PERFORMANCE EVALUATION OF TEHRAN BUS RAPID TRANSPORT (BRT) ROUTES BY THE TWO-STAGE DATA ENVELOPMENT ANALYSIS (DEA) MODEL

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ABSTRACT

Managing buses and bus transport routes is a serious challenge for any city and its efficient implementation is a vital issue for municipalities and transportation companies. Routing public transportation systems too is a very complicated problem that not only affects the performance efficiency and construction/exploitation costs, but also has an important part in such performance indicators as the passenger transport, travel speed, savings in the travel time, land use variations, and environmental effects. Data Envelopment Analysis (DEA) is an optimization-based method widely used to measure the relative performance efficiency of the public transportation systems.

Effort has been made in this paper to evaluate the performance of bus routes in a public transportation system using the Two-Stage DEA model. A conceptual framework is presented for the performance evaluation and appropriate input-output indicators are selected to calculate the performance efficiency and service efficacy of each route. Then the achievement function (model) is analyzed and bus routes that need to be reset and optimized are identified. Ten bus routes have been selected in Tehran for practical applications.

Keywords: *Performance Evaluation, Public Transportation, BRT Route, Data Envelopment Analysis, Two-Stage DEA.*

1. Introduction

Performance evaluation in urban services, especially transportation, is an attractive and popular subject. The increased traffic congestion and the related problems, especially the transportation-caused pollution, have made the transportation improvement quite necessary.

Despite its numerous merits in terms of flexibility and low investment costs, the bus transport system does not obviously satisfy its users because of its low service quality which is largely due to the lack of proper assessment systems.

In Iran, before vehicles entered the country, such facilities as horse wagons and droshkies were used to move people in Tehran and other large cities [13]. With the expansion of car production and creation of its infrastructures over the past decades, the use of public transport has declined sharply despite the provision of many transportation plans in different cities. Today, since the existing transportation mode is inconsistent with the citizens needs and cannot estimate their requirements, much effort is being made to improve the conditions of the public transportation in cities, especially in large ones, because, as a major component of achieving sustainable development, and with such merits as the capability of displacing high passenger volumes, possibility of being used by various social classes, and having public and economic benefits, the public transportation highly contributes to the air pollution reduction in urban areas [11].

Since Tehran bus transport network has a high share in the passengers' daily displacements, effort has been made in this paper to evaluate its bus system efficiency through a precise, novel, practical-natured approach and the latest DEA methods.

Tomazinis has determined a set of indicators to measure the performance of the public transportation system and has defined such conceptual aspects as efficiency, productivity, and quality of service[12]. Nolan have proposed a large number of indicators that can be used to evaluate the transportation system performance and many researchers have used many of their suggested indicators to analyze the performance and productivity of the transportation system[8]. According to Karlaftis, the problem with these studies is that the variety of indicators, that generally show conflicting performance results, makes it difficult to arrive at an overall conclusion. He then concluded that one indicator (or a smaller set) would suffice to describe the transportation system performance [6]. Different methods and data were used to achieve this, but the main problem was that the performance criteria were different in different studies; Karlaftis & Tsamboulas led these performance evaluation problems to the DEA approach [7].

Efficiency measurement by the DEA approach began based on the work of Farrell [5]. Charnes, Cooper et al. presented an efficiency evaluation model for the production possibility with constant return to scale that was later developed by Banker, Charnes et al. for both the constant and decreasing return to scale[2,3]. Using the DEA approach, Viton has evaluated the efficiency of a French bus company[6]. With the same approach, Viton has evaluated the efficiency of the US bus system during 1992-1988 to detect its variations using Russell (static) and Malmquist (dynamic) criteria (two productivity variation measures)[15]. Using the DEA approach, Nolan, Ritchie et al. have analyzed the efficiency of the US multi-mode bus transit system[8]. Boilé has analyzed the technical efficiency and relative co-scale of a group of public bus transport systems [5]. Using the DEA approach, multi-variate linear regression model, logit model, and cluster analysis, Pina and Torres have evaluated the efficiency of the private and public sectors in providing public transportation services[10]. Using the DEA approach with a productive efficiency point of view, Odeck and Alkadi have examined the performance of the Norwegian public bus transport companies that use the government subsidies[9].

Different models can be based on different inputs and outputs; the following is an example:

Inputs:
* Subsidy per passenger (maximum line capacity)
* Line capacity (bus)
* Maximum number of buses that can be used in each line

Outputs:

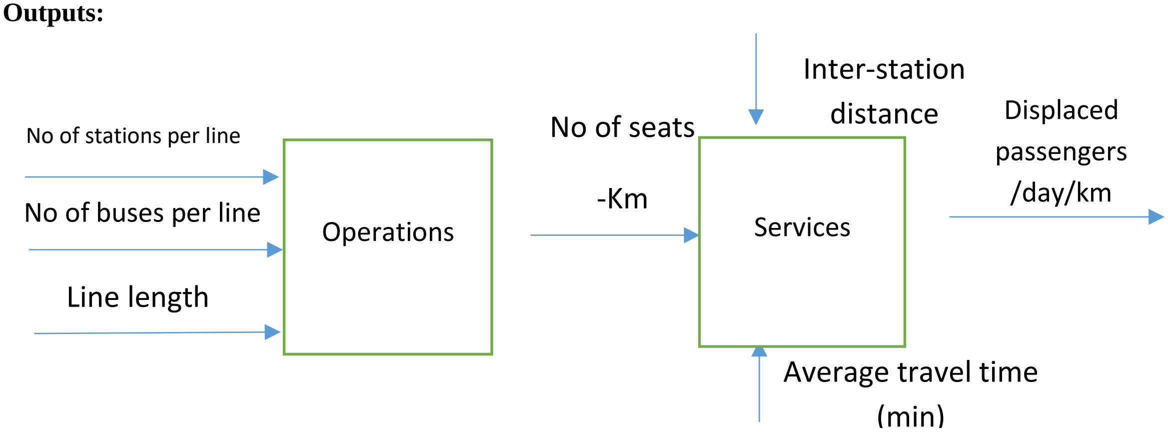


Fig. 1- DEA network model

* Ratio of (bus-km)/residents for each line (residents around stations)
* Population around stations, income level, vehicle ownership, land use, etc. (an estimation of the line passengers)
* Vehicle ownership (cannot be used). The DEA output as a dependent variable can be, e.g., exogenous, and its effect on the DEA output can be obtained.
* Line length affects efficiency (affects frequency)
* Shuttle time/distance of each line
* Number of stations per line
* Number of intersections with traffic, each line’s length of common route.

Proposed model of the DEA network:

Fig. 1 shows the proposed DEA model based on the literature review and the case studied.

2. Efficiency of the operations division

$$\text{Max}\ \frac{U_A^T Y_{A_0}}{V_A^T X_{A_0}} = E_{AA}$$

$$\text{s.t}\ \frac{U_A^T Y_{A_j}}{V_A^T X_{A_j}} \le 1 \qquad j = 1, \dots, n$$

$$U_A^T, V_A^T \ge 0$$

3. Services division efficacy

MAX $\frac{U_B^T Y_{B_O}}{V_B^T X_{B_0}+D\times\mu_A^T Y_{A_0}} = E_{AB}$

s.t $\frac{U_B^T Y_{Bj}}{V_B^T X_{B_j}+D\times\mu_A^T Y_{A_j}} \leq 1 \quad j = 1, \dots, n$

$\mu_A^T Y_{A_0} = E^*{}_{AA}$

$\omega_A^T X_{A_j} - \mu_A^T Y_{A_j} \geq 0 \qquad j = 1, \dots, n$

$\omega_A^T X_{A_0} = 1$

$\omega_A^T, \mu_A^T, U_B^T, V_B^T, D \geq 0$

4. Total efficiency

$e_{AB} = \frac{1}{2}(E_{AA}^* + E_{AB)}^*$

MAX $\frac{1}{2}[\frac{C^T Y_{A_0}}{V_A^T X_{A_0}} + \frac{U_B^T Y_{B_0}}{C^T Y_{A_0}+V_B^T X_{B_0}}]$

s.t $\frac{C^T Y_{A_j}}{V_A^T X_{A_j}} \leq 1 \qquad j = 1, \dots, n$

$\frac{U_B^T Y_{Bj}}{C^T Y_{A_j} + V_B^T X_{Bj}} \leq 1 \qquad j = 1, \dots, n$

$c^T, V_A^T, V_B^T, U_B^T \geq 0$

After linearization, this model will have the following form:

MAX $\frac{1}{2}(C_A^T Y_{A_0} + \mu_B^T Y_{B_0}) = V_p$

s.t $\omega_A^T X_{A_j} - C_A^T Y_{Aj} \geq 0 \quad j = 1, \dots, n$

$\omega_B^T X_{Bj} + k \times C_A^T Y_{Aj} - \mu_B^T Y_{Bj} \geq 0 \qquad j = 1, \dots, n$

$\omega_A^T X_{A_0} = 1$

$\omega_B^T X_{B0} + k \times C_A^T Y_{A0} = 1$

To measure the efficiency, the first step is to determine the inputs and outputs of each decision making unit; selecting the best set of inputs and outputs is a very important step in computing the efficiency. Table 1 shows the data used (from performed researches) to identify indicators.

Table 1 - Input and output data related to Tehran BRT lines

DMU (bus route)	No of stations	No of buses	Line length (km)	No of seats-km	No of seats-km	Average station distance (km)	Average travel time (min)	No of displaced passengers (daily)
1	25	124	18.7	246	246	0.748	45	250000
2	28	116	20	214	214	0.714	65	200000
3	18	95	13.5	270	270	0.75	40	150000
4	24	100	21.5	172	172	0.895	70	170000
5	10	40	8.5	68	68	0.85	25	65000
6	34	92	16	184	184	0.401	51	180000
7	39	105	18	215	215	0.461	65	200000
8	6	40	8	185	185	1.33	25	70000
9	52	139	36	142	142	0.692	80	250000
10	15	100	10.3	308	308	0.685	55	180000
	Inputs of the operations section			Operations output	Inputs of the services section			Services output

5. Results and model analysis

The model has been solved by the GAMS software which is used to solve linear programming problems. The best way to get a comprehensive picture of the performance of the routes is an all-inclusive comparison of operational efficiency with the service efficacy.

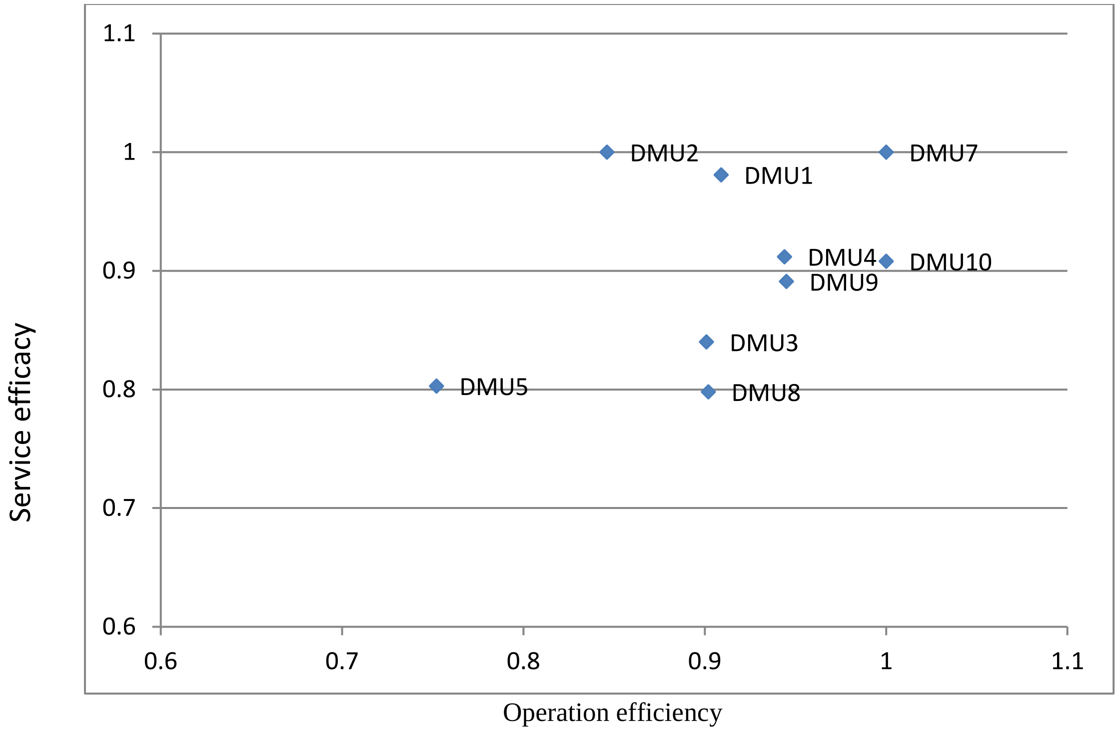
Table 2- Evaluation results of the bus routes performance

DMU	Total efficiency	Operations efficiency	Service efficacy
1	0.945	0.909	0.981
2	0.923	0.846	1
3	0.87	0.901	0.84
4	0.928	0.944	0.912
5	0.777	0.752	0.803
6	0.948	0.941	0.938
7	1	1	1
8	0.85	0.902	0.798
9	0.918	0.945	0.891
10	0.954	1	0.908

Due to its flexibility and coordination with the nature of the transportation performance assessment problems, DEA can be used as a comprehensive performance evaluation method.

According to Table 2, Route 7 is the most efficient (operational efficiency and service efficacy equal to 1), Route 8, despite its fewer stations and lower line length, has low service efficacy and should be re-planned, and Routes 1, 4, and 10, should continue as they are because both their operation efficiency and service efficacy are high. Routes 3 and 8 have high operation efficiency but low service efficacy; hence, they should plan properly to attract more passengers and optimize themselves for providing better services. Routes 2 and 5 have high service efficacy but low operation efficiency; therefore, they need to be rechecked.

According to Graph 1, routes with acceptable operation efficiency but low service efficacy need support, and operation efficiency can be improved through increased exploitation and better management.



Graph 1- Operation efficiency vs. service efficacy

6. Conclusions and suggestions for future studies

Bus and bus transport route management is a serious challenge for every city and its efficient implementation is a critical issue for municipalities and transport companies. Routing of the public transportation systems too is a very complicated issue that affects the operation efficiency, construction/exploitation costs, and such performance indicators as the passenger transport, travel speed, travel time savings, land use variations, and environmental pollution. This paper has presented a conceptual framework to evaluate the performance of the BRT routes and has used the Two Stage DEA model to calculate their operation efficiency and service efficacy. To illustrate how the research methodology works, use has been made of ten bus routes in Tehran for practical examples. Results were used to identify the routes with low service efficacy and high operation efficiency for which appropriate re-planning is necessary to increase their service efficacy, attract more passengers, and optimize their service delivery. Since such social route affecting factors as schools, hospitals, and so on have not been considered in this paper, they can be taken into account in the future research works; considering inter-route transition points too is another suggestion for future studies.

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