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WARSAW UNIVERSITY OF TECHNOLOGY Index 351733	DOI: 10.24425/ace.2020.135223
FACULTY OF CIVIL ENGINEERING COMMITTEE FOR CIVIL AND WATER ENGINEERING	ARCHIVES OF CIVIL ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945	Vol. LXVI ISSUE 4 2020

A DATA ENVELOPMENT ANALYSIS BASED FOR EVALUATING EFFICIENCY OF BUS PUBLIC ROUTES

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The public transport service is highly essential to meet the demand due to a rapidly growing population and mobility. Thus providing public service and improve its service becomes an urgent need in recent years. In Iraq, the Bus system represents the backbone in public transportation, which is based mainly on highway infrastructure. To meet the growing mobility needs, enhancing public service provided only by bus routes is essential. Measuring bus route performance represents one of the crucial transit research topics in the last recent years. The current study tries to investigate the urban public route's efficiency utilizing the "data envelopment analysis (DEA)" technique. To analyze route performance, DEA is using, and performance measures include route design, cost, service, operation, and comfort efficiency are selected and calculated for different routes. Efficiency and effectiveness are the output of this process. Bus company owners can also use the results of this study to improve their services, attract new customers, and better manage their resources.

Keywords: DEA; Efficiency; Effectiveness; Bus Routes; Public Transport; Bus service.

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1. INTRODUCTION

Public transport is a shared service; it is available to use by the general community. Increasing attention to public transportation is an urgent need to increase transit ridership, reducing air pollution, energy consumption, and try to encourage the community to leave driving alone. The growth rate of private cars in Iraq has increased to become 3.5%, with extensive vehicle registrations occurred after 2003 [1]. This increase has its effects on the weakness of the public transport system. Accordingly, traffic congestion, air pollution, accidents, and the need for parking spaces have increased. Public transport is an active mode to reduce GHG emissions; therefore, they must give priority in planning for urban economic development, the recommended policy is to increase investment in public transportation. (International Association of Public Transport, 2006).

Organizations must try to improve service performance with financial constraints to attract more users [2]. The bus service currently suffers from severe delays, which represent the primary discouraging reasons to use bus public transport. In addition to that, the service is not comfortable for all users. Planner decision-makers must search to define problems faced by public transport and try to provide an attractive public transport service.

In many developed countries, public transport was studying extensively. Still, this study represents the first of its kind in Iraq due to the absence of technical resources and the lack of related data to measure transit performance. It tries to study some aspects of bus routes and estimate the efficiency of each route. An efficient transit system can lead to less operational costs, waiting time, better utilize vehicles with increase comfort to passengers. This study shows a methodology that could help transit operator to evaluate their resources.

2. BACKGROUND

Public transportation has an essential role in carrying out daily activities of communities by providing mobility and accessibility; this creates an increasing need to measure and monitor the performance of the service they provide [3]. Transit performance was studying by many transportation Planners [3]–[10]. Marcius Carvalho et al., 2015 [11] show that the DEA application is very significant in the urban transport area. Viton (1998) [12] applied a non-parametric DEA procedure to estimate the productive efficiency of a transit system. Karlaftis (2004) [5] used DEA to assess the US transit systems efficiency for five years; they found the existence of positive relations between efficiency and effectiveness. Asit Bandyopadhyay et al. [13] try to measure bus route performance in Kolkata in related to financial and operational aspects, a modified DEA based on semi-oriented radial measure model was proposed, this method gives an improved efficiency compared with the conventional model. Jin-Seok Hahn et al. (2010) [14] try to improve bus service by using a "network Data Envelopment Analysis (DEA) model" to evaluate the transit system to get a more realistic condition. The operator running a transportation service and the user consumed; it considered in the model by placing the user and operator outputs in the model [15]. Fielding et al. 1985 [16] states that Cost-efficiency measures connect service inputs "labor, capital, fuel" to the service output "vehicle hours, vehicle miles, capacity miles, service reliability." Cost-effectiveness measures connect the level of service consumption (passengers, passenger miles) to service inputs. Service-effectiveness measures indicate the level of service outputs consumed, as shown in Figure 1. In the literature, the primary use of the DEA approach is to examine the transit system performance while limited research presented on evaluates subunits such as bus route performance. Existing literature showed an absence to assess the efficiency of public transport in Iraq.

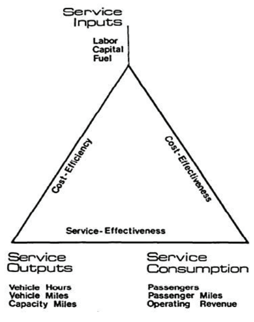

Figure 1. Efficiency- Effectiveness of Public Bus Routes, fielding et al. 1978[16]

3. THE DEA MATHEMATICAL MODEL

The DEA is a non-parametric method applied to compare the efficiency measurement of several units with the same objectives using linear programming. It gives an image of a general measure performance of different units. Firstly, Charnes et al. (1978) [17] introduced it, and later Banker et al. (1984) [18] extended this technique. A key advantage of DEA was by handled multiple inputs and outputs; this gives comprehensive consideration for analysis units. Inputs and outputs of units depend on the properties of the system analyzed. Inputs represent resources to run the service, and the output represents the quality of service provided. Decision-making units (DMUs) are units evaluated by DEA, they are a collection of divisions or any other systems, and for example, it may be hospitals, banks, or transit systems. DEA is used to estimate weights in an objective and economical manner based on linear programming [19]–[21]. DMUs use various inputs to produce a specific output. DEA procedure tries to measure the most efficient DMUs and refer to inefficiencies in the other DMUs [22], [23]. DEA is a useful tool characterized as a non-parametric model; it can use multiple inputs/outputs. It works with various inputs and outputs that have a different unit. DEA finds a frontier that represents the efficiency and calculates the efficiency score for all DMU under consideration.

A few features of DEA are:

- It avoids subjective evaluation; in the beginning, it does not need any weight.
- It does not require default input and output function.
- It suggests the change could occur to increase performance improvement

DEA is a linear programming problem as formulated in the equation below to determine the efficiency score E_k for each DMU_k:

$$Max.E_k = \frac{\sum_{j=1}^{n} U_j^k Y_j^k}{\sum_{i=1}^{m} V_j^k X_i^k} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$Max.E_k = \frac{\sum_{j=1}^{n} U_j^k Y_j^r}{\sum_{i=1}^{m} V_j^k X_i^k} \leq 1, \text{ the DMU is one of R, r=1,2,...., R}$$

$1 \leq K \leq R$

$$U_j^k \geq \varepsilon > 0, j = 1,2,3,4$$

$$V_i^k \geq \varepsilon > 0, i = 1$$

Where

u_j^k is a variable that represented the output j weight under the aim of maximizing efficiency

v_i^k is a decision variable that represented the input i weight under the aim of maximizing efficiency

And ε is a non-archimedean number

The most popular DEA models are "Charnes-Cooper- Rhodes (CCR) and Banker-Charnes-Cooper (BCC)"; they represent the basic models in the analysis approach [24]. The mathematical description of CCR model can represented as follows:[20], [23], [24]

$e_{o=\max} \sum_r u_r y_{ro} \, / \sum_i v_i x_{io}$ ....(2)

$s.t.\ \sum_r u_r y_{ro} \, / \sum_i v_i x_{ij} \ \leq 0, a$ all j

$u_r, v_i \ \geq \varepsilon, \ \ all\, r, i.$

ε is a non-archimedean value; it designed to remain a positive sign for variables.

The CCR model assumes fixed returns to scale, that the scale has no effects when there is an addition in inputs, outputs could then increase [25].

The DEA method can be "input-oriented or output-oriented." Input oriented means to try to decrease inputs while saving the same values of outputs [24]. In contrast, output-oriented seeks to maximize output using the same input levels [24].

Cooper et al. (2000)[24] state if the number of DMUs higher than the number of inputs and outputs, discrimination can be lost between DMU. Therefore, it suggested that the minimum number of DMUs would be the total of outputs and inputs.

The BCC model can formulate as listed below:

$e_o^* = \max[\, \sum_r u_r \, y_{ro} - u_o] \, / \, \sum_i v_i \, x_{io}$ ....(3)

s.t. $[\sum_r u_r y_{rj} \ - uo] - \ \sum_i v_i x_{ij} \ \leq 0$ $\qquad j = 1, \ldots \ldots, n$

$u_r \geq \varepsilon$, $v_i \geq \varepsilon$,

u_o unrestricted in sign

4. CASE STUDY

Several bus routes operating in Baghdad city are elected as a case study for evaluating their efficiency; these routes are shown in Figure 2. The author conducts three surveys: a ride check survey, a point check survey, and a user opinion survey during the AM peak period for three days. During the ride check survey, the boarding and alighting was recorded manually at every bus stop. Various locations of the stops recorded using GPS devices. The data collected using GPS include the route length, number of stops, speed, travel time, and exact location of the bus stop. During the point check survey, frequency, and headway data collected. Also, another survey is conducted. This survey gives information about the user's opinion for their satisfaction toward comfort during the traveling.

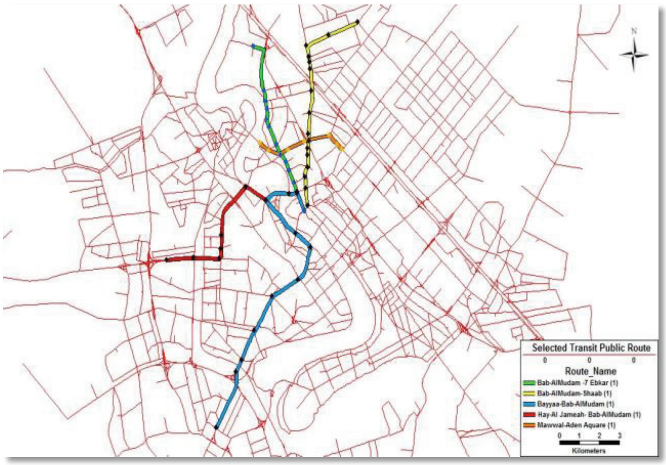

Figure 2. Selected Bus Routes

5. TRANSIT PERFORMANCE INDICATORS

Transit performance indicators give planners an attempt to improve route efficiency for better performance in the future [26]. Reliability and travel time and are the most factors affecting transit performance. Several indicators selected for measuring transit system performance [5].

Index indicator selection is the critical step in this study and needs to base on some rules as follows:

- Indexes should get it easily
- Indexes should represent the main characteristics of bus routes
- Indexes should be few as possible

The input and output of the DEA model should follow some basic requirements, such as values of input/output, that should be positive. After data collected and acquitted, index indicators calculated. The following, an explanation to define service indicators were explored in this study:

- Headway: It is the time interval separation between successive buses.

- Dwell time: It is the boarding/ alighting interval at stops.
- Load rate: it is a vital index; it indicates the comfort of passengers. Passengers feel comfortable when the load rate value is lower, while higher load rate value indicates more costs for operators.
- Fleet size: is the total number of vehicles operated for every route.
- Fuel consumption: is a necessary input to evaluate efficiency analysis of public routes. Because limited data available and the lack of information on fuel consumption have led to the use of travel time value in this study to reflect fuel consumption value, as the travel time increases the fuel consumption also increased.
- Ridership: Due to there is no data relating to travel demand for bus routes operating in Baghdad city. Therefore values of travel demand for selected bus routes are used based on results from Asmael N. 2018 [27], which minimizes effort to estimate demand values.
- Route Directness: represent the distance traveled by car to the distance traveled by bus; the big ratio is the better.
- Frequency is an important factor used to specify route operation; it represents the number of buses cross a given point during an interval [28].

Data of five bus routes operating inside Baghdad city center were collected, and their characteristics were identified in Table 1. Data were collected using manual counting and GPS; it has been organized, verified, and used in the analysis.

Table 1. Route Properties

Name	Route Code	No .of Stops	Length Km	Fleet size	Travel Time Minute	Dwell Time Second	Frequency	Passenger/hr
Bab- Moatham- Shaab	R1	20	11	400	38	17	150	2552
Bab- Moatham – 7Ebkar	R2	13	8.5	24	24	11	12	171
Mawwal- Aden Square	R3	9	4.6	200	14	16	66	2364
Hay-AlJameah- Bab-Moatham	R4	10	10	50	35	9	20	407
Bayaa- Bab- Moatham	R5	13	15	238	56	17	43	1392

6. DEA APPLICATION

For finding the efficiency of bus routes using the DEA, a list of efficiencies defined, which include: route design, cost, service, operation, and comfort. Then find a list of variables and categorized as input (X) and output (Y), input and output variables selected according to the defined efficiency, and based on the data availability. By applying the DEA model for different assumptions, like (CRS) and (VRS), all DMU unit's efficiency can be estimated. Due to minimize the cost of service, the input-oriented DEA selected. Using the CCR model, the weights (ui, vj) of inputs and outputs are first estimated. DEA Solver LV8 (2009) [29] used for this task. When the weights calculated, then the efficiency of each bus route evaluated. The best efficient route can rank using this model. An inefficient unit can be detected, the sources of their inefficiency can be determined, and methods to improve their performance can apply.

6.1 DEA MODEL SPECIFICATIONS

The route performance measures evaluated concerning its effect on the operator, user, and community. Different route efficiencies were used. The performance measures consist of;

- Cost-efficiency is an indicator for the financial and route productivity,
- Service efficiency is an indicator to measure the operation of bus routes,
- Route design efficiency is an indicator to measure the spatial coverage and directness,
- Comfort efficiency is an indicator that measures the comfort perceived by users.

All the measures used are shown in Table 2.

Table 2- Measures of the DEA model

Measures Index	**Input (X)**	**Output (Y)**
Service Efficiency (quality of service)	Total no. of stop	Av. Operation speed
	Delay	
	Number of intersections	
Service effectiveness	Vehicle –Km	No. of Passenger
Route Design Efficiency	Population density covered	Route directness

	Ridership/route	Spaces
	No. of transfer	
Operational efficiency	Time	No. of passenger
	Length	
	Stops	
Technical (Cost) efficiency	Fleet size	Vehicle –KM
	Travel time	No. of Passenger
	Revenue	
Service availability	Fleet size	Number of Hour service
	Frequency	
Comfort	Length	User opinion
	Travel time	
	Load Factor	
	No. of Stop	

6.2 DEA APPLICATION RESULTS AND DISCUSSION

DMU, in our case, is every bus line under evaluation. To apply the DEA method, Arc GIS is used to estimate bus attributes. Issues concerned with the inefficient operation of bus routes identified, DEA based measures can be determined to identify these issues. The score scale of Lao and Liu (2009)[30] used to classify the efficiency and effectiveness of various public routes as listed in the following Table 3:

Table 3- Scores of Efficiency [30]

Score	Efficiency / effectiveness
1	Efficient/effective system
0.6-1	Fairly efficient/effective system
Less than 0.6	Inefficient/ineffective system

The slack analysis discussed too. The presences of slack indicate decrease input or increase output to keeping the same efficiency. When slacks value equal zero, it means DMUs are efficient [17], [24]. The following Tables show the results of DEA application, and the routes are classified according to efficiency and effectiveness scores as follows:

1. Service Efficiency

From the results of Table 4 and Figure 3, it appears that R1 and R5 are less efficient than other routes. These routes have a longer travel time and, accordingly, lower speed. The reason is that the layout of route R1 goes through the residential and shopping center, where there are many signal intersections and stops. Route R1 could be efficient if the number of buses working during hours reduced because some bus services run nearly empty while others overloaded due to the larger number of buses operating during the hour. While Route R5 can be efficient if the length of the route shortened or decreased the number of intersections.

Table 4. Slack Analysis for Service Efficiency of Bus Routes

Service Efficiency				Slack			
No.	DMU	Score	Rank	No. Stop	Delay	No. Intersection	Speed
1	R1	0.612	4	1.632	5.712	0	0
2	R2	1	1	0	0	0	0
3	R3	1	1	0	0	0	0
4	R4	1	1	0	0	0	0
5	R5	0.5318	5	0	0.266	0.479	0

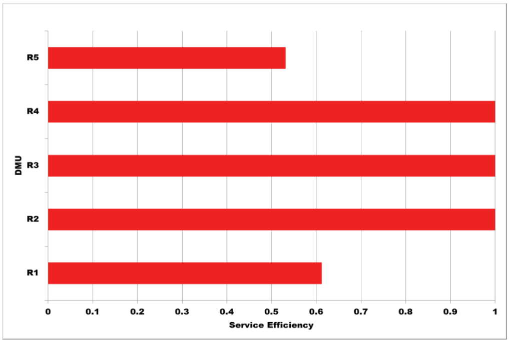

Figure 3. Service Efficiency of Bus Routes [29]

2. Service Effectiveness

This measure answers the following question: is the supply meet the demand requirement? The number of fleet size is vast for all routes, and due to traffic congestion and random operation of buses, more than one bus arrives at a stop; this causes one of the buses is full of passengers, whereas the next bus is empty. This case causes inefficient transit usage. It observed from Table 5 and Figure 4 that R3 is the most effective and efficient one. The offered supply is meeting the demand requirements without the excessive operation of empty busses, which increases operation cost. It recommended that the schedule strictly forced.

Table 5. Slack Analysis for Service Effectiveness of Bus Routes

Service Effectiveness				Slack	
No.	DMU	Score	Rank	Veh-km	Passenger
1	R1	0.1986	5	0	0
2	R2	0.2153	4	0	0
3	R3	1	1	0	0
4	R4	0.2613	3	0	0
5	R5	0.2772	2	0	0

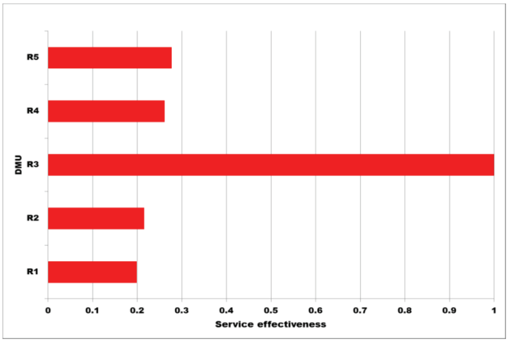

Figure 4. Service Effectiveness of Bus Routes

3. Operational Efficiency

From Table 6 and Figure 5, it observed that all routers have an efficiency score of less than 0.6 except R3. Route R5 has long travel time, among other routes. From the slack results, the efficiency can be improved; if the travel time reduced, the increase in travel time is due to traffic congestion. The overall operation of buses is bad because of the longer travel time due to overcrowding. It is essential to enhance the running environment by making the bus route to pass through fewer intersections and provide it with transit signal priority (TSP).

Table 6. Slack Analysis for Operational Efficiency of Bus Routes

Operational Efficiency				Slack			
No.	DMU	Score	Rank	Stop	Time	Length	Passenger
1	R1	0.4858	2	0	2.851	0.378	0
2	R2	0.0501	5	0	0.154	0.093	0
3	R3	1	1	0	0	0	0
4	R4	0.1549	4	0	2.936	0.758	0
5	R5	0.4077	3	0	14.521	3.406	0

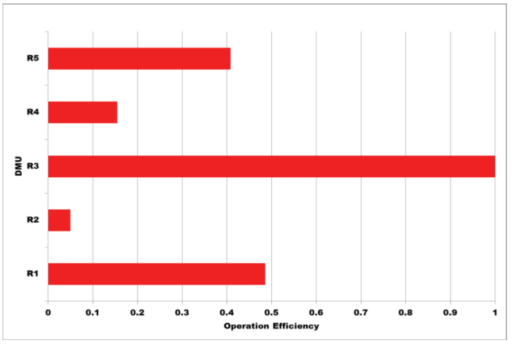

Figure 5. Operation Efficiency of Bus Routes

4. Comfort Efficiency

From the results of Table 7 and Figure 6, R1 and R5 have scored less than 0.6; the user opinion value measures the comfort, the survey conducted to measure user satisfaction toward the bus service. It has appeared that the user has discomfort when using R1 or R5. So to increase efficiency, it is preferable to decrease travel time to increase comfort.

Table 7. Slack Analysis of Comfort Efficiency of Bus Routes

Comfort Efficiency				Slack				
No.	DMU	Score	Rank	No.Stop	Travel Time	Length	Load factor	User opinion
1	R1	0.4643	5	4.786	10.449	2.807	0	0
2	R2	0.8553	3	4.368	9.68	3.82	0	0
3	R3	1	1	0	0	0	0	0
4	R4	0.975	2	3	23.316	6.3	0	0
5	R5	0.5909	4	3.182	26.185	6.564	0	0

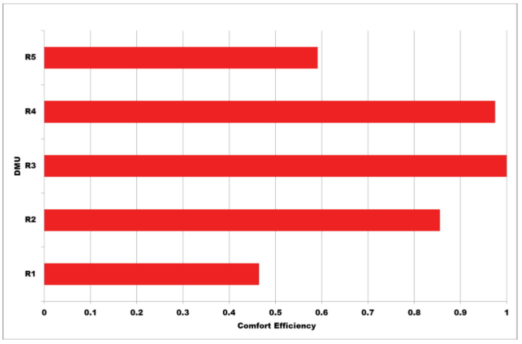

Figure 6. Comfort Efficiency of Bus Routes

5. Route design efficiency

From the results of Table 8 and Figure 7, it has appeared that all routes have good design except R5 needs to shorten its length.

Table 8. Slack Analysis of Route Design Efficiency of Bus Routes

Route Design Efficiency				Slack				
No.	DMU	Score	Rank	Ridership	Population	Transfer	Space km	Route Directness
1	R1	1	1	0	0	0	0	0
2	R2	1	1	0	0	0	0	0
3	R3	1	1	0	0	0	0	0
4	R4	1	1	0	0	0	0	0
5	R5	0.574	5	349.833	24728	0	0	0

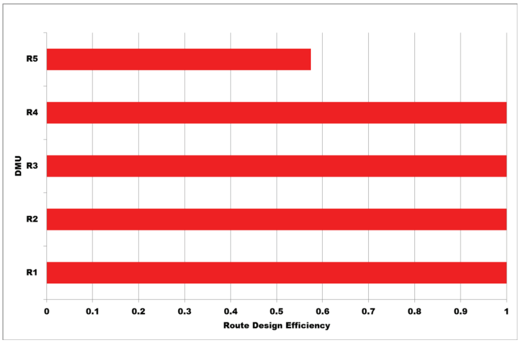

Figure 7. Route Design Efficiency of Bus Routes

6. Cost Efficiency

Two inputs (travel time and frequency per hour) and two outputs (revenue and number of the passengers) utilized in this model. A literature review explored to estimate fuel consumption. Due to the data limitation, travel time used as an alternative to measuring the cost of fuel, so with the travel time increases, fuel consumption is increased too. From the results of Table 9 and Figure 8, it has appeared that R2 has less efficiency because the revenues of this route were less than other routes, this is due to the availability of this route is just during peak hours while others hour of the day there is no service. Also, this route has less fleet size. While for route R1, it has a score value of less than 0.6, which indicated inefficiency. The reason for this value is that this route has the largest fleet size, high frequency of vehicles running during peak hour, which in turn increases operation costs as this appeared in a slack analysis, which includes reducing travel time accordingly minimize fuel consumption.

Table 9. Slack Analysis of Cost Efficiency of Bus Routes

Cost Efficiency				Slack			
No.	DMU	Score	Rank	Travel Time	Freq.	Revenue	No. of Passenger
1	R1	0.475	4	1683.18	0	0	0
2	R2	0.3978	5	45.499	0	0	0
3	R3	1	1	0	0	0	0
4	R4	0.6188	3	0	0	0	15.449
5	R5	1	1	0	0	0	0

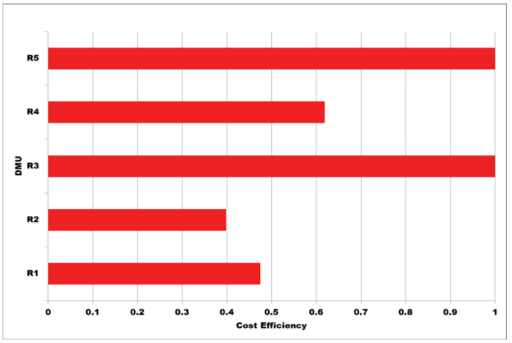

Figure 8. Cost Efficiency of Bus Routes

7. Service Availability

The results are shown in Table 10 and Figure 9; it appears that routes R1, R3, and R4 have a deficiency in the availability of service when compared with other routes. R2 route, even it operated within a limited hour interval service, has a good efficiency because the principal of the DEA approach is to decrease input then decrease cost. R2 has a lower input value compared with other routes, which, accordingly, its efficiency is better.

Table 10. Slack Analysis of Service Availability of Bus Route

Service Availability				Slack		
No.	DMU	Score	Rank	Fleet size	Frequency	Hour of Service
1	R1	0.2267	5	22.667	0	0
2	R2	1	1	0	0	0
3	R3	0.5152	3	35.03	0	0
4	R4	0.3	4	3	0	0
5	R5	0.7907	2	120.186	0	0

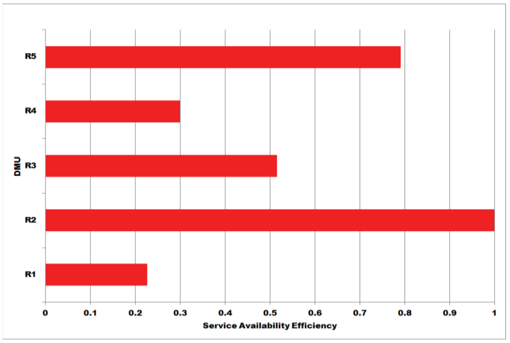

Figure 9. Service Availability of Bus Routes

From an analysis of the data results, significant problems occurred in bus routes of Baghdad city are as follows:

- Delay is the primary factor affecting the operation of public transport in the peak period
- During off-peak periods, the load rate is low because of the high number of vehicles (fleet size), which is indicating that all the buses have half-full occupancy; this is because of a higher number of buses working during the hour.
- A bus stop is every place passenger wants to board or alight, there is no specific place for a bus stop, and this would increase the number of bus stops, which results in discomfort able for bus passenger.
- Bus service operated within capacity during certain peak times. However, in off-peak time is partially full or empty.

7. COMPOSITE EFFICIENCY

Seven measure indexes used to evaluate the performance of bus routes in Baghdad city; some of these measures assess in point of operator view, and some others evaluate from the perspective of the user view. So to find a comprehensive evaluation based on these views, a composite efficiency was developed based on the AHP method using the Satty method. Seven experts in highway engineering were selected to conduct the survey, and the resulted weight shown in Table 11 with the consistency ratio (CR) equals 0.07, which is a satisfactory value [31].

Table 11. Weight from AHP and Composite Efficiency

Measures	Routes	Service Efficiency	Service effectiveness	Route Design Efficiency	Operational efficiency	Cost efficiency	Service availability	Comfort	Composite Efficiency
	R1	0.612	0.198	1	0.48	0.47	0.2267	0.464	0.5
	R2	1	0.215	1	0.05	0.39	1	0.85	0.7
	R3	1	1	1	1	1	0.515	1	0.9
	R4	1	0.26	1	0.15	0.61	0.3	0.97	0.6
	R5	0.53	0.277	0.574	0.4	1	0.79	0.59	0.6
Weight from Saaty		0.20	0.09	0.20	0.12	0.12	0.14	0.13	

From the results of Table 11, it appears that all the routes have inefficiency in performance except R2 and R3. However, these routes still have a deficiency in performance because the measures are lower or equal to 0.6 [30], so, necessary improvement should have taken place. It is observed that several routes have low service effectiveness, which indicates there is a necessity to reduce vehicle fleet size and route length. Reduction in vehicle fleet size must be according to demand requirement, which can preserve the resources. It is shown that several policies suggested to increase the efficiency of these bus routes include the following:

- It is essential to enhance the running environment by adopting the following measures make the bus route to pass through fewer intersections and provide it with transit signal priority (TSP).
- There is no defined bus stop location, so realignment of bus stop according to the demand requirement is encouraging.
- The data results show the low efficiency of all bus routes and a weak connection between resources and transit performance.
- To increase the service quality, make an exclusive bus lane and separate it from the mixed traffic flow when the road right of the way allows.
- The road system is considered the foundation of public transport, so improve the road system can enhance the efficiency of public transport performance by increase accessibility, vehicle flow, and reduce environmental effects.

8. CONCLUSIONS

A public transportation operation that mainly based on the highway network suffers from many problems mentioned above. This paper evaluates existing public routes, to find existing issues and try to find a solution to get optimum performance. The developed models give an indication of the overall efficiency of bus routes and show the causes of inefficient bus routes and recommend the solution. From this study, the following recommended points should be considered:

1- It is proved through this study, the great ability of the DEA analysis approach to explore and define the different problems of bus route performance.
2- From a service efficiency point of view, delay and number of stops are the primary factors affecting the operation; therefore, bus stops should be defined at specific points to increase the velocity of the bus.
3- Scheduling is essential to be applied, which ensures operate buses, according to the demand requirement during the off-peak period and to use minimum resources.
4- From the point of service effectiveness, accessibility of most bus routes should be increased and decrease the number of the bus fleet of some routes.
5- Overall improvement of public transportation is crucial. From the cost-efficiency point, fuel consumption must be reduced due to high delays during the trip.
6- It is recommended to use transit signal priority (TSP) to give buses the priority, which is essential to enhance bus operation and increase its effectiveness.
7- All the routes show fair efficiency except R3, so there is a need to improve its effectiveness.

ACKNOWLEDGMENT: The authors extend gratitude to Al-Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad _Iraq for their assistance in completing the manuscript requirements

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LIST OF FIGURES AND TABLES:

Received: 28.04.2020, Revised: 24.08.2020