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APPLYING THE METHODOLOGY DATA ENVELOPMENT ANALYSIS IN THE DEFENCE SECTOR: LITERATURE REVIEW

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Abstract: *In solving the problems, decision-makers should take into account the qualitative and the quantitative aspects. The discipline of operational research with its methods and techniques help decision-makers in making better decisions. One of its leading methodologies is the non-parametric methodology data envelopment analysis (DEA), which can be used in evaluating the efficiency of entities (decision-making units – DMUs) that use the same inputs to produce the same outputs. According to the last DEA bibliography published in 2017, from 1978, when the seminal paper of DEA was published, until the end of the 2016, there was rapid increase in the published articles in journals. DEA is applied in various areas: agriculture, defence sector, education, energetics, healthcare, public policy, sport, transportation, etc. In this paper we provide a literature review on the DEA application in the defence sector. Most of the analyzed articles have been published in journals, and we focus on the country where the research was conducted, the observed period, the sample of analysis, the used model, and the application.*

Key words: *efficiency, DEA, defence sector, literature review.*

Introduction

The word 'efficiency' has Latin origin, '*efficax*', and presents an indicator of success. To measure the efficiency of entities there are two approaches: the econometric (parametric) approach and mathematical-programming (non-parametric) approach. In this paper the emphasis is put on the non-parametric approach, i.e. on the leading methodology data envelopment analysis (DEA). DEA is a methodology for measuring the relative efficiency of decision-making units (DMUs) that use the same inputs in order to produce the same outputs, which can be in different amounts. Cook and Zhu (2008, p. 25) point out that the term DMUs refers to the operating procedures, processes or entities that are assessed. Defining DMUs is generic and flexible, and

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they can be cities, governments, banks, universities, hospitals, information systems, etc. The seminal work of DEA was written by Charnes, Cooper and Rhodes in 1978. Since then a large number of articles have been published, and there are several DEA bibliographies (Emrouznejad and Thanassoulis, 1996 a,b, 1997; Seiford, 1994, 1997; Tavares, 2002; Gattoufi, Oral and Reisman, 2004 a,b; Emrouznejad, Parker and Tavares 2008). In addition, Emrouznejad and Yang (2018) give a literature review on DEA in the first four decades (1978 – until the end of 2016), so they analyze only DEA-related articles published in journals. In the covered period there are 10.300 DEA-related journal articles, there are identified 11.961 distinct DEA authors, and most of the articles are published in the following four journals: European Journal of Operational Research, Journal of the Operational Research Society, Journal of Productivity Analysis, and Omega. The most popular application areas are: energy, industry, banking, education, and healthcare, including hospitals. In 2015 and 2016 the top application fields were: agriculture, banking, supply chain, transportation and public policy. In this paper a literature review is given on the DEA application in the defence sector. In addition to the introduction given in Section 1, in Section 2, the basis of DEA is given in Section 3 where the literature review of the application of DEA in the defence sector is presented, in Section 4 where the DEA application in the defence sector in Macedonia is described, and the last section which contains the conclusion.

The non-parametric methodology DEA

Data envelopment analysis evaluates the relative efficiency of decision-making units by constructing an efficiency frontier based on the data for the used inputs and outputs. Charnes et al. (1994, pp. 5-6) point out that the DMU that lies at the extreme frontier is efficient, while the DMU that lies below this frontier is relatively inefficient. DEA allows the sources and amounts of inefficiency to be determined, and based on this information, steps for improving the efficiency of the inefficient DMUs could be set. The advantage of DEA is that it does not require any assumption about the functional form.

Bowlin (1998, pp. 16-19) defines the basic issues which are important in using DEA. In the formulation of the DEA model the input/output values are required to be greater than or equal to zero and the functional relationship of inputs and outputs should have the mathematical property called isitonoisity. This property (isitonoisity) means that an increase in the input will result in the same increase in the output without decreasing any other input. In the case when there are multiple inputs and outputs chosen, while the number of DMUs that comprise the sample for analysis is small, the efficiency frontier will be created with more DMUs. A general rule of thumb is that the number of DMUs should be at least 3 times more than the total of the inputs and outputs. For example, if there are 3 inputs and 2 outputs chosen, the sample of analysis should be at least 15 (=3x(3+2)). One way to overcome the problem of multiple inputs and outputs and a small number of DMUs is to use the DEA technique known as window analysis, with the help of which the number of decision-making units can be increased, and also a time dimension can be included in the efficiency analysis. The next requirement, according to Bowlin (1998), is the control of the weights of inputs and outputs and the

homogeneity of DMUs. By solving the DEA model the weights of the variables are determined. Each weight is calculated to present the decision-making unit in the best possible light, relative to the other units that comprise the sample of analysis. In this way, an input or output can gain weight that is inadequate, so in order to overcome this problem DEA models with weight restrictions can be applied, details can be found in Cooper, Seiford and Tone (2007, pp. 178-194). Cvetkoska and Savic (2017) combine DEA with the most well-known multi-criteria decision-making method, the analytic hierarchy process (AHP) - so that the weights for the criteria that are obtained by solving the AHP model will serve to set restrictions on the weights of the variables of the DEA model. In addition, DEA requires a relatively homogeneous set of entities. This means that all the entities included in the evaluation set should have the same inputs and outputs, and their values must be positive.

What follows is a brief description of some of the basic DEA models.

The Charnes-Cooper-Rhodes (CCR) model, introduced in 1978 by Charnes, Cooper and Rhodes, and the Banker-Charnes-Cooper (BCC) model, introduced by Banker, Charnes and Cooper in 1984, are basic DEA models. Cooper et al. (2007) 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, 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 unfavourable conditions through SE. Inefficiencies can occur because of inefficient operation, due to the unfavourable conditions or because of the two stated reasons.

The CCR and BCC model enable 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 in Cooper, Seiford and Tone (2007, p. 45, p. 92). With these basic DEA models, the ranking of the identified efficient DMUs could not be performed, so Andersen and Petersen (1993) overcame this DEA disadvantage by proposing a modified DEA model for ranking efficient DMUs, i.e. for measuring super-efficiency.

DEA notes rapid growth in its application due to the developed DEA software that enables results to be obtained in a short amount of time, which enables decision-makers to devote more of their time in analyzing the results in order to make a good decision.

Applying DEA in the Defence Sector: Literature Review

A total of 16 studies published in the period between 1983 and 2016 have been analyzed (Table 1). Most of the studies are published in journals. The studies represent the efficiency and productivity in the defence sector and they have solely been concentrated around various maintenance functions in the military, especially in the US Army and Asian countries like Taiwan, China, Korea and etc. In the presented research, the Malmquist productivity index is used in three studies, the DEA technique window analysis is used in two studies, and according to the orientation of the model, in most of the studies the input-oriented model is used in DEA. The smallest sample for analysis comprises 5 DMUs, and the largest consists of 559 DMUs. In terms of the covered period, the shortest is 3 months, while the longest is 20 years (from 1990 to 2010).

Table 1. Literature review on DEA in the defence sector

	Author(s)/year	Country	Period	Sample	Model	Issues
1	Charnes et al. (1983)	US	October 1981 -May 1982	14 DMUs	Input-oriented (IO) CCR, Window Analysis	Efficiency of the maintenance units in the US Air Force
2	Bowlin (1987)	US	October 1982- March 1984	7 DMUs	DEA Window Analysis	Performance of US Air Force real-property maintenance activities
3	Roll, Golany and Seroussy (1989)	Israel	quarter	5 DMUs	IO CCR	Performance of maintenance units of the Israeli Air Force
4	Charnes (1990)	US	1 quarter of 1990	53 DMUs	Advertising Effective-ness DEA Model	The impact of advertising resources on the recruitment of high quality prospective soldiers for the US Army
5	Clarke (1992)	US	1983-1986	17 DMUs	IO CCR	Maintenance performance of US Army air bases
6	Sun (2004)	Taiwan	January-June and July-December 2000	30 DMUs	Output oriented (OO) DEA NCN–AR	Performance of maintenance shops in the Taiwanese Army

7	Nakabayashi and Tone (2005)	Japan	1984-1997	18 DMUs; 252 DMUs	Super-SBM-Input- Constant; Malmquist-Input-Constant	Verification of the end of the Cold War
8	Forika (2008)	Hungary	2006	559 DMUs	OO CCR	Efficiency measurement possibilities for military higher education
9	Lu (2011)	Taiwan	2007	31 DMUs	IO BBC	Supply of supplementary foods and products of the military outlets in the Taiwanese Army
10	Wen-Min and Mei-Hui (2011)	Taiwan	2006	28 DMUs	Modified super-Slack Based Measure (SBM) model	Operating efficiency and the benchmark-learning roadmap of Taiwanese military financial units
11	Hanson (2012)	Norway	3 years	11 DMUs	Specified IO DEA model for the units of one branch of the Norwegian armed forces: Malmquist-Input-Constant	Efficiency of the Norwegian armed forces
12	Hatami-Marbini et al. (2012)	Belgium, USA and Iran	1993-2012	18 DMUs	fuzzy DEA-BCC	The problem of NATO enlargement
13	Wang and Wang (2012)	China	unknown	12 DMUs	DEA model	Quantitative effect evaluation of engineerization management
14	Choon-Joo, Won-Joon and Bong-Kyoo (2012)	Korea	1993-2007	14 DMUs	Revenue DEA model	Offset trends
15	Zhou and Liu (2014)	China	1990-2010	21 DMUs	Malmquist Productivity Index (MPI) combined with DEA	The defence spending impact on economic productivity
16	Georgieva, Naumovski and Cvetkoska (2016)	Macedonia	2007-2009	36 DMUs	OO BBC	Efficiency of operating countries in NATO-led mission, ISAF

Source: Authors.

Three studies from this table have been selected and analyzed below.

Nakabayashi and Tone (2005) 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. The new index, the RMI, represents the relative efficiency of a nation's military force, which they analyze. The study indicates the possibility of applying DEA for comparative analysis of different phenomena related to international relations and the defence sector.

In the study of Hanson (2012) the sample consists of yearly observations from eleven Home Guard districts over three years. The model, despite some drawbacks associated with the use of best practices in this area, enables a meaningful and measurable expression for the output of an operational unit, the Home Guard of the Norwegian armed forces.

In the study which addresses the problem of NATO enlargement, Hatami-Marbini et al. (2012, pp.19-21) emphasized that, in political discussions, the enlargement process has sometimes been depicted as favouring socially and economically stable countries, with the only political uncertainty related to the issue of intra-member conflicts (e.g. Cyprus). The NATO enlargement process is a complex multi-criteria 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. By using DEA, the authors confirm the hypothesis that decisions are not based on socio-economic stability. In fact, even excluding statutory neutral countries such as Ireland, Sweden, and Switzerland, the outcome correlates poorly with the real ascension. In detail, the order of integration of some former Soviet republics compared to the former Yugoslavian republics clearly suggests that other mechanisms are at play.

DEA Applications in the Defence Sector in the Republic of Macedonia

The first study in the defence sector in Macedonia that applies DEA is a part of the doctoral dissertation, by Naumovski (2015). That research was published in the proceedings of the XLIII International Symposium on Operational Research (SYM-OP-IS 2016) (Georgieva, Naumovski and Cvetkoska, 2016).

Georgieva, Naumovski and Cvetkoska (2016) measure the relative efficiency of participating countries in a NATO-led mission in Afghanistan, ISAF, for a period of three years (2007-2009) by using DEA, or more precisely, the output-oriented BCC DEA model. The sample consists of 36 DMUs (participating countries). Two inputs and one output have been selected. The inputs are: the total population of each participating country, and the GDP per capita of the participating countries (in US dollars), while the number of soldiers (troops) of each participating country per rotation is the selected output. Based on the obtained results, only 6 participating countries in ISAF were identified as relatively efficient, thus their contribution to ISAF was the largest. They

are: Albania, Estonia, Macedonia, the United Kingdom, the United States, and Iceland, except in 2009 where Iceland was replaced by Luxemburg. Macedonia is one of the major contributors to the ISAF mission. The results also show that, in terms of all of the NATO-partner countries, Macedonia is the largest contributor to the ISAF mission. In addition, according to the results of the analysis in the observed period (2007-2009), the conclusion is that certain partner countries have expressed greater willingness and capability in terms of their contribution to NATO-operations and missions. Actually, due to the fact that the NATO-partner countries, such as Australia, Austria, Finland, New Zealand, and Sweden have far greater human and economic resources than Macedonia, their contribution to NATO missions should be more significant. Concurrently, compared with the NATO member countries, Macedonia's contribution is significantly larger than those NATO member countries that have a far larger population and greater economic opportunities (France, Germany, Netherlands, etc.). Additionally, compared to other countries in the region, Albania and Macedonia are major contributors to ISAF, as opposed to Bulgaria, Greece, and Romania. Regarding the NATO member countries, those relatively efficient are: Albania, Estonia, Iceland, the United Kingdom and the United States, as well as Luxembourg, in 2009, instead of Iceland. As always, the lead in the NATO operations and missions is given to the United States, accompanied by the United Kingdom. The study also gives an overview of Slovenia's efficiency in ISAF, as a NATO member country. The country is also compared with Estonia, which is relatively efficient. The efficiency score of the Republic of Slovenia is 0.3095, 0.3002 and 0.2660 in 2007, 2008 and 2009, respectively. In order for Slovenia to be relatively efficient in ISAF, in the years that are the subject of analysis, it should increase the number of troops that are participating in the mission. Due to the fact that the participation of the Republic of Slovenia in the NATO-led operation in Kosovo is far different, the inefficiency in ISAF is probably influenced by the fact that Afghanistan is quite a distant region and the presence in the Western Balkans is in the focus of Slovenia's participation in international operations and missions. Additionally, the special interest in the stability and security of the region of South East Europe contributes to the increasing presence of the Slovenian Armed Forces in NATO operations on the Balkans (SFOR in Bosnia and Herzegovina and KFOR in Kosovo).

Stojanovski (2017) has also applied DEA in his doctoral dissertation and he has measured the efficiency of the US military interventions.

The results that are obtained with DEA confirm the actual situations and thus we believe that its application by researchers in the area of the defence sector will note an increase in the period that follows.

Conclusion

Making good decisions in this increasingly competitive and dynamic world is not at all easy. Decision-makers face numerous challenges, and the key to success is in their timely

response. If they are faced with a problem that is similar to the current one, experience can help them make a decision, but if the problem is new, complex, it is best to consider both qualitative and quantitative aspects.

Operational research practitioners can help decision makers to make better decisions for the problems they face by constructing models that best show the real situation, solving them by using adequate analytical methods of operational research and implementing the solution.

To measure the efficiency of entities that use the same inputs to produce the same outputs, the most widely used is the non-parametric methodology data envelopment analysis. The information obtained by this methodology enables taking steps to improve the efficiency of the identified inefficient entities. From the beginning of its application, until today, DEA has seen a rapid growth and numerous success stories in various areas.

This article provides a literature review on the application of DEA in the defence sector. The analyzed papers reflect the possibility of extensive use of DEA for measuring the efficiency in the defence sector, and in our country the first research on its application in this sector was made in 2015.

DEA is applicable for analysis of different phenomena related to a plethora of security challenges, therefore our next challenge should be to create a security and defence model that would respond to the global security challenges that the world is facing, and to which the Western Balkan countries are not immune (for example, the migrant crisis).

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