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OPERATIONAL EFFICIENCY AND ENERGY SAVING ANALYSIS OF URBAN TRANSPORTATION: THE CASE OF AKCARAY

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Abstract

Light rail systems are sustainable, energy-efficient, and eco-friendly alternatives to public transport systems that can offer solutions to increasing traffic density. As a solution to that traffic congestion, Akcaray, the first public transportation light rail system in Kocaeli, was launched by Ulasımpark in Kocaeli in 2017. In this study, operational efficiency and service level performance of 12 trams belonging to Akcaray, and 4 bus lines that interact with Akcaray route are compared with one another by Data Envelopment Analysis. It is found out that while the performance efficiency score of Akcaray is 100% in all 12 trams, it is 100% for one bus line only out of 4 busses. In addition, transportation costs, such as energy/fuel, maintenance cost, accident and environmental costs are calculated, and compared separately for both transportation options. Because Akcaray offers less energy consumption per passenger, it is calculated that USD 317,737/year can be saved, thus as a result, Akcaray consumes 1,3 million Sm3 compressed natural gas less while performing public transportation.

Keywords: Public transport, energy saving, light rail system, data envelopment analysis

1. Introduction

Kocaeli is located in Turkey’s most important transit location of transportation with its land, rail, and sea routes. Due to the increase in the city’s population and the traffic volume, existing transportation routes and networks are not sufficient to meet the need. In addition to the fact that the natural geographical situation of the city cannot allow the existing transportation routes and roads to expand, public transportation has become prominent in the face of the increasing traffic congestion. This rise leads to a huge increase in energy consumption and environmental pollution for Kocaeli. As a way to solve this phenomenon, public transportation has become a significant method that enables traveling with less energy and pollution, but with higher number of passenger on the designated routes.

While seeking a solution proposal for public transportation it is necessary to pay attention to criteria, such as travel time, cost, accident risk, vehicle comfort, initial investment, operational and maintenance cost, environmental impact, compatibility with the city in terms of architecture and engineering, ability to respond to increasing demand (expansion), and sustainability. Therefore, Akcaray Light Rail System (LRS) is presented as the ideal solution for the city by Kocaeli Metropolitan Municipality and its subsidiary Ulasımpark. Rail systems, as alternative sustainable transportation methods to increasing traffic density, are used in urban transportation. These systems are preferred because they are fast, safe, clean, and environmental friendly and, they reduce the risk of accidents, operating costs, and noise pollution, also save travel time and energy consumption, and create positive effects on urban land use when they are compared to other public transportation systems [28].

Akcaray, as an alternative solution to public transportation, started its first journey in June 2017. It carries a total of 12 low-floor two-way trams (Figure 1) and 9.1 km of Sekapark-Otogar locations, and the route of the tramline is shown in Figure 2 [17].

Figure 1. Akcaray light rail system

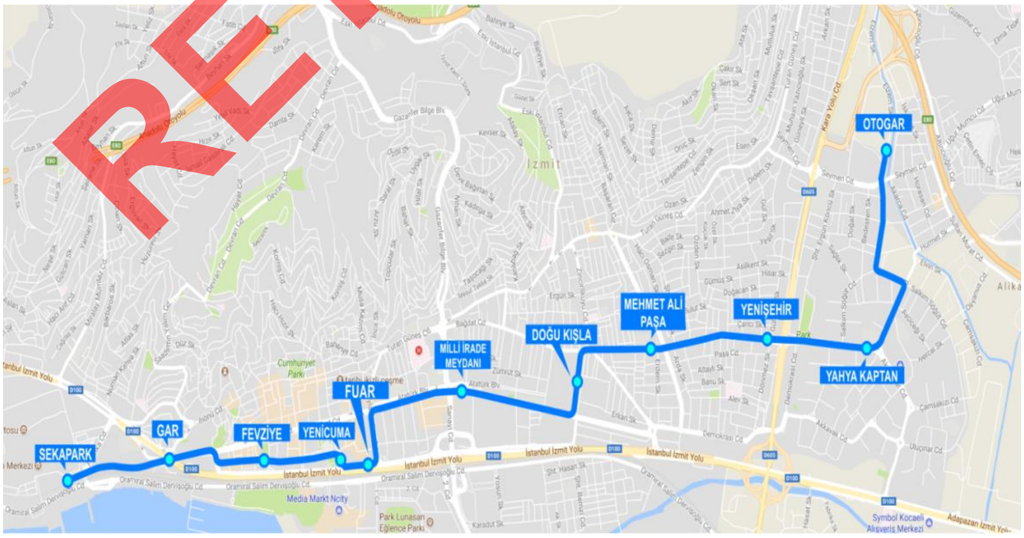

Figure 2. Akcaray light rail system route and stations

2. Literature review

In terms of energy consumption, [38] conducted a study regarding technical and economic evaluation of Istanbul urban public transportation system, and they found out that rail system consumes 0.08 kWh/seat.km energy in Istanbul. They also expanded their research and concluded that if there are 300 passengers on board, the energy consumption is 1.11 kWh/passenger, and it is 0.34 kWh/passenger when there are 1,200 passengers on board. There are also some other studies dealing with the passenger and energy consumption relatedly demonstrates that as the number of passengers increases, the energy consumption per passenger decreases [27]; [24].

LRSs are alternative transportation systems to city buses (diesel or compressed natural gas (CNG) fuel), and they run along the same fixed routes as buses. However, the fuel consumption is a major difference between LRS and bus [33] has determined that for bus transportation, the fuel/energy consumption per passenger is 0.81 €/km, while it is 0.525 €/km for LRS. In addition to that [19] has examined the feasibility and advisability of introducing LRS to medium-sized towns with a population between 100,000 and 300,000 inhabitants in five Central European countries: Poland, the Czech Republic, Slovakia, Austria, and Hungary. They state that the fuel/energy consumption cost of LRS is 0.12-0.15 $/km.passenger.

Many studies with regards to the assessment of a rail system within the literature have been carried out. To place an example, [35] analyze Hong Kong's mass urban rail system performance and they find out that the urban rail system has the fuel/energy consumption rate of 0.076-0.093 kWh/passenger.km and produces 0.055-0.071 kg CO$_2$-equivalent/passenger.km. As it can be deduced from various studies, LRS is beneficiary for municipalities who runs public transportation. That is the reason why the LRS is distributed in many cities, such as Adana, Ankara, Antalya, Bursa, Eskisehir, Gaziantep, Samsun, Kayseri, and Konya in Turkey like in other countries. Although the studies regarding the performance of the rail systems within other countries may vary, studies about LRS in Turkish cities are limited [17] in number. Hence, no study has been conducted on the service performance analysis or efficiency evaluation of Akcaray which has been operating for three years. Therefore, covering a lack found in the literature, within the scope of this study, Akcaray's operational efficiency and service level performance is assessed with the Data Envelopment Analysis (DEA) method, which is one of the multi-criteria decision-making methods. DEA, as a solution technique, is a commonly used powerful performance measurement method, which uses the linear programming model in the background.

DEA, as a data-oriented approach that converts multiple inputs into multiple outputs [8] is used to evaluate the performance of a number of decision-making units (DMU), and is one of the most frequently used efficiency measurement techniques. It was first developed by Charnes, Cooper and Rhodes [10]; [40];[41];[5] state that originally developed in economics to evaluate entities converting several inputs into multiple outputs, DEA has now been evolved into a general benchmarking tool for multi-criteria decision-making. DEA results provide managers with information on managerial performance and operational efficiency of many transport methods, so there are many studies in literature on public transportation (like city buses and LRS) performance assessment done with DEA. [11] utilized DEA to determine operational efficiency and service level performance in 30 different city bus lines, and high and low efficient lines are identified. [14] also employ DEA method to compare efficiency analysis of 179 communal public transport bus companies in Germany. [13] similarly estimates the technical efficiency rate in the regional bus transportation sector by using DEA and find out the implications of efficiency scoring for tender conditions. From buses to more general regional transport issues, [34] propose an improved DEA model to design an approach for measuring the efficiency of regional transportation sector, which as they point out, has also become a major contributor to China's energy consumption and environmental pollution. They aim to show how urgent developing a sustainable and cleaner transportation system has recently become in China.

One of the common outcomes of previous studies indicates that LRS system, as a green transportation system, uses less energy and generates less CO_2 and environmental pollution in comparison with other transport vehicles, such as city buses [9]. To address this issue, [23] also suggest that LRS is a viable transportation mode. [7] compares four Asian and four European high-speed rail systems using the actual system characteristics and performance between the years 2007 and 2012 to investigate the production efficiency and service effectiveness by network DEA. The DEA model shows that Asian high-speed rail systems are fully efficient regarding production efficiency and service effectiveness.

Existing literature proves that DEA can be used to analyze a public transportation system. As it is indicated by [31], DEA cannot solve all of the problems originated from energy, however, DEA may provide an important initial step to handle various issues for developing a sustainable society from the perspective of energy policy, environmental policy, and corporate strategy.

This current paper examines the operational efficiency of Akcaray and the amount of saved energy that it has provided in terms of public transportation. The comparison of Akcaray's operational efficiency and service level performance with bus lines that interact on Akcaray's route is made by DEA. The results from the DEA model and the actual energy consumption per passenger carried on board are compared in detail for Akcaray and bus lines. The final objective of this study is to provide valuable information for the individuals and institutions involved in the process of comparison/determination between LRS and CNG city buses.

3. Methodology

The essential objective of this study is to evaluate the operational efficiency and service level performance of 12 trams, and 4 bus lines along with the calculation of their energy saving. Therefore, DEA is selected and applied as a performance assessment method. The method used in this study has two stages. Selection of suitable DEA model for 12 tram and 4 bus lines, collection of data, determination of input, and output variables to be used in the model, and examination of the results run by the model, constitutes the first stage. In the second stage, in the light of the available data, overall transportation cost is calculated, and compared for both (Akcaray and bus line) transportation options to identify which method is more energy efficient than the other.

3.1 Model selection

DEA is a non-parametric approach that measures the relative efficiency of DMUs by comparing multiple inputs with outputs [40] But, while doing this, DEA does not need to anticipate the relationships between inputs and outputs [15]; [25]. DEA accepts the efficiency levels of the highest performing DMUs as a limit, and then calculates the potential improvements of these units needed to in order for other DMUs to make it more effective according to this limit. In order to better explain how this DEA methodology works, Figure 3 is presented below. Out of a total seven decision units whose activities are relatively measured only one decision unit, point b, is active, other points are below the efficiency limit. Since the specified efficiency limit covers all points, a mathematical expression of this technique is called DEA [40]; [11].

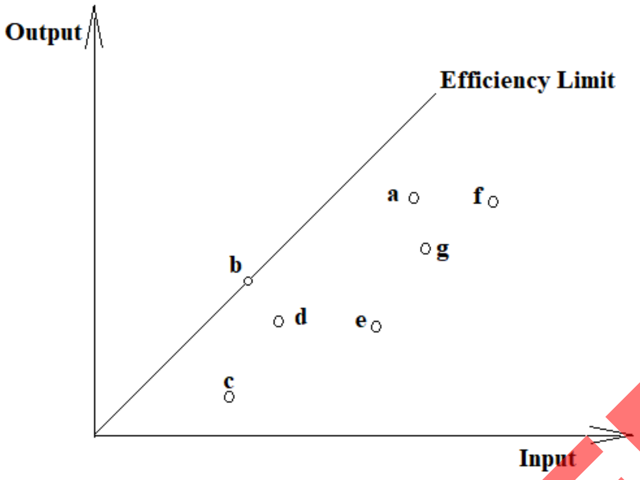

Figure 3. Illustration of the DEA approach

This model aims at maximizing the ratio of outputs to inputs in its most basic form, and it requires this ratio to be between 0 and 1. According to DEA results, the efficiency levels of the DMUs that are above the activity limit are 1, that is, 100%. DMUs with an efficiency value equal to 1 are therefore considered to be effective, and constitute the efficiency limit. DMUs with an efficiency value less than 1 are relatively ineffective, and their relative efficiency values also define the distance to the activity limit. To make it more precise, if the effectiveness of a decision unit is 0.7, this decision unit must reduce all inputs by 30% to be effective [10]; [11]. In other words, the input-oriented models are concerned with whether or not the decision units use their inputs effectively to produce the current output quantities. Although the most widely used models in the literature are CCR (Charnes, Cooper and Rhodes model) and BCC (Banker, Charnes and Cooper model), both methods have input and output oriented applications, and quite often, both methods are used together [4]. In the analysis of this study, CCR, which is a basic DEA model, is used as an input-oriented activity measurement. Assuming that there are *s* DMUs to be evaluated in terms of *n* inputs and *m* outputs, the mathematical expression of how to maximize the output/input ratio is provided below. As observed, the efficiency of *j* (j = 1,2,3, ..., *s*) is obtained from the solution of the programming model.

Efficiency = Output/Input

$$\mathrm{DMU}_k = \theta_k = \frac{\sum_{r=1}^{m} u_{rk} y_{yk}}{\sum_{r=1}^{n} v_{jk} x_{jk}} \tag{1}$$

$$\text{subject to:} \quad \frac{\sum_{r=1}^{m} u_{rk} y_{rz}}{\sum_{r=1}^{n} v_{jk} x_{jz}} \ast 1; \quad z=1,\ \ldots,\ s \tag{2}$$

$$u_{rk} v_{jk} / 0; \qquad r=1,\ldots,m; \qquad j=1,\ldots,n \tag{3}$$

In this formulation, *k*th DMU is evaluated in the set of $z = 1, \ldots, s$ DMUs, with an efficiency measure of θ_k rated relative to all other DMUs. The output data y_{rk} are the value of output *r* for DMUk, while x_{jk} is the input *j* for DMUk. u_{rk} is the coefficient or weight assigned to outputs *r* computed in the solution to the DEA model. Similarly, v_{rk} is the coefficient of weight assigned to inputs j computed in the DEA model [26]; [41].

For each DMU, the weight input/weight output ratio is not expected to exceed 1, but it is expected to take a value between 0 and 1. If $\theta_k = 1$, which means that it is efficient relative to other units. On the other hand, there are two ways to increase the effectiveness of a DMU is either by reducing the amount of input while keeping outputs constant, or increasing the amount of output while keeping the inputs constant [5].

3.2 Analysis and application

The steps of DEA implementation consist of selection of DMUs, selection of input and output variables, data acquisition, selection of the model, and lastly, selection of software. One of the software for the solution of DEA model is Efficiency Measurement System (EMS) [6]. The software employed in this study is EMS 1.3.0.

3.3 Input and output variables decision

The success of the DEA method depends on the accuracy of selecting the right input and output variables. For this reason, special attention should be given to select the inputs or outputs. As presented in Table 1, there is a variety of research paper addressing the number of multiple variables in passenger transport systems to measure the operational service efficiency [11].

Table 1. Preferred inputs and outputs in the existing studies

Author	Inputs	Outputs
Chu et al. (1992)	Vehicle arrival time Population density The ratio of households without cars Financial support per passenger	Number of trips
Güner and Coşkun (2016)	Frequency Service time (min) Number of stops per km Deviation from shortest distance (km) Journey time (min)	Number of unconnected trips
Karlaftis (2004)	Number of buses Number of employees Fuel consumption	Total number of passengers
Karlaftis and Tsamboulas (2012)	Number of employees Fuel consumption Capital	Total number of passengers
Lao and Liu (2009)	The subscribers using the bus around 400m Amount of disabled people	Total number of passengers
Sanchez (2009)	Number of employees Fuel consumption Number of buses	Frequency Average age of buses Avg. number of stops per line Security level
Sun et al. (2017)	Staff number Fixed assets	Operating cost Net profit
Wei et al. (2017)	Total operation time per day Number of operating buses per day Total operating mileage per day	Average daily ridership

Zhang et al. (2016)	Number of standard vehicles Number of employees Government subsidy	Passenger satisfaction Prime operating revenue

While trying to identify inputs and outputs variables used in this analysis of Akcaray and city buses, similar literature have been examined as shown in Table 1.

3.4 Cost calculation

For this analysis, the datasets given by Ulasımpark are used to calculate overall costs. Initially, the maintenance cost for buses is calculated by Equation (4).

$$\text{Bus maintenance cost per passenger} = \frac{\text{Maintenance cost per unit km x daily road taken}}{\text{Average passenger carried per trip}} \tag{4}$$

Another cost parameter is road/LRS maintenance/repair expense. The road maintenance/repair expense is taken as 0.31 USD/km vehicles [36]. The Equation (5) is used to calculate road maintenance cost per passenger.

$$\text{Road maintenance cost per passenger} = \frac{\text{Maintenance cost per km x daily distance taken}}{\text{Average passenger carried per trip}} \tag{5}$$

[1] reviews the operating costs of urban rail systems in his study, and he mentions that the cost for line maintenance for each tram is 0.175 USD/km. As in the road maintenance cost calculation, Akcaray’s line maintenance cost is calculated with Equation (6).

$$\text{Line maintenance cost per passenger} = \frac{\text{Maintenance cost per km x daily distance taken}}{\text{Average passenger carried per trip}} \tag{6}$$

Lastly, there is an environmental benefit, which is carbon dioxide (CO_2) emission and its cost of using Akcaray instead of CNG buses, which should be included in the content of this research. The CO_2 emission of a bus is 0.089 kg/km, while the emission of LRS is 0.065 kg/km [3]; [29] propose a new term called "the social cost of carbon" which represents the economic cost associated with climate damage resulting from the emission of additional tons of carbon dioxide (tCO2). The social cost of CO_2 is accepted as 417 USD/ton according to the study presented by [29].

The environmental cost of a tram and a bus can be calculated by Equation (7);

$$\text{Environmental emission cost per passenger} = \frac{\text{Maintenance cost per unit km x daily road taken x unit disposal cost}}{\text{Average passenger carried per trip}} \tag{7}$$

4. Calculation

In this study, service time, rotation time, trip frequency, and fuel consumption are selected as the input indexes and number of journeys are selected as the output indexes. They are taken into account drawn on the data received from Ulasımpark as well as existing researches about this topic.

I. Service Time (min/day) (Total transportation time per day) (input)

II. Rotation Time (min) (Total travel time from the beginning of the line to the end) (input)

III. Trip Frequency (trip/day) (Total number of trips per day) (input)

IV. Fuel Consumption (USD/day) (Fuel consumption per vehicle) (input)

V. Number of Journeys (amount/day) (Number of trips provided per day) (output)

In the operational efficiency model, the input and output data for DMU units to be analyzed within this study belonging the year 2019 for 12 trams and 4 bus lines can be seen in Table 2.

Table 2. 2019 data (input and output values) for Akcaray and bus lines

Line/ Route	Service Time (min/day)	Rotation Time (min)	Trip Frequency (trip/day)	Fuel Consumption (USD/day)	Number of Journeys (amount/day)
Tram 1	940	70	27	175	3,492
Tram 2	575	70	16	107	2,138
Tram 3	721	70	21	135	2,68
Tram 4	608	70	17	113	2,258
Tram 5	709	70	20	132	2,636
Tram 6	734	70	21	137	2,728
Tram 7	710	70	20	132	2,637
Tram 8	544	70	15	101	2,017
Tram 9	642	70	18	120	2,386
Tram 10	701	70	20	131	2,607
Tram 11	641	70	18	119	2,382
Tram 12	765	70	22	143	2,845
Bus line 1	1,920	120	16	77	742
Bus line 2	3,060	180	17	60	1,026
Bus line 3	1,920	240	8	39	522
Bus line 4	3,060	180	17	78	1,730

The descriptive statistics of inputs and outputs for twelve trams and four buses are presented covering the average level, standard variance, the maximum level and minimum level in Table 3. According to these statistics, the maximum (3,492) and the minimum (522) number of journeys per day evince the substantial difference of journey/passenger amount between tram and buses. Besides, service time, rotation time, and fuel consumption of each means of transportation reveal significant variations.

Table 3. Descriptive statistics of input and output variables

Value	Service Time (min/day)	Rotation Time (min)	Trip Frequency (trip/day)	Fuel Consumption (USD/day)	Number of Journeys (amount/day)
Max.	3,060	240	27	175	3,492
Min.	544	70	8	39	522
Average	1,141	98	18	113	2,177
Standard Deviation	834	52	4	33	782

All of the input and output data given in Table 2 are analyzed by using EMS 1.3.0 software. The results of the EMS software are presented in the Tables 4,5,7,8 below. The result obtained from the software is that the efficiency value/score for almost all trams is 1 (100%), which is given in Table 4. For the bus lines, it is 0.45 (45%) for line 1, 0.76 (76%) for line 2, 0.61 (61%) for line 3, and 1 (100%) for line 4.

As evident from Table 4, in terms of the values in the reference set, tram 2 is 2 times (the value calculated on benchmarks), tram 5 is 3 times, tram 8 is once, tram 10 and 12 is twice, and finally bus line 4 is 3 times referenced by inactive DMUs. In other words, in order to increase the efficiency score of the Tram 3, which is 0.99, 69% of the Tram 10 and 31% of the Tram 12 should be taken as a sample for Tram 3.

Table 4. CCR efficiency scores and reference sets

Line/Route	Efficiency Score	Benchmarks (Reference sets)
Tram 1	1 (100%)	1
Tram 2	1 (100%)	2
Tram 3	0.99 (99%)	10 (0.69) 12 (0.31)
Tram 4	0.99 (99%)	2 (0.50) 11 (0.50)
Tram 5	1 (100%)	3
Tram 6	0.99 (99%)	5 (0.12) 10 (0.37) 12 (0.50)
Tram 7	1 (100%)	0
Tram 8	1 (100%)	1
Tram 9	0.99 (99%)	2 (0.50) 5 (0.50)
Tram 10	1 (100%)	2
Tram 11	1 (100%)	1
Tram 12	1 (100%)	2
Bus line 1	0.4501 (45%)	5 (0.11) 16 (0.26)
Bus line 2	0.7603 (76%)	16 (0.59)
Bus line 3	0.6152 (61%)	8 (0.04) 16 (0.25)
Bus line 4	1 (100%)	3

With the help of the data obtained from the EMS software, input-oriented activity score and the residual values of the variables are calculated, and the results are given in Table 5. According to the CCR model, the efficiency values and residual values of the variables are also determined.

Based on these results, it seems that reducing 520 minutes from the service time of the bus line 3, 389 minutes of the bus line 3, in addition, reducing 31 minutes from the rotation time of the bus line 2, 100 minutes of the bus line 3; and reducing 1 trip from the tram 3, 1 trip from the bus line 1, and 3 trips from the bus line 2 would all increase the operational efficiency of these analyzed lines. These conclusions can be followed in Table 5.

Table 5. CCR input-oriented activity score and residual values of variables

Line/ Route	Operational efficiency scores	Service Time (min/day) 1.input residual	Rotation Time (min) 2.input residual	Trip Frequency (amount/day) 3. input residual	Fuel Consumption (USD/day) 4. input residual	Number of Journeys (amount/day)
Tram 1	1	0	0	0	0	0
Tram 2	1	0	0	0	0	0
Tram 3	0.99	0	0	0.37	0.19	0
Tram 4	0.99	0	0	0	0	0
Tram 5	1	0	0	0	0	0
Tram 6	0.99	0	0	0	0.5	0
Tram 7	1	0	0	0	0	0
Tram 8	1	0	0	0	0	0
Tram 9	0.99	0	0	0	0	0
Tram 10	1	0	0	0	0	0
Tram 11	1	0	0	0	0	0
Tram 12	1	0	0	0	0	0
Bus line 1	0.4501	0	0	0.58	0	0
Bus line 2	0.7603	519.91	30.58	2.89	0	0
Bus line 3	0.6152	388.16	99.37	0	0	0
Bus line 4	1	0	0	0	0	0

In the drawn analysis, twelve trams, which do the similar work on the same route and four other buses, are used as an example. The input variables are changed to construct a new analysis model with different combinations to make a sensitivity analysis and a comparison of the first model. In the following analysis, instead of using twelve trams, one tram is used. The average input and output values of each tram are calculated, this average is assigned to one tram. This tram which has average value of twelve trams is compared to four other bus lines. The aim is to determine whether there is any change in the outcome, when each tram is not included into the analysis. Accordingly, the input and output values used for this second calculation are given in Table 6.

Table 6. Data for tram and bus lines (input and output values)

Line/Route	Service Time (min/day)	Rotation Time (min)	Trip Frequency (trip/day)	Fuel Consumption (USD/day)	Number of Journeys (amount/day)
Tram	690	70	20	129	2,568
Bus line 1	1,920	120	16	77	742
Bus line 2	3,060	180	17	60	1,026
Bus line 3	1,920	240	8	39	522
Bus line 4	3,060	180	17	78	1,730

The descriptive statistics of inputs and outputs for one tram and four buses are presented covering the average level, standard variance, the maximum level and minimum level in Table 7.

Table 7. Descriptive statistics of input and output variables

Line/Route	Service Time (min/day)	Rotation Time (min)	Trip Frequency (trip/day)	Fuel Consumption (USD/day)	Number of Journeys (amount/day)
Max.	3,060	240	20	129	2,568
Min.	690	70	8	39	522
Average	2,130	158	15.6	77	1,317
Standard Deviation	882	58	4	30	746

Table 8 indicates the efficiency values of the lines that constitute the data set. While the efficiency value of the tram is 1 (100%), it is 0.45 (45%) for the bus line 1; 0.76 (76%) for the bus line 2, 0.61 (61%) for the bus line 3, and 1 (100%) for the bus line 4. With respect to the values in the reference set, the tram is referenced twice (the value calculated on the benchmarks), and the bus line 4 is referenced three times by the inactive DMUs given in Table 8. In other words, in order to increase the efficiency score of the bus line 1, which is 0.45, 12% of the tram and 26 % of the bus line 4 should be taken as a sample for bus line 1.

Table 8. CCR efficiency scores and reference sets

Line/Route	Efficiency Score	Benchmarks (Reference sets)
Tram	1 (100%)	2
Bus line 1	0.4501 (45%)	1 (0.12) 5 (0.26)
Bus line 2	0.7603 (76%)	5 (0.59)
Bus line 3	0.6166 (61%)	1 (0.04) 5 (0.25)
Bus line 4	1 (100%)	3

CCR input-oriented efficiency score and data obtained in the residual values of variables are determined and the results are given in Table 9. The results reveal that reducing 520 minutes from the service time of the bus line 2, 405 minutes of the bus line 3, reducing 31 minutes from the rotation time of the bus line 2, 101 minutes of the bus line 3, reducing 1 trip from the bus line 1, and 3 trips from the bus line 2 would increase the operational efficiency of these analyzed lines. These conclusions can be followed in Table 9.

Table 9. CCR input-oriented activity score and residual values of variables

Line/Route	Operational efficiency scores	Service Time (min/day) 1.input residual	Rotation Time (min) 2.input residual	Trip Frequency (trip/day) 3. input residual	Fuel Consumption (USD/day) 4. input residual	Number of Journeys (amount/day)
Tram	1	0	0	0	0	0
Bus line 1	0.4501	4.65	0	0.53	0	0

Bus line 2	0.7603	519.91	30.58	2.89	0	0
Bus line 3	0.6152	405.2	101.08	0	0	0
Bus line 4	1	0	0	0	0	0

As a conclusion of this analysis, initially, Akcaray trams (twelve units) and four bus lines are entered into CCR model. Then, a single tram that has the average of the input and output values of each tram is compared to these four bus lines. The data obtained from both analyses are found out to be very close to each other and the efficiency scores of the second model are at least as good as the first model. In the first phase of this research, operational efficiency and service level performance of Akcaray and bus lines are determined. In addition, some calculations are made empirically to support and recheck these DEA results. Therefore, fuel consumption and number of carried passengers are used to calculate the energy/fuel cost per unit passenger for each transportation vehicle for both Akcaray and bus lines. This way, along with the results of the DEA model, the real savings of Akcaray in public transportation can be calculated. Therefore, not only the operational service level efficiency, but also the gained energy amount can be identified for Akcaray.

5. Results and discussions

As a consequence, the bus lines 1, 2, and 3 turn out to be the ones with the low performance (with an efficiency score below 1). On the contrary, all trams and the bus line 4 prove to be the most operationally active DMUs. As this operational service level efficiency results are obtained from DEA, an additional energy/transport cost analysis represents another feature and/or benefit of Akcaray.

5.1 Energy/Fuel cost

The data received from Ulasımpark is used to determine the fuel consumption of tram and bus. In accordance with the figures of Ulasımpark, 30,805 passengers/day can be transported with a fuel cost of 1,546 USD/day provided twelve Akcaray trams operate. In this case, the cost per passenger turns out to be 0.050 USD/passenger. On the other hand, in the case of transportation with four bus lines on the same route, only 4,020 passengers/day can be transported with the fuel cost of 261 USD/day. The transportation cost becomes 0.065 USD/passenger for the bus. The transportation cost and passenger figures of both ways are provided in Table 10.

Table 10. The difference between Akcaray and bus transportation

Specification	Unit	Bus	Akcaray	Difference
Energy/Fuel Cost	USD/passenger	0.065	0.050	0.015
Passenger amount	Passenger/day	4,020	30,805	26,785
	Passenger/year	1,467,300	11,243,825	9,776,525

If Akcaray was not in operation, and the transportation activity would continue to be carried out with the existing 4 bus lines, and only 1,467,300 passengers/year could be carried. However, now, thanks to Akcaray, 11.2 million passengers/year can be transported with cheaper cost that means less energy consumption. Due to the fact that 9,776,525 passengers can be transported 0.015 USD less cheaper, a saving of 146,647 USD/year can be made with transportation with

Akcaray. It is worth mentioning here that this saving only takes account of vehicle fuel cost. A model based on other operational costs is taken into consideration in the real economic evaluation of Akcaray. The maintenance, acccident and environmental costs along with operational costs are among the most important cost components of public transportation concepts used in this analysis. In order to strengthen this research, it is highly suggested by [23] that mostly operational expenditure is neglected, and is not considered as a part of the transportation cost performance literature to examine the real cost performance of LRS projects. However, for a more realistic analysis, some other operational expenditure, along with the energy spent per passenger, maintenance cost, comfort and safety, the amount of environmental impact (noise/emission, etc.) should also be considered [12] and added to the calculation to make it more precise.

5.2 Maintenance, accident and environmental cost

In addition to the fuel cost in road transport, maintenance costs, maintenance/repair costs of roads, additional costs arising from traffic accidents, and environmental pollution-related costs should be added in determining the overall transportation costs.

5.2.1 Maintenance cost

According to the date received from Ulasımpark, maintenance cost for CNG fuel bus transportation is calculated according to Equation (4):

$$\frac{0.041\ \text{USD/km x } 9.1\ \text{km/trip}}{68\ \text{passenger/trip}} = 0.0055\ \text{USD/passenger}$$

The maintenance cost of Akcaray is 0.0026 USD/passenger due to data came from Ulasımpark.

5.2.2 Road/LRS maintenance/repair expense

The road maintenance/repair expense can be calculated by Equation (5):

$$\frac{0.31\ \text{USD/km x } 9.1\ \text{km/trip}}{68\ \text{passenger/trip}} = 0.041\ \text{USD/passenger}$$

The line maintenance for each tram per trip is also calculated by Equation (6):

$$\frac{0.175\ \text{USD/km x } 9.1\ \text{km/trip}}{131\ \text{passenger/trip}} = 0.012\ \text{USD/passenger}$$

As realized, the cost for road maintenance for each trip is 0.041 USD/passenger while it is 0.012 USD/passenger for Akcaray.

5.2.3 Accident cost

Traffic accidents can occur depending on the instantaneous traffic volume on the road, the type of vehicle used, road and the weather conditions, and the driver. [22] examines the methods available to estimate accident costs and comes up with some figures such as the cost of the accident which is 0.11 USD/vehicle.km for the bus while 0.44 USD/vehicle.km for the LRS.

Taking these into account, accident cost values for the bus and Akcaray are calculated and presented in Table 11.

Table 11. Cost of accident

Specification	Unit	Bus	Akcaray
Cost of accident	USD/vehicle.km	0.11	0.44
Distance	km	9.1	9.1
Accident cost on the route	USD/vehicle	1	4
Average passenger carried per trip	passenger/trip	68	131
Total cost of accident	USD/passenger	0.015	0.031

5.2.4 Environmental cost

Using the Equation (7), the environmental cost of a bus is calculated and presented below:

$$\frac{0.089 \text{ kg/km x } 9.1 \text{ km/trip x } 417 \text{ USD/ton x } 0.001 \text{ ton/kg}}{68 \text{ passenger/trip}} = 0.0049 \text{ USD/passenger}$$

While the environmental cost of a tram can be calculated according to Equation (7) as given below:

$$\frac{0.065 \text{ kg/km x } 9.1 \text{ km/trip x } 417 \text{ USD/ton x } 0.001 \text{ ton/kg}}{131 \text{ passenger/trip}} = 0.0019 \text{ USD/passenger}$$

The environmental cost of bus is 0.0049 USD/passenger, where this figure is 0.0019 USD/passenger for Akcaray.

5.3 Overall transportation cost

A comprehensive cost analysis is done and the results are illustrated in Table 12 where costs are evaluated together in terms of energy/transport cost, maintenance cost, maintenance/repair cost of the road/LRS used, additional costs arising from traffic accidents, and environmental emissions.

Table 12. Cost comparison between bus and Akcaray

Cost Types	Bus (USD/passenger)	Akcaray (USD/passenger)
Energy/Fuel	0.065	0.05
Bus/Tram maintenance	0.0055	0.0026
Highway/LRS maintenance	0.041	0.012
Highway/LRS accident	0.015	0.031
Environmental	0.0049	0.0019
Total	0.13	0.0975

As can be seen from Table 12, there is 0.0325 USD/passenger overall cost difference between bus and Akcaray. Accordingly, the difference in cost between transportation by Akcaray and by bus is presented in Table 13.

Table 13. Bus and LRS detailed transportation cost comparison

Specification	Unit	Bus	Akcaray	Difference
Overall Costs	USD/passenger	0.13	0.0975	0.0325
Passenger Amount	Passenger/day	4,020	30,805	26,785
Difference in Passenger Amount	Passenger/year	1,467,300	11,243,825	9,776,525
Total Saving	USD/year			317,737

If only the energy/fuel cost per passenger is considered, the amount of savings achieved with Akcaray is 146,647 USD/year. When other transportation costs, such as vehicle maintenance cost, road/LRS maintenance cost, accident cost, and environmental cost are also included, and this saving amount increases up to 317,737 USD/year. Therefore, it is derived from this research that Akcaray makes a great contribution to Kocaeli and country’s economy. If CNG unit price of 0.25 USD/Sm^3 [2] is taken into account, 1.3 million Sm^3 CNG less is consumed for public transportation purposes with the amount of savings obtained in Akcaray. Consequently, CNG consumption decreases by 0.68% thanks to Akcaray in Turkey where 192 million Sm^3 of CNG is consumed annually.

Urban transportation running on fossil fuels cause pollution and require high energy. This fact forces municipalities to increase efficiency of transportation in terms of higher service quality with less energy consumption. In order to reduce the amount of energy spent for public transportation activities, LRS seems to be an ideal transportation type. LRS both reduces the impact of urban mobility and is probably the most valid method for provinces, such as Kocaeli with relatively high geographical constraints. In this study, the operational efficiency of twelve trams belonging to Akcaray and four bus lines that operate on the same route is analyzed by conducting multi-criteria decision-making tool for the first time. DEA have been in the use of performance measuring and to compare different methods of public transport within the literature but DEA analysis is combined with energy saving calculation to compare light rail system and city buses with this study.

By using this approach, this paper calculates and combines the overall transportation cost per passenger, and the operational efficiency values/scores. While doing this, two separate approaches have been used. Firstly, twelve trams and four bus lines that interact with the Akcaray route, secondly with one tram values (average values of twelve trams are taken) and four bus lines are analyzed separately. As understood from the results, some minor differences have occurred between two DEA calculations, and the efficiency scores of the second model are at least as good as the first model. Results suggest that efficiency scores can provide limited information about performances of trams and buses only to make a comprehensive comparison among them or to comment on their cost/energy consumption analysis. To make this study more valuable and worth reading, overall transportation cost comparison is added as a means of verification of DEA results.

6. Conclusion

This study is aimed to give an idea to individuals and institutions that are in the process of deciding to invest in light rail systems or for those who are going to prepare a feasibility report about light rail systems. The combination of DEA and overall transportation cost analysis made in this research allowed to determine the best performing transport solution for Kocaeli. In the light of this study's findings, the following implications are provided accordingly:

- While annually 1,467,300 passengers can be transported by bus, 11,243,825 passengers can be carried with Akcaray as a result of the public transportation activity. The difference between both is 9,776,525 passengers annually.

- The energy/fuel cost difference between the bus and Akcaray is 0.015 USD/passenger.

- When a comparison is made that takes into account all other costs besides energy/fuel cost, the cost of transportation by bus is 0.13 USD/passenger, while this cost is calculated as 0.0975 USD/passenger for Akcaray.

- If only the energy/fuel cost per passenger is taken into account, the amount of savings achieved with Akcaray is 146,647 USD/year, whereas, when other transportation factors, such as vehicle maintenance cost, highway/LRS maintenance cost, accident cost, and environmental cost are all evaluated together, this saving amount turns out to be 317,737 USD/year.

- The total annual saving made with Akcaray is achieved by less energy consumption. Therefore, 1.3 million Sm^3 CNG less is consumed, and, thus, CNG consumption have decreased 0,68 % in Turkey thanks to Akcaray.

- These savings will, most probably, increase when the capacity of Akcaray increases with the new lines added to the existing ones.

- What is more, one of the strongest sides of Akcaray is that it both reduces the travel time and consumes less energy spent on public transportation. Besides, it is viable due to its technological, economic, and environmental features. Because the buses run on CNG, this can be an advantage as the transportation cost is less per passenger. But, they carry fewer passengers than Akcaray, which makes Akcaray favorable in the field of public transportation.

- The operational performance efficiency of Akcaray and the amount of savings provided are demonstrated in this article.
- Future work is needed to deal with some other energy saving opportunities such as recovery of lost energy caused by braking while Akcaray approaching the stops, energy-efficient/eco driving, vehicle mass reduction, and with more efficient consumption of energy in the wagons of Akcaray.

- Localization of some equipment, spare parts, and systems belonging to Akcaray may also reveal different saving possibilities that need to be researched.

The results that can be drawn from the analysis revealed in this study show that Akcaray is far better transportation alternative than CNG buses. This paper covers a gap of Akcaray's operational efficiency and its real energy saving potential for the first time. In this respect, this study makes a great contribution to the existing literature.

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