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Pamuar, S. Dragan; orovi, D. Boban

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DEA MODEL FOR MEASURING THE QUALITY CONTROL OF PUBLIC TRANSPORT NETWORKS

Pamučar S. *Dragan*, Đorović D. *Boban*, University of Defence, Military Academy, Deanery, Belgrade

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Abstract:

Data Envelopment Analysis (DEA) is a mathematical programming technique successfully used to quantify the efficiency of companies in the manufacturing and service sector. The analytic process developed on the basis of this, using real input and output parameters, increases objectivity in the quantification of efficiency and helps to identify best practices. The paper shows how DEA can be applied to the quality control of public passenger transport (PPT) networks. A PPT line in the network is seen as a Decision Making Unit (DMU) which achieves a certain level of efficiency, where quality is viewed from the perspective of users. DEA is used to determine optimal quality parameters, thus helping to define the total cost of PPT lines, or the total shortfall in funds and the subsidies needed for the normal operation of the public transport network.

Key words: *Data envelopment analysis, mathematical programming, quality control, public passenger transport networks, efficiency.*

Introduction

Public passenger transport – PPT is an indispensable element of city life meeting the basic need for mobility, and the quality of transport services affects the efficiency of a wide range of human activity. For many people on modest incomes, and also for certain social groups (students, the

dpamucar@gmail.com

disabled, pensioners, the elderly, the unemployed, etc.) public passenger transport is often the only option for the realization of transportation needs. The PPT system indirectly affects the rational use of urban areas, traffic congestion, speed and capacity, safety and environmental pollution. Furthermore, it entails large investment in resources: vehicles, employees, facilities and equipment, energy, etc. so it is in the interest of the entire urban economy that every PPT company should operate efficiently. When owned by the local or regional public authority, public passenger transport networks are seldom run for profit, but rather as a public service. This means that the standard principles of free market economics (limited cost of transport, preferential transport fares for certain categories of passengers, a smaller increase in the cost of transport compared to the increase in operating expenses, etc.) are not applied as rigorously and the shortfall in funding of operative costs and the necessary financial resources for development (investment) are most often made up from other sources. When public transport is performed by private companies, of course, they operate solely with the goal of profit, which means that there is a competitive relationship, and these companies operate on the principles of market economics. It should also be noted that the introduction of the market logic, which underlies the operations of private enterprise, is aimed at cutting subsidies, and encouraging local authorities to create conditions for an improved level of service in public transport. Key trends in the field of public transport as the responsibility of local communities to ensure the mobility of people with limited access to private vehicles include; opening the service market to all transporters and all types of ownership, increasing efficiency and lowering operating costs, increasing public pressure on local government bodies to realize a uniform level of quality over the entire network, with acceptable cost of public transport, and a single ticket for all transporters and modes of transportation.

The main problem in all towns in Serbia with an organized public transport system is the lack of a clearly defined funding policy and the uneven quality of the traffic network. The first problem is the result of the fact that public transport is not profitable in all segments of its operation because it is a public service. This means that, while the revenue generated from ticket sales cannot cover the operating costs of carriers, in most cities there is no funding mechanism via which the city would subsidise its PPT so it can continue to perform its function normally. Also, because the transport should be available as and when required by passengers, and at prices acceptable to the different types of users, there are constant conflicts of interest between the transport company and its beneficiaries, in a broader sense the city, and in a narrower sense, the direct users i.e. passengers. It is important for all participants in this process to accept the fact that public transport services are essential in the lives of citizens, but that they are expensive to implement and must be accessible to everyone. Another problem relates to the uneven quality of the entire line network, which means that some urban lines are more efficient than others, and thus deliver higher quality.

The aim of the author was to use DEA to measure the quality of the PPT network, and determine the optimum quality parameters of the traffic network system, and to determine the total vehicle operating costs for each line. Applying DEA could determine the total cost of the PPT system (complete network), or the total shortfall in the funds required to operate the public transport network normally. The DEA method will be made on real data from the PPT network in the city of Nis.

DEA approach and methodology

The idea of efficiency measurement was developed by M. J. Farrell during mid-twentieth century when he used the non-parametric efficiency limits approach to measure relative distances from border efficiency [1]. This measurement, which is well known as empirical or relative efficiency, was later expanded on by researchers, especially Charnes [2]. They called the technique Data Envelopment Analysis or DEA. The popularity of non-parametric DEA grew in businesses that require the definition of a number of input and output parameters of efficiency because business analysis had previously been based on one measure as the primary benchmark for efficiency. However, one dilemma that arises is how to display benchmark comparisons when there are a number of criteria. Only very rarely is one measure alone sufficient to measure efficiency. Financial indicators of the relationship between the individual outputs and inputs, such as Return on Investment – ROI, and Return on Sale – ROS, can be used as indicators that characterize the financial impact. However, when best practice is required, they are not sufficient to measure efficiency more holistically. The efficiency of the business unit is a complex phenomenon that requires more than one criterion for the characterization.

Application of a single measurement does not take into account any interaction or exchange, or the relationship between different standards. Each business activity has its own specific measurement of performance.

DEA makes it possible to measure efficiency using actual input and output parameters, where the concept of efficiency refers to empirical or relative efficiency [3]. It does not require knowledge of the specific functional forms of the input and output parameters, as opposed to other traditional statistical approaches. The advantage of DEA is its ability to address multiple input and output parameters that are diverse in nature (financial, technical, social, etc.), and which express themselves in different measurement units [4]. In DEA terminology, business units, their activities or processes, are seen as Decision Making Units – DMUs. A DMU is the unit that actually makes business decisions, and whose performance is characterized by a set of inputs and outputs, and their interdependence. Decision units are compared with the weights that are assessed using the same parameters, and the larger the set of units, the more objective is the analytical process [2, 5].

Let us analyze a set of n DMU observations. Each observation, DMUj ($j = 1, 2, 3, ..., n$) uses m inputs x_{ij} ($i = 1, 2, 3, ..., m$) to produce s outputs y_{rj} ($r = 1, 2, ..., s$). The efficiency limit of operations, or the Best Practice Line, as it is called, is determined by these n observations, through the consistent application of the methodology which requires the realization of several steps.

The first stage in the DEA is the selection of the DMU whose efficiency is to be measured, i.e. the decision unit selection. It is necessary that the units, whose effectiveness is analyzed, are related to the same organizational unit (internal efficiency benchmarking), the same field or sector (competitive efficiency benchmarking), that is, care should be taken not to model mutually incomparable decision units. Only in certain special cases may decision units belong to different areas or sectors [6, 7]. Next, the efficiency of common business processes and activities for different areas or sectors within particular functional groups of organizations, such as administration, marketing, manufacturing, information links and the like, is measured and benchmarked (Functional efficiency benchmarking). We should pay particular attention to the market conditions under which the selected decision units operate and exercise their activities.

The second stage of the DEA is defining the input and output efficiency parameters of the selected units of decision. The parameters are defined on the basis experience, theory and practice in the given field, and depend on the specific business under consideration [8]. The parameters should be defined as representatively as possible, i.e. parameters that best present the activities and processes to which they relate. Good input and output parameters can represent all resources (material, personnel, financial and information) that the decision units are using, in a credible way, as any realized results of its operations [9]. If the parameters are not well-designed, this can lead to a superficial interpretation and to partially correct and incorrect conclusions about the efficiency of the observed unit of decision. Also, it is important that the values of the defined parameters are obtained from reliable sources and references, and remain uniform for all units that are compared.

In the third phase of efficiency calculation, an appropriate DEA model is selected, depending on the objectives and purposes of the research results [10]. A number of calculations related to the quantification of efficiency, contributing factors and the analysis results require that the problem be defined by formulating and solving mathematical programming, with original or upgraded software for solving the DEA model [3]. The fourth stage is the materialization of the previous three, where the most important thing is to interpret the results correctly. The results of the DEA include: measuring the efficiency of the observed decision units, setting benchmarks for decision units that are inefficient, quantified parameters for reaching the limits of efficiency and other quantification in relation to comparing the efficiency of decision units.

This is the stage which defines potential opportunities to improve operations, and implement the defined and selected improvements. The main objective of this phase is to consolidate and strengthen the imperative of change. The researcher must be thoroughly familiar with the consequences and implications of the application possibilities related to business improvement and integration of the obtained findings and knowledge in the organization. This phase allows the adoption of strategic and management decisions and establishment of priorities in solving problems [8, 11, 12]. The results and detailed analysis of the results provide many opportunities for decision makers to improve operations at least to the limits of efficiency. Optimization of choice by application of fuzzy logic in practice has been applied in [13, 14, 15].

DEA application on the PPT network in the city of Nis

The city of Nis, with 250.518 inhabitants according to 2002 census is the second largest urban area in Serbia by population, following the Serbian capital, Belgrade. It is a modern university city, and the natural, social, economic, educational, healthcare, cultural and sport centre of south eastern Serbia.

The Network lines of the PPT in Nis are the consequence of the geographical position of the city and its structure. It has a distinct monocentric structure, and the eccentric location of the most attractive central zone is the main reason for the exceptional concentration of the origin terminals or passing stops for all lines in the system. This raises problems for the PPT network from the outset: a lack of infrastructure capacity and interaction with other modes of transport because of the enormous traffic pressure at the centre. On the other hand however, the elongated shape of the city, along the banks of Nisava River where the greatest concentrations of housing and businesses are, clearly indicates where the main corridor is, and where the greatest part of transportation system operation occurs, as a result of the strongest passenger flows.

The PPT network in Nis is shown in Figure 1, and has a total of 15 lines (Line 1, Line 2, Line 3, Line 5, Line 6, Line 7, Line 8, Line 9, Line 9A, Line 10, Line 11, Line 12, Line 13, Line 34 and Line 38) with a total length of 113 kilometres. The network structure has six radial lines, 7 diametric and one circular line. The longest line is the circular one, line 34, which is 21 kilometres in length. The shortest lines are Line 7 and Line 11, each with a length of 3 kilometres.

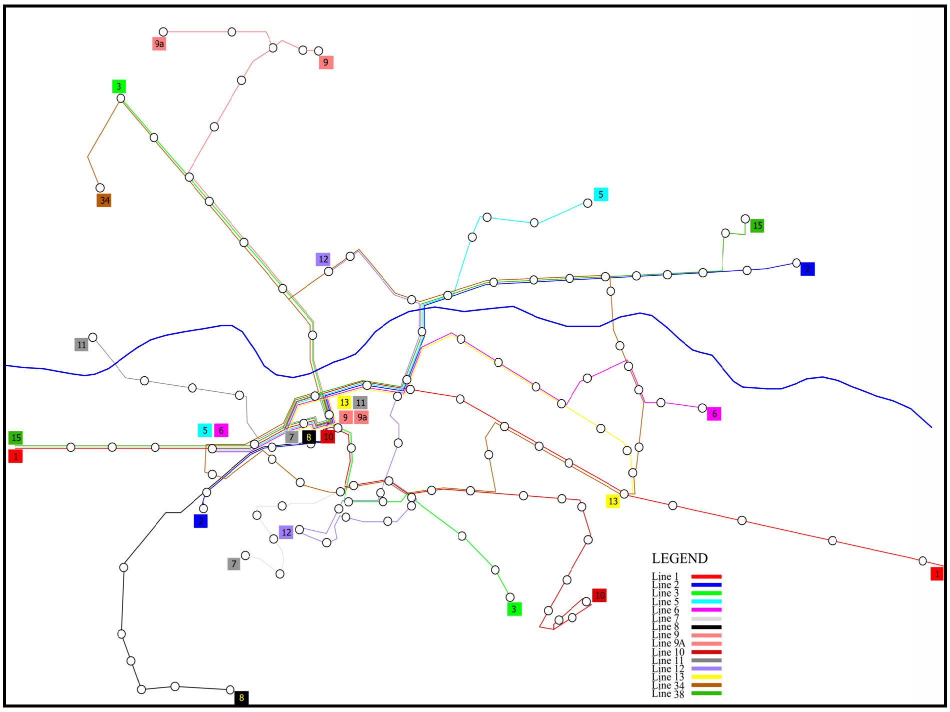

Figure 1 – Network of PPT lines in Nis

To assess the quality of the traffic network three input parameters (average length of lines (ALL), travel time (TT) and turnaround (T)) and three output parameters (frequency of vehicles (FV), average number of vehicles (ANV) and number of stops (NS)), were selected and are presented in table 1. All six parameters are basically quantified variables whose actual values are taken from the Directorate of Traffic of Nis in 2009.

The existing network has the following characteristics of transport service quality:

– The average length of the lines is 7.533 kilometres;
– The average transport time was 44.067 minutes;
– The average turnaround time is 58.667 minutes;
– The frequency of vehicles is 913 vehicles per day;
– The total number of deployed vehicles is 62 vehicles;
– The total number of stops is 242.

Table 1

Quality parameters of the PPT network in the city of Nis
(Department of Transportation, City of Nis, 2009)

PPT network lines	***ALL***	***TT***	***T***	***FV***	***ANV***	***NS***
Line 1	17	62	78	193	13	26
Line 2	7	53	69	138	9	18
Line 3	7	47	51	57	3	15
Line 5	5	38	62	72	4	12
Line 6	6	45	58	115	6	14
Line 7	3	21	30	16	1	9
Line 8	6	36	51	30	2	9
Line 9	5	34	47	35	3	11
Line 9A	5	36	46	30	3	11
Line 10	5	35	52	33	2	14
Line 11	3	28	30	20	1	7
Line 12	4	38	63	11	1	12
Line 13	4	37	54	84	4	11
Line 34	21	72	90	63	6	45
Line 38	15	79	99	16	4	28

Measuring the existing quality of the PPT network and the proposal of an optimal network

The measurement of the quality of the traffic network was performed on the basis of input and output parameters, using the input-oriented CRS (Constant Returns to Scale) model.

$$\theta^* = \min \theta \tag{1}$$

with the constraints:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{i0} \text{ , } i = 1,2,3,...,m \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0} \text{ , } r = 1,2,3,...,s \tag{3}$$

$$\lambda_j \geq 0 \text{ , } j = 1,2,3,...,n \tag{4}$$

DMU_0 is one of the DMU's which are being tested, and x_{i0} and y_{r0} are the *i*-th input and the *r*-th output of DMU_0. The DMU_0 is considered efficient if and only if the rating of efficiency $\theta^* = 1$ and the benchmarks $\lambda_j = 0$ for every *j*, except DMU_0 ,for which $\lambda = 1$ [16, 17].

Quality Scores of network lines using DEA Excel Solver are given in Table 2.

Table 2

Results of Model 1: Quality Scores of PPT network lines in the city of Nis

Input Oriented CRS								
DMU No.	***DMU Name***	***Efficiency***	***Benchmarks***					
1	Line 1	1.00000	1.000	Line 1				
2	Line 2	1.00000	1.000	Line 2				
3	Line 3	0.90524	0.303	Line 2	0.528	Line 7	0.106	Line 34
4	Line 5	0.87891	0.480	Line 2	0.317	Line 7	0.011	Line 34
5	Line 6	0.98848	0.016	Line 1	0.811	Line 2		
6	Line 7	1.00000	1.000	Line 7				
7	Line 8	0.57836	0.140	Line 2	0.485	Line 7	0.047	Line 34
8	Line 9	0.90864	0.254	Line 2	0.714	Line 7		
9	Line 9A	0.81569	0.249	Line 2	0.564	Line 7	0.032	Line 34
10	Line 10	0.98654	0.077	Line 2	1.403	Line 7		
11	Line 11	0.77573	0.074	Line 2	0.530	Line 7	0.020	Line 34
12	Line 12	0.99805	1.333	Line 7				
13	Line 13	0.98561	0.608	Line 2	0.006	Line 7		
14	Line 34	1.00000	1.000	Line 34				
15	Line 38	0.76750	0.083	Line 2	1.409	Line 7	0.307	Line 34

The result of Model 1 shows that four lines: Lines 1, 2, 7 and 34 exhibit effective existing quality (consistent quality), or meet the necessary and sufficient condition for efficiency because their efficiency scores and self benchmark are equal to one, while all other benchmarks, $\lambda j = 0$ for all $j = 1,2,3,\ldots,15$. The remaining 11 lines: 3, 5, 6, 8, 9, 9A, 10, 11, 12, 13 and 38 exhibit inefficient existing quality. This means that these lines are of lower quality than Lines 1, 2, 7 and 34. Acceptable benchmarks were obtained for these 11 lines. They suggest that for the inefficient lines: Line 3 ($\lambda 7 > \lambda 2 > \lambda 34$), Line 8 ($\lambda 7 > \lambda 2 > \lambda 34$), line 9 ($\lambda 7 > \lambda 2 > \lambda 34$), Line 9A ($\lambda 7 > \lambda 2 > \lambda 34$), Line 10 ($\lambda 7 > \lambda 2$), Line 11 ($\lambda 7 > \lambda 2 > \lambda 34$), Line 12 ($\lambda 7$) and Line 38 ($\lambda 7 > \lambda 34 > \lambda 2$), the acceptable benchmark is Line 7, for Line 5 ($\lambda 2 > \lambda 7 > \lambda 34$), Line 6 ($\lambda 2 > \lambda 1$) and Line 13 ($\lambda 2 > \lambda 7$) the most appropriate benchmark is Line 2. So, in addition to the Quality Score for each line separately, Model 1 also identified the most appropriate benchmarks for the inefficient lines. The most appropriate benchmarks are essentially good examples of what quality level the inefficient lines should progress to, for the quality of the entire network of lines to be uniform. The result of Model 1 shows that the PPT network in Nis is of uneven quality, and that as many as 11 lines out of 15 are in need of improvement. To answer the question of what should be changed on the inefficient lines and how they could improve quality and achieve the quality of their most appropriate respective benchmark, the slacks-based model was used.

$$\max\left(\sum_{i=1}^{m} S_i^- + \sum_{i=1}^{s} S_i^+\right) \quad (5)$$

with the constraints:

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- \le \theta^* x_{i0},\ i = 1,2,3,...,m \quad (6)$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} - s_r^+ = y_{r0},\ r = 1,2,3,...,s \quad (7)$$

$$\lambda_j \ge 0,\ j = 1,2,3,...,n \quad (8)$$

Using the slacks-based model we can determine the input slacks s^- (or by how much to reduce the input parameters, i.e. to rationalize) and the output slacks s^+ (the level of growth in the output parameters of efficiency as a result of the rationalization undertaken, i.e. the level of real increase in the results) for the inefficient DMU's, so that the best benchmark for each can be determined [18, 19, 20].

The input and output slacks, also using DEA Excel Solver, are given in Table 3 and 4.

The results of Model 2 are the limits for input and output of inefficient lines on the network. Specifically, the result shows how inefficient lines or lines of lower quality can reach the quality of their most acceptable standards. For example, Line 5 should reduce its turnaround time by 13 minutes, and increase the frequency of vehicles to 27 vehicles a day, increase the average number of vehicles by two, and insert one additional stop.

Similarly, in the case of line 12, it should reduce the transport time by 9 minutes and the turnaround time by 23 minutes, and increase the frequency of vehicles by 12 vehicles per day.

Table 3

CRS Results: Margins of PPT network lines input

DMU No.	DMU Name	Input slacks		
		ALL (km)	TT (min)	T (min)
1	Line 1	0	0	0
2	Line 2	0	0	0
3	Line 3	0	7	0
4	Line 5	0	0	13
5	Line 6	0	0	0
6	Line 7	0	0	0
7	Line 8	0	0	4
8	Line 9	0	1	4
9	Line 9A	0	1	0
10	Line 10	0	0	4
11	Line 11	0	6	0
12	Line 12	0	9	23
13	Line 13	0	4	11
14	Line 34	0	0	0
15	Line 38	0	2	0

Table 4

CRS Results: Margins of PPT network lines input and output

DMU No.	DMU Name	Output slacks		
		FV (vehicles/day)	ANV	NS
1	Line 1	0	0	0
2	Line 2	0	0	0
3	Line 3	44	4	0
4	Line 5	27	2	1
5	Line 6	1	2	1
6	Line 7	0	0	0
7	Line 8	69	5	4
8	Line 9	52	3	0
9	Line 9A	63	3	1
10	Line 10	10	1	0
11	Line 11	41	3	1
12	Line 12	12	0	0
13	Line 13	2	2	0
14	Line 34	0	0	0
15	Line 38	203	10	1

The necessary changes in other inefficient lines are determined accordingly, which means the optimum parameters of the quality of the traffic network, shown in Table 5, could be determined on the basis of model 2 results.

Table 5

Optimal quality parameters of PPT network lines in the city of Nis

PPT network lines	***Efficient Input Target***			***Efficient Output Target***		
	ALL (km)	***TT (min)***	***T (min)***	***FV (vehicles/day)***	***ANV***	***NS***
Line 1	17	62	78	193	13	26
Line 2	7	53	69	138	9	18
Line 3	7	40	51	101	7	15
Line 5	5	38	49	99	6	13
Line 6	6	44	58	116	8	15
Line 7	3	21	30	16	1	9
Line 8	6	36	47	99	7	13
Line 9	5	34	44	87	6	11
Line 9A	5	35	46	93	6	12
Line 10	5	35	49	43	3	14
Line 11	3	23	30	61	4	8
Line 12	4	28	40	23	1	12
Line 13	4	33	43	86	6	11
Line 34	21	71	90	63	6	45
Line 38	15	78	99	219	14	29

The optimum quality parameters of the network lines defined in the previous table establish uniform quality across the entire network of lines, and show how it is possible to define a network where each line has a uniform quality. The proposed network has the following characteristics of quality:

– The average length of the lines is 7.533 kilometres;
– The average travel time is 42.067 minutes;
– The average turnaround time is 54.867 minutes;
– The average frequency of vehicles is 1437 vehicles per day;
– The total number of deployed vehicles is 97 vehicles;
– The total number of stops is 251.

Compared to the existing network, the proposed network has the following characteristics: The average transport time is 2 min shorter, the average turnaround time is shorter by 3.8 minutes, the frequency of vehicles is increased by 524 vehicles per day, the total number of operating vehicles is increased by 35 and the total number of positions increased by 9. Compared to the existing network, in addition to the total number of positions it is of the utmost importance to increase the number of vehicles involved by 35, which will reduce the average time of travel and the average turnaround time by 2 minutes, and 3.8 minutes, respectively. This reduction will be higher when considering single lines such as Line 12 in which case the reduction will be 9 and 23 minutes, respectively.

Total cost of PTT system and the correcting model for basic transport prices

The total cost of a public passenger transport system is a function of:

Wages of employees (calculated on the basis of norms of employees by professions and occupations, and the current amount of earnings by title);

– Vehicle depreciation (calculated on the basis of annual depreciation of vehicles which is 0.2 € per km);

– Depreciation of space for storage and maintenance of vehicles (based on m^2/vehicle norms);

– The remaining costs, which include: maintenance of facilities for storage and parking of vehicles, property insurance, property taxes, utilities, office supplies and other minor costs (calculated on the basis of existing legislation);

– Regular service of vehicles at a particular mileage, as recommended by the manufacturer;

– Regular vehicle maintenance (calculated on the basis of recommendations by the manufacturer);

– The cost of fuel consumption (calculated on the basis of fuel prices and average consumption per 100 kilometres, given by manufacturer);

– The cost of vehicle and passengers insurance, and registration costs (calculated from the price list of insurance companies and relevant government bodies), and

– The cost of tire wear (calculated from the price list of tire manufacturers).

The required total operation costs for the proposed optimal route network were calculated based on the length of the line, the planned number of operating vehicles, number of turns per schedule for each line, realized annual mileage of vehicles, according to the timetable and calculated average unit price of € 1.249 / km. For each line, the operating elements, that is, line length, number of vehicles that operate on them according to the characteristic periods of time during the day, the total number of turns and total annual mileage by the timetable, are known. Knowing the total number of vehicle miles for each line determines the total cost of the lines, which are presented in Table 6. The total cost of running the PPT system represents the sum of total cost by lines, and amounts to € 8,601,950 per annum.

The PPT system generates revenue from fees and sales of individual and season tickets and from the grants and subsidies from the city budget. The optimal PPT system in Nis, with the proposed network of lines and current rates realized a total revenue of € 4,164,307.76, which is 48.41% of the required total cost. The remaining 51.59% of the required total cost should be covered from the budget of the city. This means that the unit cost of the PPT system in Nis, according to the proposed solution equals 1.333 €/km.

Generally speaking, PPT systems receive substantial subsidies and grants, so the running costs of the system are partially transferred to the administration at local, regional or state level, or combined levels in many cases and typically amount to 20 to 80%, with the shortfall made up from other sources.

Table 6

Total annual cost of PTT lines, in the city of Nis

City lines of the PPT system	***Total annual cost of the line (EUR)***
Line 1	1052580.00
Line 2	1091644.65
Line 3	322203.15
Line 5	471615.60
Line 6	725433.60
Line 7	77962.35
Line 8	494460.15
Line 9	440769.75
Line 9A	356405.25
Line 10	804716.10
Line 11	680310.75
Line 12	479337.30
Line 13	378388.50
Line 34	1032983.25
Line 38	193139.10

In most European cities significant budgetary resources – subsidies, are allocated to cover operating costs. The amount of these subsidies varies from state to state and from city to city, depending on the policy the administration is applying in relation to financial capability, the standard of living and the policy of giving priority to certain kinds of transport (individual, public, etc.). Subsidies of 50% to 60% are not uncommon in many countries, while in Serbia they range from 15% to 55% for individual cities in which a permanent mechanism for subsidies and grants has been introduced. It is important to point out that in European cities subsidies are given in situations where, in addition to light rail there is a bus subsystem. In addition to subsidies to cover operating costs, significant subsidies for capital investment are made in most European cities. They are used for fleet renewal, revitalization of existing and new infrastructure and the introduction and construction of new sub-systems of public transport. The question remains, how to alter the basic fare, which, on average, works out at € 1.333 / km for the PPT system in the city of Nis. This means that the city of Nis, i.e. its Administration of Transportation pays 1.333/km to the carriers engaged in public transportation in this city. This price remains the same until there is a change of parameters that affect it – a change in fuel prices and economic indicators for example. This means that the basic price is monitored and adjusted to a new price according to the following model:

$$NP = BP \times \left(0.2543 \times \frac{VE_{mercd}}{VE_{meis}} + 0.1102 \times IP + 0.3358 \times \frac{GS_{cd}}{GS_{is}} + 0.2997 \times \frac{PF_{cd}}{PF_{is}} \right)$$

Where:

NP – is the new price (at the time of adoption it becomes BP);

BP – basic price;

0.2543 – part of the basic price which is influenced by changes in the Middle EUR exchange rate;

VE_{mercd} – value of the EUR middle exchange rate of the control day (at the time of adoption NP becomes VE_{meis});

VE_{meis} – value of the EUR middle exchange rate of the initial state;
0.1102 – part of the basic price which is influenced by changes in retail prices;

IP – increase in the value of the initial state of retail prices (1.00) to the moment of control (at the time of adoption OC becomes 1.00);

0.3358 – part of the basic price which is influenced by changes in gross salary, in the industry;

GS_{cd} – value of the gross salary on the control day (the last published at the time of adoption NP becomes GS_{is});

GS_{is} – gross salary of the initial state (last published);

0.2997 – part of the basic price which is influenced by changes in fuel prices;

PF_{cd} – fuel prices on the control day (at the time of adoption NC becomes PF_{is});

PF_{is} – fuel prices of the initial state.

The level of price should be checked on the last working day of the month. If the parameters have not caused a change (individually or collectively) greater than 3% compared to BP, it remains valid until the

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next co1ntrol, and if the conditions change those prices, this becomes effective from the following month. In exceptional cases, if there is a significant change in fuel prices, the control can be made on the day of the change, and its impact, along with other parameters known to this day, should be analyzed. The numbers obtained experimentally for the current state of the economy in the city of Nis, which are: 0.2543, 0.1102, 0.3358 and 0.2997, stand as indications how the average EUR rate, the changes in retail prices, changes in gross salary in the economy, and changes in fuel prices, affect the correction of the transport price.

Conclusion

DEA methods of operational research in the transport sector are increasingly used for comparative analyses of entity efficiency (DMU), which work under similar conditions and using the same types of inputs to produce the same kind of output. Specifically, the lines in the network can be viewed as DMU's that achieve a certain level of efficiency, in this case the quality viewed from the perspective of users. The set of all DMU's, or lines, make up the route network of the public passenger transport system.

Evaluation of the lines quality on the PPT network lines using DEA is acceptable because it simultaneously takes into account multiple inputs and multiple outputs and objectively assesses the quality of each line on the network. Lines of lower quality are identified on the basis of the calculated values of the efficiency indexes, and the most appropriate benchmarks as a good example of the quality level these lines should have if the quality of the entire network is to be constant. DEA also provides efficient input / output levels for each inefficient unit which would make it more efficient. In this way the optimal parameters of the line quality of each line are individually defined.

These optimal parameters show how inefficient lines, or those of lower quality can reach the quality of the most acceptable standards, i.e. they show how it is possible to correct the existing network lines to produce a network that will have a uniform quality for each line. Successful implementation of this methodology with real results that can be used at the strategic and operational levels of decision-making in cities certainly depends on the quality of input data and an agreed selection of input and output parameters used in the calculations. In addition to calculations related to quality, a further step can be made with calculations of the required total cost for the proposed network of lines, obtained with the CRS and Slack-based models, determining the necessary subsidies to cover the total costs and ways of correcting the basic cost of transport.

References

[1] Farrell, M. J., The Measurement of Productive Efficiency, Journal of the Royal Statistical Society, 120, pp. 253-281, 1957.

[2] Charnes, A., Cooper, W. W., Rhodes, E., Measuring the efficiency of decision making units, *European Journal of Operational Research*, 2 (6), pp. 429-444, 1978.

[3] Cooper, W. W., Seiford, L. M., Tone. K., Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software, Boston: Kluwer Academic Publishers, 2000.

[4] Cook, D., Zhu, J., Modeling Performance Measurement: Applications and Implementation Issues in DEA, New York, Springer, 2005.

[5] Ali, A.I., Lerme, C.S., Components of efficiency evaluation in data envelopment analysis, *European Journal of Operational Research*, 80 (3), pp. 462-73, 1995.

[6] Wei, Q. L., Sun, B., Xiao, Z. J., Measuring Technical Progress With Data Envelopment Analysis, *European Journal of Operational Research*, 80 (3), pp. 691-702, 1995.

[7] Bhutta, K. S., Huq, F., Benchmarking – best practices: an integrated approach, *Benchmarking, An International Journal*, 6 (3), pp. 254-268, 1999.

[8] Thanassoulis, E., Introduction to the Theory and Aplication of Data Envelopment Analysis, Boston, Kluwer Academic Publisher, 2001.

[9] Seiford, L. M., Zhu, J., An acceptance system decision rule with data envelopment analysis, *Computers and* Operations *Research*, 25 (4), pp. 329-332, 1998.

[10] Liang, L., Wu, J., Cook, W. D., Zhu, J., Alternative secondary goals in DEA cross efficiency evaluation, *International Journal of Production Economics*, 113 (2), pp. 1025-1030, 2008.

[11] Sherman, D., Zhu, J., Service Productivity Management: Improving service performance using data envelopment analysis (DEA), Boston, Springer, 2006.

[12] Cakić, A., Clarification of a term transport chain, *Vojnotehnički glasnik*/*Military Technical Courier,* Vol. 58, No. 1, pp. 113-128, ISSN 0042-8469, UDC 623+355/359, Belgrade, 2010.

[13] Pamučar, D., Using fuzzy logic and neural networks during decision making proces in transport, *Military Technical Courier/Vojnotehnički glasnik*, Vol. 58, No. 3, pp 125-143, ISSN 0042-8469, UDC 623+355/359, Belgrade, 2010.

[14] Božanić, D., Pamučar, D., Evaluating locations for river crossing using fuzzy logic*, Military Technical Courier/Vojnotehnički glasnik*, Vol. 58, No. 1, pp. 129-145,ISSN 0042-8469, UDC 623+355/359, Belgrade, 2010.

[15] Đorović, B., Ljubojević, S., Dimić, S., Optimizing transportation processes using the route model, *Military Technical Courier/Vojnotehnički glasnik,* Vol. 53, No. 1, pp. 76-85, ISSN 0042-8469, UDC 623+355/359, Belgrade, 2005.

[16] Charnes, A., Cooper, W.W., Lewin, Y., Seiford, L.M., Data envelopment analysis: Theory, methodology and applications, Kluwer Academic Publish, Boston, 1994.

[17] Zhu, J., Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets and DEA excel solver, Boston, Kluwer Academic Publishers, 2003.

[18] Tone, K., A slacks-based measure of super-efficiency in data envelopment *European Journal of Operational Research*, 143 (1), pp. 32-41, 2002.

[19] Tone, K., Tsutsui, M., Network DEA: A slacks-based measure approach. *European Journal of Operational Research*, 197 (1), pp. 243-252, 2009.

[20] Du, J., Liang, L., Zhu, J., A slacks-based measure of super-efficiency in data envelopment analysis: A Comment, *European Journal of Operational Research*, 204 (3), pp. 694-697, 2010.

PRIMENA DEA METODOLOGIJE U PROCESU KONTROLE I MERENJA KVALITETA MREŽE LINIJA JAVNOG GRADSKOG PREVOZA PUTNIKA

OBLAST: matematika, operaciona istraživanja
VRSTA ČLANKA: originalni naučni članak

Sažetak:

DEA pristup omogućava da se matematičkim programiranjem implicitno procenjuje odnos većeg broja ulaznih i izlaznih parametara uspešnosti. Analitički proces koji je razvijen na bazi DEA metodologije koristi ulazno-izlazne parametre i predstavlja pogodan alat za kvantifikaciju efikasnosti sistema javnog prevoza putnika i praktičnu identifikaciju optimalnih rešenja. Rad prikazuje na koji način DEA metodologija može da se primeni u procesu kontrole kvaliteta javnog prevoza putnika (JPP). Mreže linija JPP posmatraju se kao Decision Making Units (DMU) koje poseduju određeni nivo kvaliteta usluge, a definišu korisnici usluge, odnosno putnici. DEA metodologija korišćena je radi definisanja optimalnih parametara kvaliteta usluge i definisanja ukupne cene koštanja postojeće mreže linija JPP-a. Na kraju, u radu je predložena optimizacija mreže linija JPP-a.

Uvod

Značaj i uloga prevoza putnika je nezamenjiva funkcija u životu svih građana, privrede i svih aktivnosti u gradu. Kvalitet prevozne usluge ovog sistema utiče na efikasnost svih proizvodnih, pratećih procesa i drugih aktivnosti ljudi u gradu. Uloga lokalnih vlasti u ovim procesima je ključna, jer one moraju da stvore uslove za dugoročan stabilan sistem prevoza putnika. Pored toga, treba omogućiti da se sistem razvija u kontrolisanim uslovima, a koji će realizovati zahtevani kvalitet kao jedini pravi pokazatelj njegove uspešnosti.

Naime, delatnost javnog gradskog i prigradskog prevoza putnika nije profitabilna, jer nema standardne ekonomske karakteristike, pre svega zbog činjenice da se radi o javnoj usluzi. Navedena konstatacija odnosi se na slučaj obavljanja ove funkcije od strane javnih preduzeća koja su u vlasništvu lokalnih ili regionalnih vlasti, pošto posluju u okruženju nepostojanja standardnih principa slobodnog tržišta (ograničenje cena prevoza, povlašćene cene prevoza za pojedine kategorije putnika, manji porast cena prevoza u odnosu na porast troškova poslovanja, itd.). U ovom slučaju, nedostajuća sredstva do nivoa cene koštanja – operativnih tekućih troškova poslovanja preduzeća (bez stvaranja uslova za ostvarivanje profita), kao i potrebnih finansijskih sredstava za razvoj (investicije) obezbeđuju se, pre svega, subvencijama države.

Generalno govoreći, u srpskim gradovima sistemi JGPP uživaju velike subvencije i dotacije, tako da se tekući troškovi funkcionisanja ovog sistema iz cene usluge pokrivaju sa 20 do 80%, a ostatak se obezbeđuje iz drugih izvora. Investicije se, po pravilu, pokrivaju iz sredstava lokalnih, regionalnih i centralnih vlasti kojima je interes da investicijama realizovani kvalitet približe i izjednače sa zahtevanim.

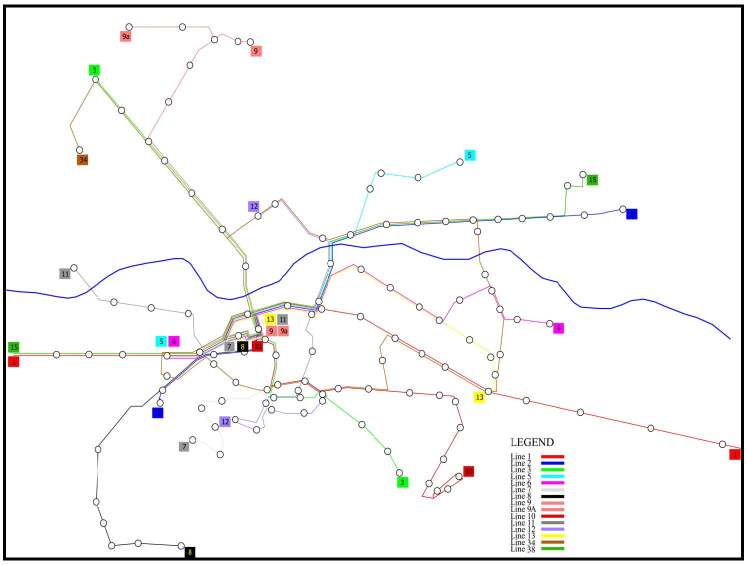
U radu je prikazana primena DEA metodologije u definisanju kvaliteta javnog gradskog prevoza putnika u Nišu.

DEA pristup i metodologija

Ideju merenja efikasnosti razvio je M. J. Farrell sredinom dvadesetog veka kada je koristio pristup neparametarske granice efikasnosti za merenje efikasnosti kao relativne udaljenosti od granice efikasnosti [1]. Ovo merilo, koje je u literaturi poznato kao empirijska ili relativna efikasnost, kasnije je posebno prošireno u radovima Charnesa, Coopera i Rhodesa [2]. Oni su ovu tehniku nazvali analizom obavijanja podataka ili DEA (engl, Data Envelopment Analysis). DEA omogućava da se meri efikasnost primenom stvarnih ulaznih i izlaznih parametara, pri čemu se pojam efikasnosti odnosi na empiričku ili relativnu efikasnost [3]. Ona ne zahteva poznavanje specifične funkcionalne forme među ulaznim i izlaznim parametrima, za razliku od drugih tradicionalnih statističkih pristupa. Prednost DEA je u mogućnosti razmatranja više ulaznih i izlaznih parametara koji su raznorodni (finansijski, tehnički, socijalni, itd.) i izražavaju se u različitim mernim jedinicama. Poslovne jedinice, njihove aktivnosti ili procesi u DEA terminologiji posmatraju se kao jedinice odlučivanja DMU (Decision Making Units), što je, u stvari, jedinica koja donosi poslovne odluke, a čiju efikasnost karakteriše skup ulaza i izlaza, odnosno njihova međuzavisnost.

Primena DEA metodologije u merenju kvaliteta javnog gradskog prevoza putnika u Nišu

Mreža javnog gradskog prevoza putnika u Nišu prikazana je na slici 1. Mreža ima ukupno 15 linija (linija 1, linija 2, linija 3, linija 5, linija 6, linija 7, linija 8, linija 9, linija 9A, linija 10, linija 11, linija 12, linija 13, linija 34 i linija 38) i ukupnu dužinu od 113 kilometara. Najduža je kružna linija 34, ukupne dužine od 21 kilometar. Najkraće su linije 7 i 11, duge po 3 kilometra.



Slika 1 – Mreža linija javnog prevoza putnika u Nišu

Radi merenja kvaliteta linija javnog prevoza putnika definisana su tri ulazna parametra (srednja dužina linija, vreme vožnje i vreme obrta) i tri izlazna parametra (frekfencija nailaska vozila, srednji broj vozila i broj stanica na liniji).

Merenje kvaliteta postojeće mreže prevoza putnika i definisanje parametara optimalne mreže

Merenje kvaliteta javnog gradskog prevoza putnika bazirano je na ulazno-izlaznim parametrima, koristeći ulazno orijentisan CRS (Constant Returns to Scale) model.

$$\theta^* = \min \theta \qquad (1)$$

sa ograničenjima:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{i0},\ i = 1,2,3,...,m \qquad (2)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0},\ r = 1,2,3,...,s \qquad (3)$$

$$\lambda_j \ge 0,\ j = 1,2,3,...,n \qquad (4)$$

Sistem JGPP predstavlja jedan od sistema JGPP-ova koji se procenjuju, a x_{i0} i y_{r0} jesu i-ti ulaz i r-ti izlaz za JGPP, respektivno, pri čemu je sistem JGPP efikasan ako i samo ako je ocena fikasnosti $\phi^* = 1$ i $\lambda_j = 0$ za svako j osim za JGPP0 za koji je $\lambda = 1$.

Za ocenu pune efikasnosti izabran je Slack-based model koji meri efikasnost koristeći iste podatke i omogućava punu ocenu neefikasnim sistemima JGPP.

Rezultati merenja kvaliteta mreže linija primenom softvera DEA Excel Solver prikazani su u tabeli 2.

Ukupna cena JGPP i korekcija postojećeg modela

Ukupna cena JGPP je funkcija koja zavisi od određenih parametara. To su:

– plata zaposlenih radnika;
– amortizacije upotrebe vozila;
– amortizacije održavanja vozila;
– tekući troškovi koji obuhvataju: održavanje prostora za parkiranje vozila i skladištenje rezervnih delova, osiguranje vozila, takse, snabdevanje rezervnim delovima i ostali tekući troškovi;
– redovno održavanje vozila nakon pređene određene kilometraže koju je deklarisao proizvođač;
– redovno održavanje vozila;
– troškovi potrošnje pogonskih tečnosti;
– troškovi osiguranja vozila i putnika;
– troškovi registracije vozila i
– trokovi amortizacije pneumatika.

Zaključak

DEA je moderna metoda operacionih istraživanja koja se u sektoru transporta sve više koristi za komparativnu analizu efikasnosti entiteta (DMU) koji rade pod sličnim uslovima i koriste iste vrste ulaza da bi proizveli iste vrste izlaza. U slučaju ocene efikasnosti kvaliteta sistema JGPP-a, DEA metoda je prihvatljiva, jer istovremeno uzima u obzir više ulaza i više izlaza i objektivno ocenjuje relativnu efikasnost – na osnovu izračunate vrednosti indeksa efikasnosti deli DMU na relativno efikasne i relativno neefikasne.

Na osnovu izračunate vrednosti indeksa efikasnosti izvršena je podela DMU-ova na relativno efikasne i neefikasne. Primenom DEA, pored relativne efikasnosti sistema JGPP-ova, identifikovani su benčmarkovi sa efikasnim linijama JGPP-a, a koje pružaju primer dobre operativne prakse za neefikasni DMU.

Primenom DEA metodologije prikazani su efikasni ulazno-izlazni nivoi za svaku neefikasnu jedinicu sa kojima bi ona postala efikasna. Uspešna primena ove metodologije svakako zavisi od kvaliteta ulaznih podataka, usaglašenog izbora ulaznih i izlaznih parametara koji se koriste u kalkulacijama i zahteva dinamički aspekt posmatranja, odnosno ocenu efikasnosti za više godina.

Ključne reči: *Data envelopment analysis, matematičko programiranje, kontrola kvalliteta, javni gradski prevoz putnika, optimizacija.*

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