ISSN 2744-1741
Original Research

Defense and Security Studies
Vol. 3, January 2022, pp.83-100
https://doi.org/10.37868/dss.v3.id199

Using Data Envelopment Analysis (DEA) for measuring efficiency in the Defense Sector

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Received Oct. 3, 2022
Revised Nov. 15, 2022
Accepted Nov. 17, 2022

Abstract

The way to improve the efficiency and effectiveness of public spending, which is a top priority for any government in any country, implies the introduction of Performance-Based Budgeting (PBB). One of the more advanced government-wide performance budgeting systems that uses performance information systematically in the preparation of the government budget is program budgeting. It is important to keep in mind that without systematic development and use of program performance information and adequate and effective performance indicators, program budgeting in the defense sector does not make sense as a tool to improve the efficiency and effectiveness of the defense resource management process.

Only by defining and tracking success can it be known if the defense organizations and units perform efficiently and effectively. In this article, Data Envelopment Analysis (DEA) was considered an instrument that can be used to measure, evaluate, and analyze the efficiency of the state and government as a whole, as well as commercial and non-profit organizations, including military units. It can be used as an instrument to hold managers accountable for their performance, which is critical to effective PBB. In this article, DEA has been applied to NATO members and some Eastern Europe post-Soviet aspirant and partner countries (Ukraine, Georgia and Moldova) to understand how efficient each country is at achieving its military power.

In order to demonstrate the feasibility of using DEA to examine the efficiency of the infantry battalions of the infantry brigades under the Eastern and Western Commands of the Georgian Defense forces (GDF), an illustrative analysis of the efficiency of the aforementioned units was carried out using fictitious data.

Keywords: Program budgeting; Performance; Efficiency; Effectiveness; Data Envelopment Analysis.

1. Introduction

The introduction of Performance-Based Budgeting (PBB) is a way to improve the efficiency and effectiveness of public spending, which is a top priority for any government in any country. This approach implies focusing rather on the results of spending and the achievement of policy objectives than on the management of inputs and provides budget decision-makers with greater discretion in the use of resources and in deciding the input mix. However, simultaneously, increased flexibility, and weakened central controls are counterbalanced by stronger internal controls and oversight and accountability mechanisms to hold managers accountable for the results of their performance. PBB implies the systematic use of performance information in the budget process to make results a central determinant of budget funding decisions, and thereby make budgeting a powerful instrument for maximizing government's efficiency and effectiveness.

Program budgeting is one of the most advanced nationwide performance budgeting systems that systematically uses performance information in the preparation of the state budget where expenditures are classified into groups of similar activities or projects (i.e. programs) with common outputs and outcomes.

The main differences between the traditional line-item budget method and the program budget method are presented in the Table 1.

Table 1. The main differences between the traditional line-item budget method and the program budget method [26]

Budget Method	**Characteristics**	**Primary Organization Feature**	**Budget Focus**
Line-Item Expenditure Budget	Expenditure by commodity or resource purchased	Resources Purchased	Control of Resources
Program Budget	Expenditure Related to Public Goals Cost data across organizational lines	Achievements (products or outputs)	Planning

Defense is an important part of the public sector, and its organizations consume large amounts of public resources. Improving the efficiency and effectiveness of managing defense funds and ensuring a successful defense budgeting process implies introducing the performance-based (program) budgeting approach in the defense sector as well.

The systematic development and use of program performance information is critical to achieving a good defense program budget. Without adequate and effective performance indicators and their application to assess the performance of program managers, program budgeting in the defense sector does not make sense as a tool to improve the efficiency and effectiveness of the defense resource management process; this will only make it easier and simpler for the ministry to allocate and use budgetary resources by loosening line item controls, without obtaining the core benefits of program budgeting.

Van Dooren et al. [1, p. 20] argue that "performance can be defined as outputs and outcomes." The principal tool of program budgeting identified by Robinson [2, p. 2], along with "budgetary expenditure classification in terms of outcome/output groups ("programs"), is "the systematic gathering of performance information (through indicators, evaluation, etc.) to inform decisions about budgetary priorities between competing programs." Performance-based budgets require information on inputs (measured in monetary terms), outputs (units of output), efficiency and productivity data (cost per activity), and effectiveness information (level of goal achievement) [3].

In the case of the defense ministry, performance information (outputs, outcomes, and indicators) and its systematic development and use are critical to achieving a good defense program budget and an effective resource allocation. The existence of a clear linkage between resource allocation and desired/produced outputs and outcomes is crucial for defense decision-makers to provide them with the ability to compare the costs and benefits of alternative spending options and choose the most effective ones, as well as monitor and control performance.

The old management adage "you can't manage what you can't measure" applies to the defense sector as well. Without defining and tracking success, it is impossible to know if the defense organizations and units are successful.

When considering the defense sector's activities, two aspects can be distinguished. The first concerns the products/services (outputs) produced by defense entities through the use of resources and is related to efficiency ("doing things right"). The second aspect, which concerns the impact of the produced products or services (outputs) on the objectives set for defense, is related to effectiveness ("doing the right things").

As Webb & Angelis [24, p.21] noted, "to measure efficiency, we must understand the relationship between the cost of inputs and the amount of outputs […] to measure effectiveness, we must understand the relationship between the organization's goals and objectives [or outcomes] and its outputs […]."

In order to do the right things (or to achieve effectiveness), defense policy-makers and decision-makers have to choose and develop the right mix of subprogram (intermediate) outputs to produce the final output (military capability) of the defense program, maximizing their preference value for outcomes, while subprogram managers have to do things right when responsible for producing outputs efficiently [13].

Data Envelopment Analysis (DEA) can be seen as a tool to measure and evaluate the effectiveness and efficiency of the state and government as a whole, as well as non-profit and commercial organizations, units and subunits (including defense organizations and units). It can be used as an instrument to hold managers accountable for their performance which is critical to effective PBB.

The results of the DEA analysis, in the form of potential improvements, offer management (commanders) opportunities to explore in search of higher performance. The process includes identifying the main sources of inefficiency, as well as those units that can become a benchmark for others.

In this study, DEA has been applied to NATO members and some Eastern Europe post-Soviet aspirant and partner countries (Ukraine, Georgia and Moldova) to understand how efficient each country is at achieving its military power. The efficiency of the decision-making units was measured with a CCR model.

As for the Georgian Defense Forces (GDF) units, in particular the infantry battalions of the infantry brigades under the Eastern and Western Commands, there are significant limitations in conducting such research due to the secrecy of detailed information, especially regarding the output of the defense program, namely, the military capability and its indicators – readiness levels of units. In addition, due to the peculiarities of the current defense program structure, obtaining accurate cost information, such as detailed information on the cost per battalion for any given period, should be very problematic. Therefore, in order to demonstrate the feasibility of using DEA to examine the efficiency of operational units, an illustrative analysis of the efficiency of the aforementioned infantry battalions was carried out using *fictitious data.*

2. Data Envelopment Analysis (DEA)

2.1 The use of the DEA in measuring performance

An excellent mathematical programming tool that can be used to measure, evaluate, and analyze performance is data envelopment analysis (DEA), which has been used to evaluate the performance of many different types of organizations, including government, not-for-profit and commercial units and subunits since it was first introduced in the late 1970s.

As a comparative performance measurement tool, DEA is aimed at facilitating "a program to improve performance, not to provide a simple grading of service providers" [4]. According to Avkiran, DEA is a non-parametric method that provides a comparative ratio of weighted outputs to inputs for each decision-making unit (DMU), i.e., a relative efficiency score, which is usually reported as a number from 0 to 100% or 0 to 1. A unit scoring less than 100% is considered inefficient compared to other units in the sample [5].

Efficiency can be defined as a "degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality" [4, p. 14]. Sherman defines efficiency as "the ability to produce products or services with the minimum level of resources required" [6, p. 3]. Farrell recognized the importance of measuring the extent to which outputs could be increased through higher efficiency without the use of additional inputs [7]. The Pareto optimality condition for efficient production states that a DMU is inefficient if the output can be increased without increasing any input and without decreasing any other output; likewise, a DMU is inefficient if the input can be decreased without decreasing any output and without increasing any other input [8].

DEA measures the efficiency of decision-making units (DMUs) using linear programming techniques, envelops observed input-output vectors as tightly as possible and allows to consider multiple input-output vectors at the same time without any assumptions on data distribution. In each case, efficiency is measured by proportional changes in inputs or outputs. According to Ji and Lee, "a DEA model can be subdivided into an input-oriented model, which minimizes inputs while satisfying at least the given output levels, and an output-oriented model, which maximizes outputs without requiring more of any observed input values" [9, p. 268].

The original Charnes, Cooper, and Rhodes (CCR) DEA model utilizes linear programming to produce an efficiency measure for a DMU, requiring only that the DMUs convert similar inputs to similar outputs and that these can be quantified. The logic of the model implies, first, defining the underlying premise that efficiency is the sum of weighted outputs over the sum of weighted inputs [10]. The DEA model for the kth DMU can be formulated as follows:

$$\text{Max } E_k = \frac{\sum_{r=1}^{t} U_r Y_{rk}}{\sum_{i=1}^{m} V_i X_{ik}}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{t} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \leq 1 \qquad j = 1,\ldots\ldots n$$

$$U_r \geq 0 \qquad r = 1,\ldots\ldots t$$

$$V_i \geq 0 \qquad i = 1,\ldots\ldots m,$$

Where:

Objective function
E_k = the efficiency index of the kth DMU;

Parameters
y_{rj} = the amount of the rth output for the jth DMU;
x_{ij} = the amount of the ith input for the jth DMU;
t = the number of outputs;
m = the number of inputs; and
n = the number of DMUs

Decision variables
u_r = the weight assigned to the rth output; and
v_i = the weight assigned to the ith input [11].

Generally, in the defense sector area, DEA efficiency and productivity studies have focused on various support functions such as maintenance and recruitment, as well as operational units, the core area of defense (see Table 2).

Table 2. Bibliography of DEA in the military [12]

Paper	Field	Inputs	Outputs	Observa tions
Lewin and Morey (1981)	Recruitment	10	2	43
Charnes et al. (1985)	Maintenance	8	4	42
Bowlin (1987)	Maintenance	3	4	21
Bowlin (1989)	Accounting and finance	1	5	18
Ali et al. (1989)*	Recruitment	n/a	n/a	n/a
Roll et al. (1989)	Maintenance	3	2	10-35
Clarke (1992)	Maintenance	4	2	17
Ozcan and Bannick (1994)	Hospitals	6	2	23
Bowlin (2004)	Civil reserve air fleet	4	7	37-111
Brockett et al. (2004)	Recruitment	1	10	n/a
Sun (2004)	Maintenance	6	5	30
Farris et al. (2006)	Engineering design projects	4	1	15
Lu (2011)	Outlets	4	2	31
Kalin (2021)	Logistics	4	1	34
Hanson (2012)	Operational units	3	1	11
Hanson (2019)	Combat units	3 (1)	1 (1)	12

*Paper not available.

Hanson conducted interesting research that examined the productivity and efficiency of the core area of the Norwegian armed forces, operational units, using Data Envelopment Analysis (DEA). A model has been developed to analyze the productivity and efficiency by DEA for the operational units of the armed forces. As Hanson noted, "By aggregating activity standards and quality measures the model enables a meaningful and measurable expression for the output of an operational unit" [12, p. 25].

In another study, Hanson used a scenario-based planning approach to develop an effectiveness measurement model for situations where traditional methods such as two-stage regression fail due to long time lags and lack of variation in the variables. According to Hanson, "from a sample of 12 combat units in the Norwegian Armed Forces, producing different outputs, [it was found] that inefficiencies in output mix can explain most of the changes in overall effectiveness over a four-year period of time" [13, p. 1].

2.2 Examining the efficiency of NATO members and some partner countries in achieving military power by using DEA

DEA has been applied to NATO members and some Eastern Europe post-Soviet aspirant and partner countries (Ukraine, Georgia and Moldova) to understand how efficient each country is at achieving its military power. The efficiency of the decision-making units was measured with a CCR model.

2.2.1 Specification of Data and Variables

A total of 31 DMUs were selected for the study. These DMUs focused on NATO members and some Eastern Europe post-Soviet aspirant and partner countries (Ukraine, Georgia and Moldova). The study was aimed at measuring how efficiently each country achieved its military power. Four variables were retrieved from the open sources [28], [29], [30], [31]: two input variables - *Defense Expenditure, Current prices and exchange rates US dollars for 2020*; *Defense Expenditure as a share of real GDP (%) for 2020;* and two output variables - *Military Personnel for 2020;* and *Military Strength Ranking for 2022 (reversed).*

Defense expenditure refers to all current and capital spending on the armed forces of a state and in theory, the higher the level of defense expenditure, the better the military power of the state.
The commitment made in 2014 by members of the North Atlantic Treaty Organization (NATO) to increase their Defense expenditure as a share of real GDP to 2 % by 2024 is still the subject of debate about military spending in NATO [25].
In my recent article, I proposed to define the main output of a defense program as "Military Capability as a comprehensive force structure consisting of its constituent force elements/capabilities […] with an integrated set of aspects categorized as doctrine, organization, training, materiel, leadership development, personnel, and facilities, and with an appropriate readiness level assessed at a concrete time" [23, p. 94].
Therefore, in this case, it is crucial that Military Personnel be considered as an integral part of military capability (combat-ready forces), i.e., the "production" of military personnel implies the simultaneous development of the military capability as a whole (across the entire DOTMLPF spectrum).
In principle, the GFP rating (Military Strength Ranking) is a kind of indicator of the performance of the defense organization of a state, and an improved position in the ranking is evidence of increased efficiency and effectiveness of the defense programs. For this study, the reverse military power index (Global Firepower, 2022) was used, so it was assumed that the higher the military power index, the better the country. At the initial measure, the lower the military index, the better.

2.2.2 DEA Model and Results

The DEA analysis was carried out using DEA-Solver-PRO 5.0 software [22] developed by W.W. Cooper, L.M. Seiford and K. Tone. This study performed a CCR input-oriented DEA model, and the main focus was to see how efficient each country was at producing military capability and achieving its military power index, given its resources or inputs.
Table 3 and Table 4 below show the results of running the model.

Table 3. DEA Test Results

Rank	DMU	Score	Rank	DMU	Score
1	Moldova	1	17	Netherlands	0,57707535
1	United States	1	18	Bulgaria	0,570603056
1	Spain	1	19	Poland	0,569492872
1	Türkiye	1	20	Hungary	0,55453459
5	Czech Republic	0,971773347	21	United Kingdom	0,548049942
6	Ukraine	0,932569009	22	Belgium	0,533707754
7	Italy	0,909221694	23	Croatia	0,528911822
8	Portugal	0,8447062	24	Slovenia	0,5158751
9	Georgia	0,792712503	25	Slovak Republic	0,476957309
10	France	0,697923222	26	Albania	0,376089889
11	Romania	0,665795625	27	North Macedonia	0,368317769
12	Germany	0,662166375	28	Lithuania	0,28768714
13	Greece	0,634367881	29	Latvia	0,20825904
14	Norway	0,631334284	30	Montenegro	0,197800912
15	Canada	0,610115983	31	Estonia	0,157514612
16	Denmark	0,578313316			

Table 4. Projections by the CCR Model

No	DMU I/O	Score Data	Projection	Difference	%
1	United States	1			
	Defense Expenditure	7,84952E+11	7,84952E+11	0	0,00%
	Defense Expenditure as a share of real GDP (%)	3,72	3,72	0	0,00%
	Military Personnel	1346000	1346000	0	0,00%
	Military Strength Ranking (reversed)	35,8958	35,8958	0	0,00%
2	France	0,697923222			
	Defense Expenditure	52727000000	36799397750	-15927602250	-30,21%
	Defense Expenditure as a share of real GDP (%)	2,03	1,416784142	-0,613215858	-30,21%
	Military Personnel	208000	208000	0	0,00%
	Military Strength Ranking (reversed)	5,7275	5,7275	0	0,00%
3	United Kingdom	0,548049942			
	Defense Expenditure	61925000000	33937992687	-27987007313	-45,20%
	Defense Expenditure as a share of real GDP (%)	2,29	1,255034368	-1,034965632	-45,20%
	Military Personnel	156200	175283,8318	19083,83183	12,22%
	Military Strength Ranking (reversed)	5,2184	5,2184	0	0,00%
4	Italy	0,909221694			
	Defense Expenditure	26071000000	23704318784	-2366681216	-9,08%
	Defense Expenditure as a share of real GDP (%)	1,38	1,254725938	-0,125274062	-9,08%
	Military Personnel	175500	175500	0	0,00%
	Military Strength Ranking (reversed)	4,7871	4,7871	0	0,00%
5	Türkiye	1			
	Defense Expenditure	13396000000	13396000000	0	0,00%
	Defense Expenditure as a share of real GDP (%)	1,86	1,86	0	0,00%
	Military Personnel	437200	437200	0	0,00%
	Military Strength Ranking (reversed)	4,4351	4,4351	0	0,00%
6	Germany	0,662166375			
	Defense Expenditure	58902000000	39002923817	-19899076183	-33,78%
	Defense Expenditure as a share of real GDP (%)	1,55	1,026357881	-0,523642119	-33,78%
	Military Personnel	186900	186900	0	0,00%
	Military Strength Ranking (reversed)	4,3067	4,3067	0	0,00%
7	Spain	1			
	Defense Expenditure	12828000000	12828000000	0	0,00%
	Defense Expenditure as a share of real GDP (%)	1	1	0	0,00%
	Military Personnel	122500	122500	0	0,00%
	Military Strength Ranking (reversed)	3,7337	3,7337	0	0,00%
8	Ukraine	0,932569009			
	Defense Expenditure	5924000000	5524538808	-399461191,8	-6,74%

	Defense Expenditure as a share of real GDP (%)	4,1	3,823532936	-0,276467064	-6,74%
	Military Personnel	209000	209000	0	0,00%
	Military Strength Ranking (reversed)	3,4016	6,261898544	2,860298544	84,09%
9	Canada	0,610115983			
	Defense Expenditure	23595000000	14395686628	-9199313372	-38,99%
	Defense Expenditure as a share of real GDP (%)	1,44	0,878567016	-0,561432984	-38,99%
	Military Personnel	71000	111398,8073	40398,80729	56,90%
	Military Strength Ranking (reversed)	3,3736	3,3736	0	0,00%
10	Poland	0,569492872			
	Defense Expenditure	13590000000	7739408124	-5850591876	-43,05%
	Defense Expenditure as a share of real GDP (%)	2,28	1,298443747	-0,981556253	-43,05%
	Military Personnel	120000	120000	0	0,00%
	Military Strength Ranking (reversed)	3,1759	3,1759	0	0,00%
11	Greece	0,634367881			
	Defense Expenditure	5019000000	3183892393	-1835107607	-36,56%
	Defense Expenditure as a share of real GDP (%)	2,65	1,681074884	-0,968925116	-36,56%
	Military Personnel	107600	107600	0	0,00%
	Military Strength Ranking (reversed)	2,8681	2,8681	0	0,00%
12	Norway	0,631334284			
	Defense Expenditure	7272000000	4591062910	-2680937090	-36,87%
	Defense Expenditure as a share of real GDP (%)	2,01	1,26898191	-0,74101809	-36,87%
	Military Personnel	20800	54698,49719	33898,49719	162,97 %
	Military Strength Ranking (reversed)	2,6527	2,6527	0	0,00%
13	Netherlands	0,57707535			
	Defense Expenditure	13125000000	7574113967	-5550886033	-42,29%
	Defense Expenditure as a share of real GDP (%)	1,47	0,848300764	-0,621699236	-42,29%
	Military Personnel	40000	75401,12632	35401,12632	88,50%
	Military Strength Ranking (reversed)	2,5771	2,5771	0	0,00%
14	Romania	0,665795625			
	Defense Expenditure	5051000000	3362933704	-1688066296	-33,42%
	Defense Expenditure as a share of real GDP (%)	2,03	1,351565119	-0,678434881	-33,42%
	Military Personnel	66400	66400	0	0,00%
	Military Strength Ranking (reversed)	2,5072	2,5072	0	0,00%
15	Czech Republic	0,971773347			
	Defense Expenditure	3201000000	3110646484	-90353515,56	-2,82%
	Defense Expenditure as a share of real GDP (%)	1,31	1,273023085	-3,70E-02	-2,82%
	Military Personnel	26800	41984,69203	15184,69203	56,66%
	Military Strength Ranking (reversed)	2,3944	2,3944	0	0,00%
16	Portugal	0,8447062			

	Defense Expenditure	3306000000	2792598697	-513401303	-15,53%
	Defense Expenditure as a share of real GDP (%)	1,43	1,207929866	-0,222070134	-15,53%
	Military Personnel	28700	38467,306	9767,306	34,03%
	Military Strength Ranking (reversed)	2,2436	2,2436	0	0,00%
17	Hungary	0,55453459			
	Defense Expenditure	2770000000	1536060814	-1233939186	-44,55%
	Defense Expenditure as a share of real GDP (%)	1,79	0,992616916	-0,797383084	-44,55%
	Military Personnel	22700	25069,63378	2369,63378	10,44%
	Military Strength Ranking (reversed)	1,7083	1,7083	0	0,00%
18	Denmark	0,578313316			
	Defense Expenditure	4979000000	2879422001	-2099577999	-42,17%
	Defense Expenditure as a share of real GDP (%)	1,4	0,809638643	-0,590361357	-42,17%
	Military Personnel	18100	34469,74292	16369,74292	90,44%
	Military Strength Ranking (reversed)	1,6836	1,6836	0	0,00%
19	Slovak Republic	0,476957309			
	Defense Expenditure	2050000000	977762482,9	-1072237517	-52,30%
	Defense Expenditure as a share of real GDP (%)	1,96	0,934836325	-1,025163675	-52,30%
	Military Personnel	12900	19568,30014	6668,300138	51,69%
	Military Strength Ranking (reversed)	1,5252	1,5252	0	0,00%
20	Croatia	0,528911822			
	Defense Expenditure	1031000000	545308088,2	-485691911,8	-47,11%
	Defense Expenditure as a share of real GDP (%)	1,8	0,952041279	-0,847958721	-47,11%
	Military Personnel	15200	16045,33197	845,3319659	5,56%
	Military Strength Ranking (reversed)	1,4729	1,4729	0	0,00%
21	Bulgaria	0,570603056			
	Defense Expenditure	1075000000	613398285,7	-461601714,3	-42,94%
	Defense Expenditure as a share of real GDP (%)	1,55	0,884434738	-0,665565262	-42,94%
	Military Personnel	25600	25600	0	0,00%
	Military Strength Ranking (reversed)	1,3664	1,3664	0	0,00%
22	Belgium	0,533707754			
	Defense Expenditure	5427000000	2896431982	-2530568018	-46,63%
	Defense Expenditure as a share of real GDP (%)	1,05	0,560393142	-0,489606858	-46,63%
	Military Personnel	25200	31646,37661	6446,376605	25,58%
	Military Strength Ranking (reversed)	1,3265	1,3265	0	0,00%
23	Lithuania	0,28768714			
	Defense Expenditure	1176000000	338320076,6	-837679923,4	-71,23%
	Defense Expenditure as a share of real GDP (%)	2,11	0,607019865	-1,502980135	-71,23%
	Military Personnel	16300	16300	0	0,00%
	Military Strength Ranking (reversed)	0,8633	0,924254558	6,10E-02	7,06%
24	Slovenia	0,5158751			

	Defense Expenditure	568000000	293017056,6	-274982943,4	-48,41%
	Defense Expenditure as a share of real GDP (%)	1,08	0,557145108	-0,522854892	-48,41%
	Military Personnel	7000	9164,882239	2164,882239	30,93%
	Military Strength Ranking (reversed)	0,8573	0,8573	0	0,00%
25	Georgia	0,792712503			
	Defense Expenditure	292000000	231472050,9	-60527949,13	-20,73%
	Defense Expenditure as a share of real GDP (%)	1,8	1,426882505	-0,373117495	-20,73%
	Military Personnel	20650	20650	0	0,00%
	Military Strength Ranking (reversed)	0,8169	2,09945964	1,28255964	157,00 %
26	Latvia	0,20825904			
	Defense Expenditure	743000000	154736466,7	-588263533,3	-79,17%
	Defense Expenditure as a share of real GDP (%)	2,22	0,462335069	-1,757664931	-79,17%
	Military Personnel	7000	7000	0	0,00%
	Military Strength Ranking (reversed)	0,6953	0,6953	0	0,00%
27	Moldova	1			
	Defense Expenditure	44500000	44500000	0	0,00%
	Defense Expenditure as a share of real GDP (%)	0,4	0,4	0	0,00%
	Military Personnel	5150	5150	0	0,00%
	Military Strength Ranking (reversed)	0,5859	0,5859	0	0,00%
28	Estonia	0,157514612			
	Defense Expenditure	719000000	113253006,3	-605746993,7	-84,25%
	Defense Expenditure as a share of real GDP (%)	2,32	0,365433901	-1,954566099	-84,25%
	Military Personnel	6600	6600	0	0,00%
	Military Strength Ranking (reversed)	0,5455	0,5455	0	0,00%
29	Albania	0,376089889			
	Defense Expenditure	188000000	70704899,2	-117295100,8	-62,39%
	Defense Expenditure as a share of real GDP (%)	1,27	0,47763416	-0,79236584	-62,39%
	Military Personnel	6700	6700	0	0,00%
	Military Strength Ranking (reversed)	0,4276	0,701893273	0,274293273	64,15%
30	Montenegro	0,197800912			
	Defense Expenditure	83000000	16417475,73	-66582524,27	-80,22%
	Defense Expenditure as a share of real GDP (%)	1,73	0,147572816	-1,582427184	-91,47%
	Military Personnel	1900	1900	0	0,00%
	Military Strength Ranking (reversed)	0,1695	0,216157282	0,046657282	27,53%
31	North Macedonia	0,368317769			
	Defense Expenditure	154000000	56720936,47	-97279063,53	-63,17%
	Defense Expenditure as a share of real GDP (%)	1,25	0,460397212	-0,789602788	-63,17%
	Military Personnel	6100	6100	0	0,00%
	Military Strength Ranking (reversed)	0,1283	0,67508041	0,54678041	426,1%

2.2.3 Summary and Recommendations

The study showed that some states were efficient at producing their military capability and achieving the military power index utilizing the inputs provided, while others needed to improve. According to the test results, 4 out of the 31 countries (United States, Spain, Türkiye and Moldova) outputted 1.00 or 100 percent efficiency across the DEA model and can be used as benchmarks. The CCR input-oriented model we applied measures technical efficiency, or how resources are used during the production/delivery of an output (doing the things right). Since the scores of other states were below 1.00 or 100 percent, this means that the ministries of defense should look for ways to utilize the allocated budgetary resources more efficiently to achieve higher results and improve positions in the Military Strength Ranking.

2.3 A sample DEA model for measuring the efficiency of the GDF infantry battalions

In the case of the Georgian Defense Forces (GDF), the DEA can be used, for example, to examine the efficiency of operational units, particularly the infantry battalions of the infantry brigades under the Eastern and Western Commands, on delivery of readiness. However, a significant limitation in conducting such research is the secrecy of detailed information, especially regarding the output of the defense program, namely, the military capability and its indicators – readiness levels of units. Also, due to the peculiarities of the current defense program structure, it should be quite problematic to obtain accurate information regarding the inputs, for example, detailed costs per battalion for any particular period. Consequently, in order to demonstrate the possibility of using DEA for the above purposes, an illustrative analysis of the efficiency of battalions was carried out using fictitious data.

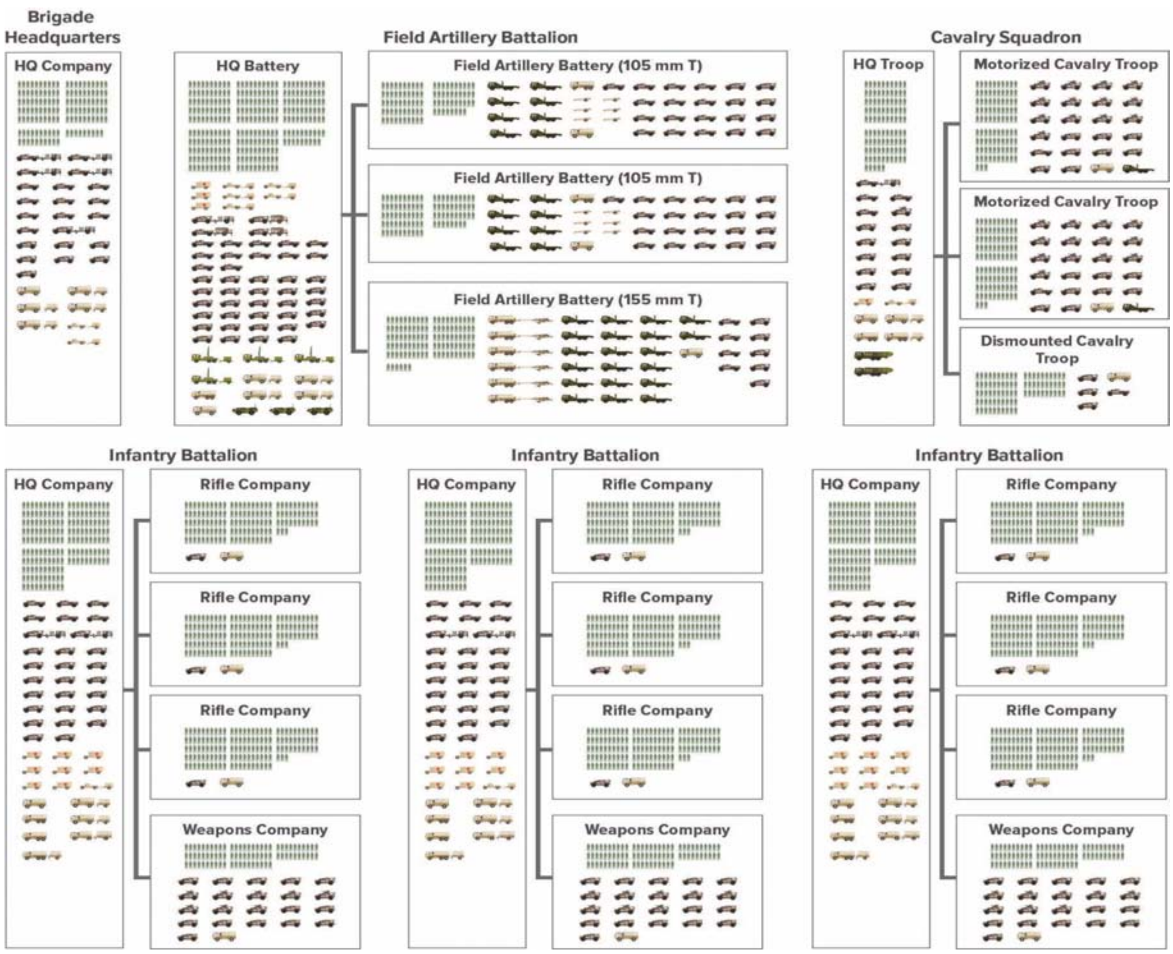

Figure 1. Units, equipment, and personnel in an Army Infantry Brigade Combat Team, excluding support battalion [17]

According to Strategic Defense Review (SDR) 2021-2025 [14], the GDF Future Force Structure, along with other military units, includes four infantry brigades under the Eastern and Western Commands.
Due to the unavailability of relevant information regarding the structure of brigades of the GDF from open sources, data on the structure of brigades of the US Army were used as an example. Infantry Brigade Combat Teams (IBCTs) constitute the Army's "light", primarily foot-mobile ground forces that can move by foot, vehicle, or air (either air landed or by helicopter) [15]. According to the Army's Field Manual (FM) 3-96, the IBCTs are employed as follows: "The role of the IBCT is to close with the enemy by means of fire and movement to destroy or capture enemy forces, or to repel enemy attacks by fire, close combat, and counterattack to control land areas, including populations and resources" [16, p. 1-2].
IBCTs are relatively independent tactical formations that are designed to include approximately 4,400 personnel [17]. As can be seen from Figure 1, there are three infantry battalions in the IBCT.

Since there are four infantry brigades in the GDF Future Force Structure, it can be assumed that there will be a total of 12 infantry battalions that will be treated as decision making units (DMUs) in our sample DEA model. Two input variables can be defined for the use of personnel and equipment: (1) Personnel Costs - pay and benefits for military personnel, compensation for civilian employees, health care costs, and travel expenses for military and civilian personnel; and (2) Material Costs - daily expenses of operating a unit, such as equipment maintenance, training, support contractors, and so on. Readiness indicators by category can be used as outputs: personnel (P-level), equipment availability (S-level), equipment readiness (R-level) and training (T-level) (see Figure 2).

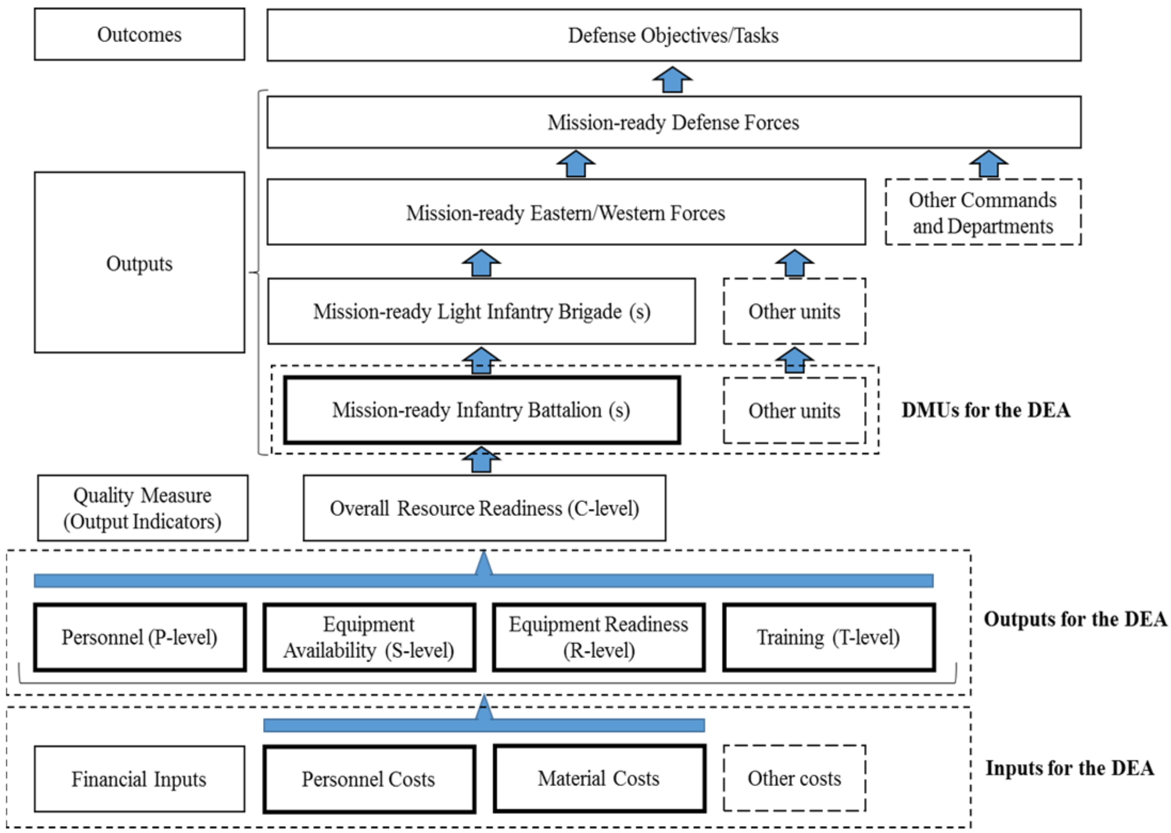

Figure 2. Data model for the DEA

It should be mentioned that according to Avkiran, "there are some rules of thumb on the number of inputs and outputs to select and their relation to the number of DMUs" [5, p. 115]. Boussofiane, Dyson and Thanassoulis argue that to obtain good discriminatory power out of the CCR and BCC models, the lower bound on the number of DMUs must be a multiple of the number of inputs and the number of outputs. For example, if there are 2 inputs and 4 outputs, the minimum total number of DMUs must be 8 for some discriminatory power to exist in the model [18].

Golany and Roll propose a rule of thumb that the number of units should be at least twice the number of inputs and outputs under consideration [19]. Bowlin mentions the need to have three times as many DMUs as there are input and output variables [20].

According to Dyson et al., a total of two times the product of the number of input and output variables is recommended [21]. For example, for a 3-input, 4-output model, Golany and Roll recommend 14 DMUs, while Bowlin recommends 21 DMUs. In any case, these figures should probably be used as the minimum for baseline performance models.

As can be seen, the variants of DMUs, inputs and outputs proposed in our example basically meet the above requirements.

Table 5 below shows the fictitious data for conducting the DEA.

Table 5. Fictitious data for conducting the DEA

DMU name	Input 1 Personnel costs GEL	Input 2 Material costs GEL	Output 1 P-level (%)	Output 2 S-level (%)	Output 3 R-level (%)	Output 4 T-level (%)
1st Infantry battalion	10 800 000	5 000 000	85	91	70	85
2nd Infantry battalion	10 200 000	5 500 000	75	82	75	85
3rd Infantry battalion	11 760 000	6 000 000	88	74	96	87
4th Infantry battalion	11 160 000	7 000 000	74	96	84	78
5th Infantry battalion	10 680 000	6 500 000	96	97	99	95
6th Infantry battalion	10 920 000	5 850 000	81	75	82	76
7th Infantry battalion	10 788 000	5 100 000	68	85	78	82
8th Infantry battalion	11 520 000	5 350 000	92	86	91	95
9th Infantry battalion	11 040 000	5 120 000	77	88	99	87
10th Infantry battalion	10 560 000	4 950 000	85	91	75	81
11th Infantry battalion	10 320 000	6 200 000	86	69	85	73
12th Infantry battalion	11 568 000	6 850 000	91	92	94	93

The exemplifying analysis was carried out using DEA-Solver-PRO 5.0 software [22]. As can be seen from the DEA test results depicted in Table 6 and 7, five of the twelve infantry battalions are efficient, while the rest show some inefficiency.

Table 6. DEA test results

Rank	DMU	Score
1	10th Infantry battalion	1
1	1st Infantry battalion	1
1	9th Infantry battalion	1
1	8th Infantry battalion	1
1	5th Infantry battalion	1
6	2nd Infantry battalion	0,970912603
7	7th Infantry battalion	0,954380827
8	4th Infantry battalion	0,947123379
9	3rd Infantry battalion	0,939071369
10	11th Infantry battalion	0,93254636
11	12th Infantry battalion	0,911386993
12	6th Infantry battalion	0,87500128

Table 7. Projections by the CCR Model

No.	DMU I/O	Score Data	Projection	Difference	%
1	1st Infantry battalion	1			
	Personnel costs GEL	10800000	10800000	0	0,00%
	Material costs GEL	5000000	5000000	0	0,00%
	P-level (%)	85	85	0	0,00%
	S-level (%)	91	91	0	0,00%
	R-level (%)	70	70	0	0,00%
	T-level (%)	85	85	0	0,00%
2	2nd Infantry battalion	0,970912603			
	Personnel costs GEL	10200000	9903308,547	-296691,4534	-2,91%
	Material costs GEL	5500000	5340019,314	-159980,6857	-2,91%
	P-level (%)	75	84,23988411	9,239884114	12,32%
	S-level (%)	82	82,23862868	0,238628682	0,29%
	R-level (%)	75	85,26924191	10,26924191	13,69%
	T-level (%)	85	85	0	0,00%
3	3rd Infantry battalion	0,939071369			
	Personnel costs GEL	11760000	11043479,3	-716520,7003	-6,09%
	Material costs GEL	6000000	5634428,214	-365571,7859	-6,09%
	P-level (%)	88	88	0	0,00%
	S-level (%)	74	90,00404513	16,00404513	21,63%
	R-level (%)	96	96	0	0,00%
	T-level (%)	87	92,00663008	5,006630078	5,75%
4	4th Infantry battalion	0,947123379			
	Personnel costs GEL	11160000	10569896,91	-590103,0928	-5,29%
	Material costs GEL	7000000	6432989,691	-567010,3093	-8,10%
	P-level (%)	74	95,01030928	21,01030928	28,39%
	S-level (%)	96	96	0	0,00%
	R-level (%)	84	97,97938144	13,97938144	16,64%
	T-level (%)	78	94,02061856	16,02061856	20,54%
5	5th Infantry battalion	1			
	Personnel costs GEL	10680000	10680000	0	0,00%
	Material costs GEL	6500000	6500000	0	0,00%
	P-level (%)	96	96	0	0,00%
	S-level (%)	97	97	0	0,00%
	R-level (%)	99	99	0	0,00%
	T-level (%)	95	95	0	0,00%
6	6th Infantry battalion	0,87500128			
	Personnel costs GEL	10920000	9555013,98	-1364986,02	-12,50%
	Material costs GEL	5850000	5118757,489	-731242,5106	-12,50%
	P-level (%)	81	81	0	0,00%
	S-level (%)	75	78,99387085	3,993870847	5,33%
	R-level (%)	82	82	0	0,00%
	T-level (%)	76	81,84403062	5,84403062	7,69%

7	7th Infantry battalion	0,954380827			
	Personnel costs GEL	10788000	10295860,37	-492139,6349	-4,56%
	Material costs GEL	5100000	4867342,219	-232657,7807	-4,56%
	P-level (%)	68	78,80442417	10,80442417	15,89%
	S-level (%)	85	85	0	0,00%
	R-level (%)	78	78	0	0,00%
	T-level (%)	82	82	0	0,00%
8	8th Infantry battalion	1			
	Personnel costs GEL	11520000	11520000	0	0,00%
	Material costs GEL	5350000	5350000	0	0,00%
	P-level (%)	92	92	0	0,00%
	S-level (%)	86	86	0	0,00%
	R-level (%)	91	91	0	0,00%
	T-level (%)	95	95	0	0,00%
9	9th Infantry battalion	1			
	Personnel costs GEL	11040000	11040000	0	0,00%
	Material costs GEL	5120000	5120000	0	0,00%
	P-level (%)	77	77	0	0,00%
	S-level (%)	88	88	0	0,00%
	R-level (%)	99	99	0	0,00%
	T-level (%)	87	87	0	0,00%
10	10th Infantry battalion	1			
	Personnel costs GEL	10560000	10560000	0	0,00%
	Material costs GEL	4950000	4950000	0	0,00%
	P-level (%)	85	85	0	0,00%
	S-level (%)	91	91	0	0,00%
	R-level (%)	75	75	0	0,00%
	T-level (%)	81	81	0	0,00%
11	11th Infantry battalion	0,93254636			
	Personnel costs GEL	10320000	9623878,44	-696121,5601	-6,75%
	Material costs GEL	6200000	5781787,435	-418212,5652	-6,75%
	P-level (%)	86	86	0	0,00%
	S-level (%)	69	87,15708111	18,15708111	26,31%
	R-level (%)	85	88,04103148	3,041031479	3,58%
	T-level (%)	73	84,94507688	11,94507688	16,36%
12	12th Infantry battalion	0,911386993			
	Personnel costs GEL	11568000	10542924,74	-1025075,26	-8,86%
	Material costs GEL	6850000	6243000,905	-606999,0952	-8,86%
	P-level (%)	91	93,56101001	2,561010012	2,81%
	S-level (%)	92	93,80856701	1,808567007	1,97%
	R-level (%)	94	96,07991476	2,079914761	2,21%
	T-level (%)	93	93	0	0,00%

Sherman [27] argues that the DEA is best used as a tool that can focus the attention of managers. In the infantry battalions example above, potential improvements suggest opportunities for managers (commanders) to explore in search of higher performance. The process includes identifying the main sources of inefficiency as well as those units that can become reference DMUs for others.

3. Conclusions

The way to improve the efficiency and effectiveness of public spending, which is a top priority for any government in any country, implies the introduction of Performance-Based Budgeting (PBB). Program budgeting is one of the most advanced government-wide performance budgeting systems that systematically uses performance information in the preparation of the state budget where expenditures are classified into groups of similar activities or projects (i.e., programs) with common outputs and outcomes.

It is important to keep in mind that without systematic development and use of program performance information and adequate and effective performance indicators, program budgeting in the defense sector does not make sense as a tool to improve the efficiency and effectiveness of the defense resource management process. Only by defining and tracking success can it be known if the defense organizations and units perform efficiently and effectively.

In this article, DEA was considered an excellent mathematical programming and a powerful management tool that can be used to measure, evaluate, and analyze the efficiency of the state and government as a whole, as well as commercial and non-profit organizations, including military units. DEA can be applied as an instrument to hold managers at all levels accountable for their performance which is critical to effective Performance-Based Budgeting (PBB).

In this study, Data Envelopment Analysis (DEA) has been applied to NATO members and some Eastern Europe post-Soviet aspirant and partner countries (Ukraine, Georgia and Moldova) to understand how efficient each country is at achieving its military power. The efficiency of the decision-making units was measured with a CCR model.

Due to the secrecy and peculiarities of the current defense program structure, there are significant limitations in obtaining detailed information on the main output of the defense, namely, the military capability and its indicators – readiness levels of units and accurate cost information, such as detailed information on the cost per battalion for any given period. Therefore, in order to demonstrate the feasibility of using DEA to examine the efficiency of operational units, an illustrative analysis of the efficiency of the aforementioned infantry battalions was carried out using *fictitious data.*

I believe that one of the main barriers to using DEA as a valid tool for measuring and evaluating the performance of the GDF units is the current structure of the defense program.

The introduction of the defense program structure proposed in my recent article [23], which will include the Major Force Program developed on a Force Capabilities basis; the definition of capabilities embodied in a force element as the main output of the defense subprograms; and the identification of force (program) elements (e.g., departments, commands, brigades, and battalions) as cost centers, will facilitate the use of the DEA and other statistical tools to measure and evaluate the performance of the GDF units and develop proposals for its improvement.

A key precondition for the successful application of the DEA and other statistical tools in measuring and evaluating performance in the Ministry of Defense is the development of effective computerized financial management information systems (FMIS), including computerized accounting systems.

One of the challenges for the Ministry is to implement an effective management accounting system to provide managers (unit commanders) with timely, accurate, meaningful, and insightful information without which an effective decision-making process is impossible. Well-organized accounting systems are the main original source of the best quality and ultimately the most reliable primary data for the life cycle costing to support decision-making process as well as performance measurement and evaluation.

It is also crucial to include the “readiness level” as an output indicator in the defense program structure of the Georgian Ministry of Defense. The target readiness levels of the GDF units should also be specified in the Defense Program Guidance (DPG) and other planning documents of the MOD of Georgia (in the secret part of the documents), as well as procurement objectives and descriptions of acceptable risk. Defense program managers who are accountable for the resources provided must monitor the balance of inputs to readiness and the state of readiness achieved.

Disclaimer

The views represented in this paper are those of the author and don't reflect the official policy or position of the Ministry of Defense of Georgia.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

Funding information

No funding was received from any financial organization to conduct this research.

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