	C4	C5
V1-2019	49764	992	1820	2	3960
V1-2020	40985	870	1858	2	3780
V3-2020	22213	885	950	1	2002
V1-2021	51723	920	1985	3	4200
V4-2021	29812	1150	2010	1	2050
MAX	51723	1150	2010	3	4200
MIN	22213	870	950	1	2002
MIN/MAX	**MIN**	**MIN**	**MIN**	**MIN**	**1**

Table 3. Criterion weights

C1	C2	C3	C4	C5
0.172	0.171	0.136	0.185	0.335
4	**3**	**5**	**2**	**1**

4.3 Evaluation and Selection of the Most Efficient Vehicle Using the MARCOS Method

Step 1: Formation of the initial decision matrix, presented in Table 2.

Step 2: Formation of the expanded initial matrix. In this step, the initial matrix is expanded by defining the ideal (AI) and anti-ideal (AII) solutions.

Step 3: Normalization of the expanded initial matrix (X). The elements of the normalized matrix are shown in Table 4.

$$n_{ij} = \frac{x_{ai}}{x_{ij}}; \qquad x_{21} = \frac{22213}{40985} = 0.542$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}}; \qquad n_{15} = \frac{3960}{4200} = 0.943$$

Table 4. Normalized matrix

	C1	C2	C3	C4	C5
AII	0.429	0.757	0.473	0.333	0.477
V1-2019	0.446	0.877	0.522	0.5	0.943
V1-2020	0.542	1	0.511	0.5	0.9
V3-2020	1	0.983	1	1	0.477
V1-2021	0.429	0.946	0.479	0.333	1
V4-2021	0.745	0.757	0.473	1	0.488
AI	1	1	1	1	1

The weighted normalized matrix is obtained in the fourth step of the MARCOS method by multiplying values from the normalized matrix with the weighting coefficients of the criteria obtained previously using the CRITIC method, as shown in Table 5.

$$v_{ij} = n_{ij} \times w_j; \qquad v_{11} = 0.446 \times 0.172 = 0.077$$

Applying further steps 5, 6, and 7, the following results of the MARCOS method are obtained, as shown in Table 6.

Table 5. Weighted normalized matrix

	C1	C2	C3	C4	C5
AII	0.074	0.129	0.064	0.062	0.16
V1-2019	0.077	0.15	0.071	0.093	0.316
V1-2020	0.093	0.171	0.07	0.093	0.302
V3-2020	0.172	0.168	0.136	0.185	0.16
V1-2021	0.074	0.161	0.065	0.062	0.335
V4-2021	0.128	0.129	0.064	0.185	0.164
AI	0.172	0.171	0.136	0.185	0.335

Table 6. Results of the MARCOS method

	Ki-	Ki+	fK-	fK+	Ki	Rank
V1-2019	1.445	0.707	0.328	0.672	0.609	**3**
V1-2020	1.489	0.728	0.328	0.672	0.627	**2**
V3-2020	1.68	0.822	0.328	0.672	0.708	**1**
V1-2021	1.426	0.698	0.328	0.672	0.601	**4**
V4-2021	1.372	0.671	0.328	0.672	0.578	**5**

According to the results presented in Table 6, it can be concluded that vehicle 3 (MAN T32-J-339) exhibited the highest efficiency in 2020. Following this, in terms of efficiency, vehicle 1 was next, being efficient in 2020, 2019 and 2021, while vehicle 4 was the least efficient in 2021.

5 Conclusions

In this paper, we analyzed the current state of the vehicle fleet of a local utility company in the city of Doboj, whose primary goal is the collection and transportation of non-hazardous municipal waste with efficient fuel and lubricant consumption, as well as unpredictable costs along the transportation route, including potential and ongoing vehicle breakdowns due to their age.

It is evident that the vehicles performing the aforementioned services are between 20 and 23 years old, with a depreciated lifespan and potential issues related to the availability of spare parts for repairs, as well as regular maintenance. A "red" alarm has been raised because the analyzed vehicles may fail to comply with their tasks due to regular operational demands, especially in winter conditions, when they are less reliable and often experience intermittent operational interruptions - the ignition system is frequently questioned. After defining criteria and alternatives, and applying the DEA-MCDM model, it can be concluded that the results of the DEA model show that vehicle 1 was the most efficient in 2019, 2020 and 2021, vehicle 3 was efficient in 2020, and vehicle 4 in 2021. Additionally, it can be concluded that vehicle 2 (MAN E26-A-502) was not efficient in any year and should be taken out of operation. Furthermore, the results of the CRITIC and MARCOS methods show that among the four vehicles that demonstrated efficiency in the previous period, vehicle 3 (MAN T32-J-339) was the vehicle with the highest efficiency and contributed the most to the successful operation of the company. Also, from the final results, it is concluded that vehicle 1 was next in efficiency in the years 2020, 2019 and 2021. Lastly, vehicle 4 (MAN 058-T-914) was the least efficient in 2021.

According to our analysis, the costs of regular and emergency vehicle maintenance, along with regular fuel consumption, have already exceeded their operational lifespan. The recommendation is to either lease the vehicles to less developed municipalities in Bosnia and Herzegovina for occasional use on shorter routes (with a fee for renting the vehicle with a driver), or to sell them at market price. If this recommendation is implemented, we believe it is necessary to purchase a vehicle of the same type (MAN), with a Euro 6 engine or a hybrid drive, with the participation of a local company in a lease or loan with a repayment period of 10 years. This indicator is based on professional opinion and market analysis.

An important conclusion arising from the analysis refers to the number of vehicle breakdowns, with a significant number of breakdowns directly stemming from minor traffic accidents and other incidents. Following a brief interview with the company's management, we have concluded that in certain situations, due to inappropriate speed of utility vehicles or negligence, certain damages to vehicles occur. It is frequent that drivers bear material responsibility as they are at fault for these incidents. Therefore, it is necessary to enhance the awareness of the utility vehicle crew regarding traffic behavior and precautionary measures when collecting and transporting waste, and it is particularly important for the night shift when heightened concentration is required for performing this service.

Are transition countries ready to tackle the current issue of their vehicle fleet in order to efficiently carry out regular tasks related to the flawless service of collecting and transporting non-hazardous municipal waste? Do they have a clear strategy to "engage" potential co-financiers, especially regarding potential grants for the "green" economy? These are just some of the questions that initiate discussion for new research on this highly relevant topic.

Data Availability

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

Conflicts of Interest

The authors declare no conflict of interest.

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