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DEA APPLICATIONS IN THE DEFENSE SECTOR

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Abstract: *Data Envelopment Analysis (DEA) is a non-parametric methodology that can be used to measure the relative efficiency of homogenous entities (Decision Making Units (DMUs)) that use the same inputs to produce the same outputs. Since its introduction in 1978, there has been a notable growth in the published papers where DEA is applied in various areas, such as: education, banking, finance, energetics, agriculture, health care, sport, the defense sector, etc. The aim of this paper is to present the application of DEA in the defense sector. 15 studies published in the period between 1983 and 2014 are analyzed. The emphasis in the analyzed studies is on the observed period, the sample, the used variables, the models, and the obtained results.*

Keywords: *Non-parametric methodology, Data Envelopment Analysis, Defense Sector.*

1. INTRODUCTION

In order to measure the efficiency of entities, there can be found two approaches in the literature: the parametric or econometric approach, and the non-parametric or the mathematical programming approach. In the framework of this paper the emphasis is on the non-parametric approach, i.e. on Data Envelopment Analysis (DEA). This non-parametric methodology was introduced in the literature of the discipline Operational Research (OR) in 1978 by Charnes, Cooper & Rhodes [1].

DEA enables measuring of the relative efficiency of entities that use the same inputs to produce the same outputs (in DEA terminology these entities are known as Decision Making Units (DMUs)), and on the basis of the data for the used variables, i.e., inputs and outputs, an efficiency frontier is constructed.

Emrouznejad, Parker & Tavares [2] made a bibliography of DEA in which there are included more than 4.000 articles from its introduction to 2007. The focus of this paper is the application of DEA in the defense sector.

The defense sector performance is a complex phenomenon, which requires fundamental improvement of the effectiveness and efficiency of the defense capabilities that are closely related to available national resources and expressed through military power, the military structure, the level of equipment, and also through readiness and sustainability of the military forces.

This paper is organized in the following way: the Introduction, presented in Section 1; the non-parametric approach DEA is explained in Section 2; the application of DEA in the defense sector is presented in Section 3, and the Conclusion is given in Section 4.

2. DATA ENVELOPMENT ANALYSIS (DEA)

DEA is a specifically designed technique that measures the relative efficiency of DMUs by constructing an efficiency frontier. According to Charnes, Cooper, Lewin & Seiford [3, pp.5-6] the efficient DMU lies at the extreme frontier and the DMU that is relatively inefficient lies below this frontier. This non-parametric methodology allows to determine the sources and amounts of inefficiency, which is particularly valuable information for the inefficient DMUs in order to improve their efficiency. The advantage of this methodology is that it does not require any assumption about the functional form.

One of the basic DEA models is the CCR model that was introduced in 1978 by Charnes, Cooper and Rhodes [1], and Banker, Charnes and Cooper [4] in 1984 introduced the BCC model. Cooper, Seiford & Tone [5, p.152] indicate that the result that is obtained by solving the CCR model is known as (global) technical efficiency (TE), whereas the result that is obtained by solving the BCC model is known as (local) pure technical efficiency (PTE), and if the decision making unit has a CCR and BCC result that is 100%, then its scale efficiency is highest, but if the unit is 100% BCC-efficient, and the CCR result is low then this unit is operating locally efficient, but not globally, due to the size of the scale of the unit. Scale efficiency (SE) is the ratio between the two results: CCR and BCC result, for more details see [5, pp.152-154], and by decomposing the technical efficiency of its constituent parts, TE = PTE x SE, the sources of inefficiency can be presented, i.e. inefficient operating is presented by PTE, and unfavorable conditions through SE. Inefficiencies can occur because of inefficient operation, due to the unfavorable conditions or because of the two stated reasons.

The basic DEA models (CCR and BCC model) allow to calculate the maximum efficiency of the DMU relative to other DMUs that comprise the sample. Those DMUs that are inefficient can be ranked based on their levels of efficiency, which is not the case for efficient DMUs, whose result of efficiency is 1 (100%). For more details when a DMU is CCR, or BCC efficient, see [5, p.45, p.92]. One of the disadvantages of these basic DEA models is that with them can not be performed the ranking of the identified efficient DMUs, so Andersen & Petersen [6] have proposed a modified DEA model for ranking efficient DMUs, i.e.- for measuring super-efficiency.

If the sample of analysis is comprised by a small number of DMUs, and there are selected multiple inputs and outputs, then the efficiency frontier will be created with more DMUs. To overcome this problem a DEA technique known as Window Analysis can be used, through which the number of decision making units can be increased and also in the efficiency analysis there can be included a time dimension.

To solve DEA models, there have been developed more programming tools that enable in a short time to be obtained results, and decision-makers can devote more of their time to analyzing the results in order to make a good decision.

DEA notes applications in banking, finance, health care, education, energetics, agriculture, sport, the defense sector, etc., and below is shown its application in the defense sector.

3. APPLICATION OF DEA IN THE DEFENSE SECTOR

Various studies have been made to adopt the DEA methodology to evaluate the operating performance of the defense sector.

In 1983, Charnes, Clark, Cooper & Golany [7] introduced an illustrative example related to measuring the efficiency of the maintenance units in the U.S. Air Force. They used the input-oriented CCR model to analyze the relative efficiency of 14 Air Force wings, during the period October 1981 - May 1982. By using DEA they indicated the differences with other approaches to this issue. They also applied the DEA technique Window Analysis in order to bring greater 'degrees of freedom' to the analysis.

Bowlin [8] evaluated maintenance activities in the U.S. Air Force during the period October 1982 - March 1984. The study involves the application of DEA to locate possible inefficiencies in the performance of US Air Force real-property maintenance activities.
Roll, Golany & Seroussy [9] have analyzed 5 maintenance units of the Israeli Air Force. The data is analyzed on a quarterly basis and they used the input-oriented CCR model. The reason of using DEA to analyze the efficiency of the Israeli Army's maintenance units is due to the difficulties proved by standard techniques. Actually the performance of the maintenance units is characterized by a large number of inputs and outputs which cannot be readily weighed and compared. Some of these factors are qualitative in nature.

Charnes [10] evaluated the impact and effectiveness of advertising resources on the recruitment of high quality prospective soldiers for the U.S. Army. By using the newly developed models and software system, Charnes undertook a detailed analysis of quarter 1 of FY 1990.

Other study related to the maintenance of the Armed Forces is Clarke's study [11]. He applied DEA to evaluate vehicle maintenance performance at 17 air bases of the U.S. Army over the period of 4 years.

Sun [12] analyzed the performance of maintenance shops in the Taiwanese Army. He observed 5 maintenance shops over two 6-month periods in 2000 (January-June and July-December). Each analysis examined 30 DMUs. For this study there have been selected five output measures and six input measures. For instance, the input variable is the total number of assigned vehicles to a maintenance shop in a specific month, and the output variable is the total number of assigned vehicles that are in serviceable condition each month. In this study the 'DEA NCN (non-controllable)-AR' model is used.

Nakabayashi & Tone [13, pp.57-70] by using DEA evaluated a nation's dependence on military forces, and verified the end of the Cold War. Through the establishment of the new 'relative military Index-RMI', they described the period after the Cold War. They used two variants of DEA models, one being the Slacks-based Measure of Super-Efficiency (Super-SBM) model of Tone and the other being the Slacks-based Malmquist model of Tone. In their study both models are input-oriented and they are based on a 'CRS-constant returns to scale' assumption, since a nation's resources (outputs) are not easily adjustable compared with the military forces, and some of the countries are found to have very high values in some of the output parameters. The new index, the RMI, represents the relative efficiency of a nation's military force, which are analyzed. The high/low index score indicates that the nation's 'dependence on military forces (DMF)' is low/high. Otherwise, RMI is presented as a ratio between the nation's resources (as outputs) and the nation's military forces (as inputs), by treating each nation as a distinct decision making unit. The nation's resources are Gross Domestic Product (GDP) territorial area and population. There is no correlation between national defense expenditure and GDP, territorial area, and population, respectively. The study includes 18 countries from all regions of the world except Latin America, Africa and Oceania, in a period of over 14 years (1984-1997). The authors have focused on the United States, Russia and Japan after the Cold War.
Forika [14] introduced efficiency measurement possibilities for military higher education with the

application of DEA. The aim of her study is to obtain information that is needed to encourage the students or the teaching staff to increase the efficiency of the learning/teaching process.

Lu [15], according to the fact that assessing the military organization's performance is an important yet complex issue, has analyzed the supply of supplementary foods and products of the 31 military outlets in the Taiwanese Army.

Wen-Min & Mei-Hui [16] explored the operating efficiency and the benchmark-learning roadmap of Taiwanese military financial units. The intent is to help military financial units to deliver more efficient services, including improvement of the Armed Forces' financial management.

Previous studies of efficiency and productivity by DEA in the armed forces have solely been concentrated around various support functions like maintenance and recruitment [17, p.2]. One reason for the lack of studies could be difficulties in modeling the production process and output of the armed forces. Hanson [17] set up a general model for the production process of an operational unit, which are a pillar of the defense sector. According to Hanson [17, p.7] the main issue when applying the model to the military is the distinction between and categorization of: (1) Outcomes; (2) Outputs; and (3) Activities in the transformation process. The model is specified for the units of one branch of the Norwegian armed forces, the Home Guard, whose objectives are several tasks that include helping to maintain sovereignty, national crises management, the reception of allied reinforcement and contributing to the safety and security of society. In the model, Hanson [17, pp.13-26] defines three input variables for the use of equipment and personnel: (1) fixed personnel costs, such as regular wages, (2) variable personnel costs, such as activity based payments, overtime pay and travel expenses, (3) material costs, such as ammunition, spare parts and maintenance. The sample consists of yearly observations from eleven Home Guard districts over three years. This gives 11 observations each year or 33 observations. The data is collected monthly and yearly. In this model a single output is defined. It has the following decomposition: high intensity troops (I-FO), reinforcement troops (RF-FO), and the district staff (DS). The DEA model is input-oriented and the productivity development over the three years is investigated by the Malmquist productivity index.

In the study which addresses the problem of NATO enlargement, Hatami-Marbini, Tavana, Saati & Agrell [18, pp.19-21] use the 'fuzzy DEA BCC' model. The NATO enlargement problem is a complex multicriteria problem that embraces qualitative and quantitative data. Potential applicant countries must conform to a large number of quantitative and qualitative entry criteria established by NATO. They emphasized that, in political discussions, the enlargement process has sometimes been depicted as favoring socially and economically stable countries, with the only political uncertainty related to the issue of intra-member conflicts (e.g., Cyprus). The authors by using a plausible set of socioeconomic indicators and a fuzzy variable for the political consensus, calculated a fuzzy DEA VRS frontier. They stated that the analysis of the obtained results confirms the hypothesis that decisions are not based on socioeconomic stability.

Wang & Wang [19] made the quantitative effect evaluation of engineerization management and established the DEA model of single aircraft shelter engineering. They analyzed the calculation results in detail and point out the importance of the one input element - personnel, which influences targets of cost and progress, related to the fact that the reduce of inputs brings increase of outputs.

Choon-Joo, Won-Joon & Bong-Kyoo [20] analyzed offset trends of the 14 offset countries in the period between 1993 and 2007. With the use of DEA, they measured the technical and value efficiencies of offsets and explained the efficiency gaps among nations to derive policy implication.

Zhou & Liu [21] by using the Malmquist Productivity Index integrated with bootstrapping, reviewed the defense spending impact on economic productivity. The study includes APEC countries in the period between 1990 and 2010.

4. CONCLUSION

The aim of this paper was to present the applicability of the non-parametric methodology DEA in the defense sector.

There have been analyzed 15 studies published in the period between 1983 and 2014. In three studies the Malmquist productivity index is used, in one study the DEA technique Window Analysis is used, and according to the orientation of the model, in most of the studies the DEA model that is input-oriented is used.

The analyzed DEA studies reflect the possibility of a wide application of DEA in measuring the performance of the defense sector.

Assessing the defense sector performance is an important national issue. This issue has a great impact on the NATO members' and partner countries' performance as well. Therefore, the application of the DEA for measuring the burden sharing in NATO-led operations and missions is our next challenge for further research.

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