Technical efficiency of hospital psychiatric care in Bulgaria – assessment using Data Envelopment Analysis

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Abstract: The present article deals with the theme of efficiency in healthcare and especially technical efficiency in psyaciatric hospital care. We used the method of data envelopment analysis (DEA), which finds increasing application in many spheres of public life, including healthcare.
We subdivided the treatment facilities in the current study in three groups and estimated technical efficiency for each group. We present a possible assesment method, which provides an opportunity for improving efficiency in the sector.
Key words: *healthcare, efficiency, DEA.*

Introduction

The constant increase of spending in national healthcare systems and the problems stemming from financial deficits, raise the need for efficiency analyses in these systems. Effective spending of financial resources is related to a certain degree to the technical efficiency of treatment facilities.
In this study we focused our attention on technical efficiency in psychiatric hospital care in Bulgaria. This sector is primarily funded by state and municipal budgets.
Psychiatric care in Bulgaria is organized at two levels – prehospital care by psychiatrists and hospital care in specialized hospitals psychiatric wards in multiprofile hospitals.
For the purposes of efficiency assessment we used the method of arranging and analyzing hospitals according to the relation between their product and used resources. This approach provides an opportunity for making optimal decions in hospital management.

Study objectives

The main tasks of the study were:
1. To assess the technical efficiency of psychiatric treatment facilities on the basis of input resources and output product.
2. To compare groups of treatment facilities in relation to their efficiency.

Methods

Treatment facilities for hospital psychiatric care were subdivided in three groups according to hospital type:
- I group – State psychiatric hospitals (SPH) – 12;
- II group – Regional dispensaries for psychic diseases with inpatient wards (RDPDI) – 12;
- III group – Psychiatric clinics and wards in multiprofile hospitals for active treatment (PCW-MHAT) – 17.

The source of necessary data was the National Centre of Health Information. We processed the primary data using formal report forms, officially regulated by the Ministry of Health in its Methodology for separate reporting of spending, obtained from the studied treatment facilities.
In essence this study comprised all psychiatric treatment facilities in the public sector.

Data Envelopment Analysis (DEA)

The basic concept of DEA was introduced by Charnes, Cooper and Rhodes in 1978. This is a technique for measuring results which can be used for assessing the relative efficiency of decision making units (DMU) in a given aggregate. All units in this aggregate are compared and the best functioning are singled out; they form the frontier of efficiency. Examples of such units are banks, hospitals, schools, universities, etc.
The relative efficiency is a relation of input-output data weighed with certain weights.

$$\text{efficiency} = \frac{\text{weighted sum of output values}}{\text{weighted sum of input values}} \qquad \textbf{(1)}$$

In practice, computation procedures amount to the solving of an optimization problem of linear programming, where the unknown values are the weights of the input-output data.
If we accept to have **n** DMU, each with **m** inputs and **r** outputs, the relative efficiency of the **p** DMU in order, is obtained through solving the following model:

$$\max \frac{\sum_{k=1}^{r} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}}$$

in the following conditions:

$$\frac{\sum_{k=} y_{ki}}{\sum_{j=} x_{ji}} \le$$

$$v_k, u_j \ge \qquad (2)$$

where:
$\mathbf{y_{ki}}$ - the quantity of production (output) **κ**, produced by the **i** DMU in order;
$\mathbf{x_{ji}}$ - the size of used resource (input) **j**, utilized by the **i** DMU in order;
$\mathbf{v_k}$ - weight of the **k** output in order;
$\mathbf{u_j}$ - weight of the **j** input in order.

The fraction formula (2) can be transformed in a linear programme model in the following manner:

$$\max \sum_{k=1}^{r} v_k y_{kp}$$

in the following conditions:

$$\sum_{j=1}^{m} u_j x_{jp} = 1$$

$$\sum_{k=} y_{ki} - \sum_{j=} x_{ji} \leq 0$$

$$v_k, u_j \geq 0 \qquad (3)$$

The equivalent envelopment form of this model (3) is:

$$\min (\theta$$

in the following conditions:

$$\sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jp} \leq 0$$

$$\sum_{i=1}^{n} \lambda_i y_{ki} - y_{kp} \geq 0$$

$$\lambda_i \geq 0 \qquad (4)$$

where:

θ is efficiency;

λ is a vector with constants Ix1

With solving an additional model input excess - s^- and output deficit - s^+ may be defined, i.e.

$$\max \left\{ \sum_{j=1}^{m} s^-_{jp} + \sum_{k=1}^{r} s^+_{kp} \right\}$$

in the following conditions:

$$\theta x_{jp} - \sum_{i=1}^{n} \lambda_i x_{ji} - s^-_{jp} = 0$$

$$- y_{kp} - \sum_{i=1}^{n} \lambda_i y_{ki} - s^+_{kp} = 0$$

$$\lambda_i \geq 0,\ s^-_{jp} \geq \ ,\ s^+_{kp} \geq 0 \qquad \mathbf{(5)}$$

The obtained value for efficiency varies in the range 0 - 1.
The main assumption in the DEA application for assessing efficiency is that single units from the studied aggregate work homogeneously i.e., have the same input mix and output mix.
The main variations of the DEA models are based on:

- Optimization of input or output;
- Economies of scale (constant or variable).

We refer to models oriented towards output, whenever the optimization problem equals maximization of the output. Respectively, models oriented towards input we have whenever the problem equals minimization of the input.
Economies of scale are related to how output values change with the variation of input ones. If output change is proportional to input change, we speak of constant returns to scale (CRS). Respectively, if the change in input does not lead to a proportional change in output, then we have variable returns to scale (VRS).
Model (4) represents the basic CRS model (Charnes, Cooper and Rhodes, 1978). The transition to a model with VRS (Banker, Charnes and Cooper, 1984) happens, when we add an additional condition for λ, $\sum_{i=} \; = \; .$

In our study we focused our attention on the assessment of technical efficiency (TE) of treatment facilities for psychiatric hospital care.
The CRS DEA models provide the opporunity to estimate total technical efficiency (TE_{CRS}). Pure technical efficiency is estimated using a VRS model (TE_{VRS}). If there is a difference between these two types of efficiency, than this means an inefficiency arising from the scale of the unit is present. All this leads to the conclusion that the scale efficiency (SE) may be defined as a ratio between total and pure technical efficiency ($SE = TE_{CRS} / TE_{VRS}$)
In order to make a judgment whether a given unit operates in the direction of increasing or decreasing the economies of scale, it is necessary to calculate the techical efficiency in non-increasing economies of scale (TE_{NIRS}). This happens when in model (4) the limitation $\sum_{i=} \; <$ is added.

In the presence of inefficiency of scale i.e., SE < 1 and if:
- $TE_{VRS} > TE_{NIRS}$, than the inefficiency of scale is due to the rising economies of scale;
- $TE_{VRS} = TE_{NIRS}$, than the respective inefficiency is due to the decreasing economies of scale.

Figure 1. Graphical representation of the DEA concept.

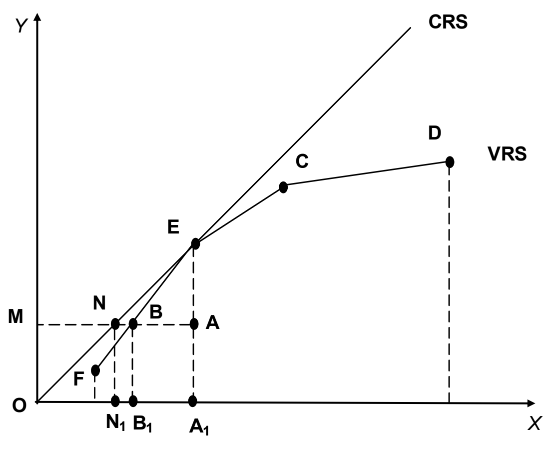


Figure 1 illustrates graphically the DEA concept. The points F, B, E, C and D represent the units which form the frontier of efficiency with VRS. The efficiency of the unit in point A is defined by the ratios:
$TE_{CRS} = MN/MA$; $MN = TE_{CRS} * MA$
$TE_{VRS} = MB/MA$; $MB = TE_{VRS} * MA$
$SE = MN/MB$
$SE = (TE_{CRS} * MA)/(TE_{VRS} * MA) = TE_{CRS} / TE_{VRS}.$

In its essence DEA is a non-parametric method and thus, some conditions and requirements for parametric methods are eliminated. Some strong sides of the DEA model may be pointed out:

- It can function with many inputs and outputs;
- It does not require a realtion between input and output;
- Comparisons between objects are direct;
- Inputs and outputs may have many different values.

Some notable weaknesses of DEA are as follows:

- Measurement error may cause substantial problems;
- DEA is not a measure of "absolute" efficiency;
- Random error is not reported;
- Intensive computations or complex computational procedures may pose a problem.

In our study we focused our attention on the optimization of input resources i.e., to assess the technical efficiency of treatment facilities for hospital psychiatric care, we applied an input-oriented DEA model (4).

Input-output data

As input data for the DEA models applied we chose the main resources at the disposal of a hospital, namely beds and medical staff. We used three inputs (resources): number of beds, number of physicians and number of nurses.
We presumed as logical, that these resources influence directly the hospital product in a qualitative and quantitative respect.
The hospital product (output) was defined as number of patients treated. Here we must note, that the volume of work depends on the duration of stay in hospital. To take into account this, we included as second output in the DEA models the number of bed-days.
The following two tables (***Tables 1 and 2***) represent the input-output data in summary.

Table 1. *Descriptive statistics of the input resources by groups of treatment facilities for hospital psychiatric care.*

Input data	**Mean**	**SD**	**Min**	**Max**
SPB				
Hospital beds	223	122	40	510
Physicians	12	4	7	18
Nurses	39	17	13	74
RDPDI				
Hospital beds	107	80	20	315
Physicians	7	4	4	15
Nurses	21	11	8	44
PCW-MHAT				
Hospital beds	48	39	10	153
Physicians	7	7	1	25
Nurses	17	15	6	62

Table 2. *Descriptive statistics of the output product by groups of treatment facilities for hospital psychiatric care.*

Output data	Mean	SD	Min	Max
SPB				
Patients treated	1 054	557	356	2 271
Bed-days	64 241	39 683	9 439	149 023
RDPDI				
Patients treated	1 500	1 024	447	3 630
Bed-days	34 023	27 836	7 202	101 477
PCW-MHAT				
Patients treated	1 985	3 602	328	15 246
Bed-days	15 173	13 323	3 562	55 155

Results

The technical efficiency of the studied treatment facilities for hospital psychiatric care was assessed in accordance with the previously stated DEA methodology.
To calculate efficiency we used software developed by the authors, based on the module for solving optimization problems "Solver" in MS Excel and a programming code of VBA.
Summarized results are presented in ***Table 3***.
Complete results for each treatment facility are presented in a separate attachment (***Application 1***).

Table 3. *Descriptive statistics of technical efficiency.*

	SPB			**RDPDI**			**PCW-MHAT**		
	TE_{CRS}	TE_{VRS}	**SE**	TE_{CRS}	TE_{VRS}	**SE**	TE_{CRS}	TE_{VRS}	**SE**
Mean	87,43%	92,97%	93,65%	80,98%	91,89%	88,61%	88,34%	91,78%	96,44%
SD	16,10%	9,80%	11,48%	16,41%	12,62%	14,89%	14,06%	12,05%	9,59%
Median	95,67%	100 %	97,76%	80,70%	100 %	95,86%	97,82%	98,95%	99,93%
Min	52,58%	74,12%	59,34%	52,39%	60,12%	52,39%	61,60%	61,87%	63,78%
Max	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Share of hospitals with 100% efficiency	42%	58%	42%	25%	58%	25%	24%	35%	24%
Share of hospitals with efficiency (< 100%)	58%	42%	58%	75%	42%	75%	76%	65%	76%

DEA provides the opportunity to define the target, which can be reached in terms of input-output data, in order to achieve efficient functioning of the unit in question. Through solving the respective models (5), the optimal solution for achieving efficiency can be found. Results for our study are presented in ***Table 4*** in summary.

Table 4. *Descriptive statistice of input-output data in the optimal decision for achieving efficiency.*

Target	Mean	SD	Min	Max
SPB (ДПБ)				
Hospital beds	225	118	96	510
Physicians	11	4	7	18
Nurses	34	13	18	57
Patients treated	1 190	497	582	2 271
Bed-days	70 190	36 473	32 340	149 023
RDPDI (ОДПСЗ)				
Hospital beds	98	80	20	315
Physicians	6	4	4	15
Nurses	18	11	8	44
Patients treated	1 548	1 022	447	3 630
Bed-days	34 504	27 546	7 202	101 477
PCW-MHAT (ПКО-МБАЛ)				
Hospital beds	43	37	10	153
Physicians	5	4	1	16
Nurses	15	14	6	62
Patients treated	2 116	3 557	357	15 246
Bed-days	15 173	13 323	3 562	55 155

The change in percentage of input-output data in the case of inefficient hospitals is presented in summary in ***Table 5***.

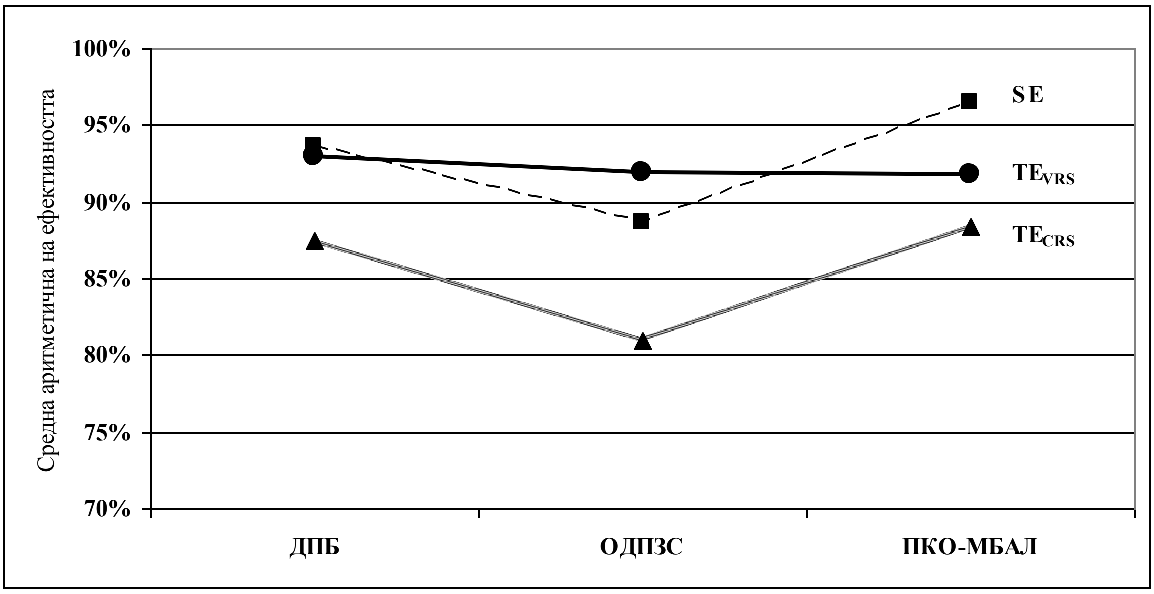
Table 5. *Change in input-output data to achieve target.*

Input data	SPH	RDPDI	PCW-MHAT
Hospital beds	-6,14%	-8,20%	-9,97%
Physicians	-8,10%	-10,76%	-33,15%
Nurses	-16,84%	-15,79%	-12,51%
Output data			
Patients treated	7,72%	3,24%	6,63%
Bed-days	1,38%	1,42%	0,00%

Discussion

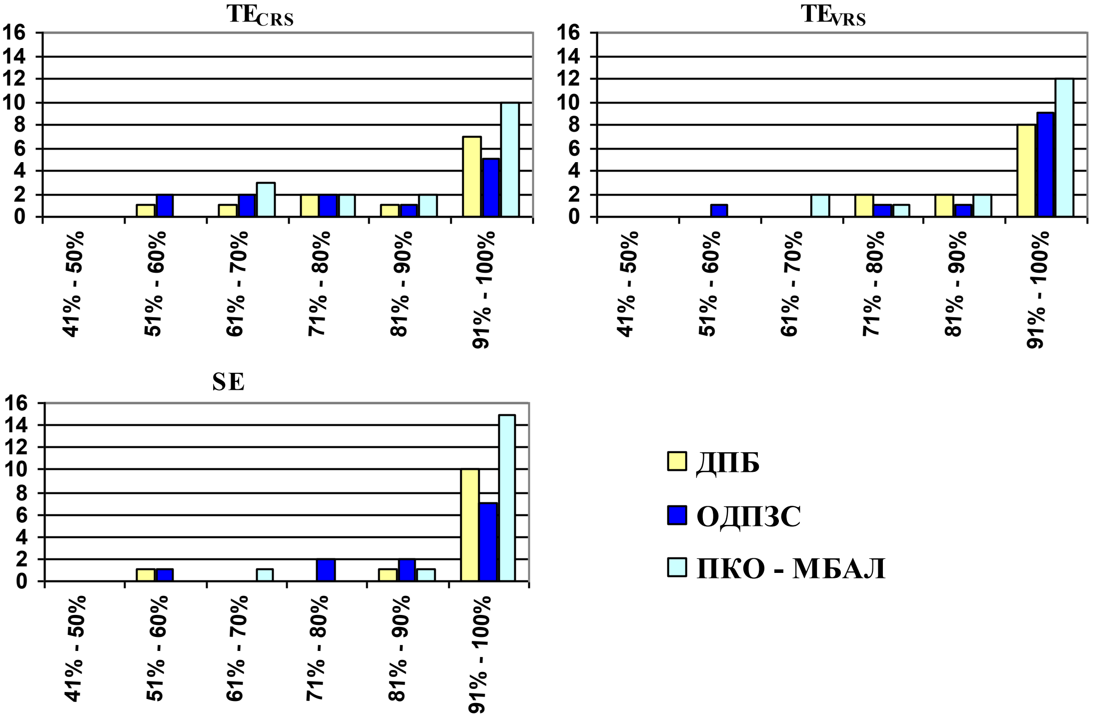
The observed difference between total (TE_{CRS}) and pure (TE_{VRS}) technical efficiency in all three groups demonstrated the presence of inefficiency resulting from scale. This difference was largest in the group of RDPDI (***Figure 2***) i.e., in this group we observed the lowest average value of scale efficiency (SE).
Pure technical efficiency was relatively uniform in all three groups and varied around 92%.
Total technical efficiency (TE_{CRS}) was lowest in the group of RDPDI and this was due, as we already noted, to the lower efficiency of scale i.e., the size of treatment facilities in this group.

Figure 2. Average values of components of technical efficiency by groups of treatment facilities for hospital psychiatric care.



In the groups of SPH and RDPDI the frontier of efficiency in variable returns to scale i.e., pure efficiency, was formed by approximately 58% of treatment facilities. The lowest percentage of purely efficient treatment facilities was observed in the group of PCW-MHAT – 35%.
The frequency distribution of hospitals with regard to efficiency is presented on ***Figure 3***.
The lowest reported total efficiency in the groups of SPH and RDPDI falls in the range 51%-60%, whereas in the group of PCW-MHAT this value falls in the range 61%-70%. The situation is analogous in terms of economies of scale. The minimum value of pure efficiency falls in different intervals for the three groups of treatment facilities, but is lowest for RDPDI.
As evident from ***Figure 3***, the number of hospitals with efficiency 91%-100% is highest.
Obtained results for the change in percentage of input-output data (***Table 5***) demonstrate a highest percentage of reduction in hospital beds and number of physicians in the group of PCW-MHAT. The required increase in the number of treated patients is highest in the group of SPH – 7,72%.

Figure 3. Distribution of the number of treatment facilities according to degree of efficiency.



Conclusions

On the basis of our study we made the following conclusions:

1. The average values of separate efficiency components are lowest in the group of RDPDI.
2. Pure efficiency is reatively uniform for the three groups.
3. Efficiency due to economies of scale is highest in the group of PCW-MHAT and lowest in the group of RDPDI.
4. Reported minimum total efficiency in the groups of SPH and RDPDI is approximately 53%, while in the group of PCW-MHAT this value is 62%.
5. The share of hospitals with 100% efficiency is highest in the group of SPH.
6. The highest percentage of changes in the input data to achieve efficiency in inefficient hospitals is observed in the group of PCW-MHAT.

DEA finds an increasing application in healthcare worldwide. In Bulgaria our study is one of the first to examine and utilise such an approach in healthcare.

__Application 1__. Technical efficiency of treatment facilities for hospital psychiatric care (2009).

SPH	**TE$_{CRS}$**	**TE$_{VRS}$**	**SE**
SPH – Tserova koria	*93,88%*	*100,00%*	*93,88%*
SPH – Sevlievo	*65,12%*	*74,12%*	*87,86%*
SPH – Karvuna	*52,58%*	*88,61%*	*59,34%*
SPH – Kardjali	*100,00%*	*100,00%*	*100,00%*
SPH – Lovech	*79,05%*	*83,24%*	*94,97%*
SPH – Karlukovo	*85,10%*	*92,29%*	*92,21%*
SPH – Patalenitsa	*100,00%*	*100,00%*	*100,00%*
SPH – Byala	*100,00%*	*100,00%*	*100,00%*
SPH – Novi Iskar	*97,46%*	*100,00%*	*97,46%*
SPH – Radnevo	*100,00%*	*100,00%*	*100,00%*
SPH – Tsarev brod	*75,92%*	*77,42%*	*98,06%*
SPH – Sofia	*100,00%*	*100,00%*	*100,00%*
RDPDI			
RDPDI – Blagoevgrad	*90,62%*	*91,10%*	*99,47%*
RDPDI "Prof. Temkov" – Burgas	*59,38%*	*60,12%*	*98,77%*
RDPDI – Veliko Tarnovo	*79,67%*	*80,35%*	*99,16%*
RDPDI – Vratsa	*79,48%*	*100,00%*	*79,48%*
RDPDI "Dr. P. Stanchev" – Dobrich	*69,06%*	*79,73%*	*86,61%*
RDPDI – Plovdiv	*81,74%*	*100,00%*	*81,74%*
RDPDI – Rousse	*92,95%*	*100,00%*	*92,95%*
RDPDI – Smolyan	*52,39%*	*100,00%*	*52,39%*
RDPDI – Sofia city	*100,00%*	*100,00%*	*100,00%*
RDPDI – Sofia region	*100,00%*	*100,00%*	*100,00%*
RDPDI – Stara Zagora	*66,49%*	*91,37%*	*72,77%*
RDPDI – Haskovo	*100,00%*	*100,00%*	*100,00%*
PCW-MHAT			
UMHAT* "Aleksandrovska" – Sofia	*67,28%*	*67,56%*	*99,58%*
MHAT "St. Marina" – Varna	*100,00%*	*100,00%*	*100,00%*
UMHAT "Dr. George Stranski" – Pleven	*100,00%*	*100,00%*	*100,00%*
UMHAT "St. George" – Plovdiv	*98,95%*	*98,96%*	*99,99%*
SHAT** "St. Naum" – Sofia	*61,60%*	*61,87%*	*99,56%*
MHAT "St. Petka" – Vratsa	*86,82%*	*88,34%*	*98,28%*
MHAT "Hristo Botev" – Враца	*63,78%*	*100,00%*	*63,78%*
MHAT "Dr. Nikola Vasilev" – Kyustendil	*98,68%*	*98,74%*	*99,94%*
MHAT "Dr. S. Iliev" – Montana	*74,11%*	*91,71%*	*80,82%*
MHAT "Rachila Angelova" – Pernik	*90,75%*	*90,87%*	*99,86%*
MHAT "St. Ivan Rilski" – Razgrad	*98,88%*	*98,95%*	*99,93%*
MHAT – Silistra	*78,66%*	*78,68%*	*99,98%*
MHAT "Dr. Ivan Seliminski" – Sliven	*85,10%*	*85,11%*	*99,99%*
MHAT – Targovishte	*100,00%*	*100,00%*	*100,00%*
MHAT "St. Pantaleimon" – Yambol	*99,34%*	*99,41%*	*99,93%*
MHAT "St. Ivan Rilski" – Dupnitsa	*100,00%*	*100,00%*	*100,00%*
MHAT – Lom	*97,82%*	*100,00%*	*97,82%*

* university hospital
** specialized hospital

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