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APPLICATION OF THE ANALYTICAL HIERARCHY METHOD IN THE AREA OF DEFENCE EXPENDITURE MANAGING

Background. ***Optimisation of defence expenditures is critical for ensuring the combat capability of the military and maintaining national security. Ukraine is increasing its expenditure on armaments and military equipment, which requires efficient management of budgetary resources to achieve maximum impact. Effective management of budgetary resources is crucial not only for ensuring the combat capability of military formations, but also for maintaining national security.***

Methods. ***The article uses the AHP method with the use of pairwise comparisons and the Saaty scale to evaluate the criteria within the BOCR concept (benefits, costs, opportunities, risks).***

Results. ***The article develops a decision-making model based on the AHP concept to help in the evaluation and selection of suppliers. The model evaluates suppliers using a set of criteria grouped into four categories: Benefits, Costs, Opportunities and Risks (BOCR). Each criterion, such as price, product quality, delivery time and supplier reliability, was assigned a weight using a pairwise comparison matrix based on the Saaty scale. The AHP approach allowed both quantitative and qualitative criteria to be integrated into the decision-making process. After evaluating the three suppliers, Supplier 1 was identified as the most suitable option with the highest BOCR of 1.033.***

Conclusions. ***The research conducted in this article has shown that the AHP-based decision-making model is an effective tool for optimising defence expenditure and improving procurement processes. Through the application of the BOCR concept, the model balances positive and negative factors, ensuring a transparent and efficient decision-making process. The use of pairwise comparisons ensures consistency of judgement and allows decision makers to rank alternatives in a systematic way. The paper emphasises the adaptability of the model to different operating environments: Microsoft Excel is used for data analysis and implementation, but programming languages can also be used. The results of the study demonstrate that multi-criteria optimisation methods such as AHP are valuable tools for optimisation in defence expenditure management, including the selection of suppliers of goods, works and services.***

Keywords: ***budget, defence expenditures, budget planning, optimisation methods, expenditure efficiency, economic and mathematical modelling.***

Background

Since the beginning of Russia's full-scale invasion in February 2022, Ukraine has faced an unprecedented challenge that requires a significant increase in military spending. This includes the purchase of modern weapons, ammunition, military equipment and personal protective equipment. The conditions of hostilities and the scale of operations require constant replenishment of stocks, which significantly increases the volume of purchases.

In light of the ongoing threats to national security, Ukraine has been forced to reconsider its attitude to the security of the state, focusing on strengthening its defence capabilities. This requires regular renewal and modernisation of the military forces, which in turn increases the need for procurement of the latest military equipment and machinery.

Significant military and financial support from international partners, such as the US, EU and NATO, provides Ukraine with additional resources to purchase the necessary equipment. This allows Ukraine not only to maintain its defence, but also to develop its military capabilities.

Ukraine is actively investing in the development of its military-industrial complex, which includes the modernisation of existing production facilities and the introduction of the latest technologies. This requires significant financial investments, which are provided through increased public spending on defence procurement.

It is worth noting that the economic stability of a country in a military conflict largely depends on the ability of the state to ensure an adequate level of defence. Military conflict forces the country to divert significant resources to military needs, which affects the economic structure and the state budget.

Thus, defence procurement has become critically important for Ukraine, and a significant increase in defence spending is necessary to ensure national security and territorial integrity of Ukraine in the context of the current military conflict. The issue of ensuring efficient and timely provision of military needs and the selection of the optimal supplier is becoming extremely important. The use of decision support models can become one of the key tools for military units to increase the efficiency and transparency of the procurement process.

The choice of suppliers should take into account the needs of the client and the company's ability to meet those needs. Therefore, it is believed that the starting point for the production and distribution process starts with the supplier. Supplier selection encompasses a number of variables that act as a filtering element, but by no means a barrier to new suppliers. The problem of supplier selection arises when the procurement process begins, whether using current suppliers or looking for new suppliers. The budget holder should consider the decision to select suppliers based on several criteria. What distinguishes the multi-criteria approach from traditional operational research approaches is the concept of subjectivity. The same criterion can be analysed differently depending on the decision maker who evaluates it.

Another advantage of multi-criteria decision support is that it takes into account both quantitative and qualitative criteria. As a comparison tool, multi-criteria analysis takes into account different points of view, which is particularly useful when drawing conclusions on complex issues.

The purpose of the article is to apply the method of hierarchy analysis (AHP) to create a decision-making model that will allow for optimal allocation of budget funds, increasing procurement efficiency and meeting priority needs within budget constraints.

Objectives of the article:

- to develop and test a decision-making model using the Analytical Hierarchy Process (AHP) method in the field of defence expenditure management, namely, in the selection of the optimal supplier of goods, works and services;
- to test this model on the basis of data close to the real one;
- to evaluate the effectiveness of using the AHP method in the field of defence expenditure management under limited budget.

Literature review. In his paper An analytical hierarchy process based procurement selection method, Iya Cheng proposes to use the analytical hierarchy method to select the best supplier offers, Iya Cheng also describes the possibility of using the Delphi method (expert evaluation method) when selecting the best procurement offer, according to the author, the use of the Delphi method ensures an objective decision (Cheung et al., 2001).

The application of the value for money model based on the analytical hierarchy process can also be found in the works of E. Labrod and P. Morlacci.

Kerim Goztepe in his article entitled A Multicriteria Decision Making Model for Military Logistics Using Analytical Network Process (ANP) explores the complexities of decision making in military logistics. The paper emphasises the challenges associated with uncertainty, rapid change and the need to consider multiple criteria simultaneously. The paper presents the Analytical Network Process (ANP) as an effective method for optimising logistics decisions in military operations. Due to the ability of ANP to take into account interdependent criteria and provide feedback, it is especially appropriate for comparing alternative courses of action (COAs). The conclusions indicate that ANP improves the quality of logistics decisions, but requires specialised training to be used effectively (Göztepe et al., 2013).

It is worth noting that the analysis of available publications in Scopus shows that the scope of use of multicriteria optimisation and hierarchy analysis methods is constantly expanding.

Methods

The methodology of the article combines BOCR methodology with the method of hierarchy analysis (AHP) to optimise the allocation of defence expenditures. The computational process was carried out using Microsoft Excel to analyse the data, build pairwise matrices, and calculate local and global priority vectors.

Results

The developed model of support for the decision of budget funds managers based on the AHP method contributes to the maximum satisfaction of users' needs by taking into account various criteria and expert assessments. The model allows systemising and analysing a large amount of data on potential suppliers. The model can also be adapted to different conditions and requirements, which ensures its flexibility and versatility. Thus, the developed model was tested on test data as close as possible to real indicators. Three suppliers were evaluated according to certain criteria, such as price, product quality, delivery time, etc. As a result, Supplier 1 received the highest BOCR score (1.033).

Example Optimization Problem. Based on the analysis of the paper conducted by the DOZORRO team, a list of criteria other than price used by contracting authorities was compiled (Transparency International Ukraine, 2021).

c – index of criterion (from 01..until 18);

n – max index of criterion;

$$c \in C = \{1, \dots, n\} \quad (1)$$

Table 1

List of non-price criteria grouped according to the BOCR methodology

№	Name group	Name criterion
1.	Benefits	price
2.		maximum possible volume of one delivery
3.		after sales service
4.		quality of packaging
5.		product quality and compliance with technical specifications
6.		product shelf life
7.		environmental friendliness of production
8.		Ukrainian production
9.	Costs	Communication and other related costs, including time costs
10.		Costs of transport, paperwork, insurance (if necessary)
11.		availability of spare parts for the product (item)
12.	Opportunities	terms of payment
13.		Supplier's experience in similar transactions
14.		Availability of material resources and specialists at the supplier
15.	Risks	Location of the supplier and difficulties in transport
16.		Possible percentage of defects
17.		Instability of the supplier, negative experience of cooperation
18.		delivery time

The next step is to form a matrix of pairwise comparisons, for which we have carried out a test distribution of key indicators and their priority in relation to each other within the group. Since the calculations used test judgements, which were subsequently displayed in the form of a pairwise comparison matrix, the matrix consistency coefficient was first calculated to ensure that the estimates were consistent.

The weighting of the criteria was assessed by analysing the preferences based on the Saaty scale of relative importance. The basic scale ranges from 1 to 9, where 1 indicates the equivalence of two elements, i.e. no preference for one over the other, while 9 indicates the absolute preference of one element over the other. It is important to emphasise that reciprocity is assumed in comparisons: if the decision-maker determines that criterion A has a value of 3 relative to criterion B, then the value for B relative to A will be 1/3 (Saaty, 1987).

When the number of pairs compared is large, there is a risk of illogical or contradictory conclusions due to possible errors. The priority(PR) for each row is calculated by dividing the geometric mean of each row by the sum of the geometric mean of all rows.

The assessment of the consistency of comparisons is evaluated using the coefficient of consistency (CR), which is calculated for each pairwise comparison matrix (formula 2-3). The condition under which the results of the survey (comparison) will be considered consistent is the following calculation.

$$IC = \frac{\delta_{max} - s}{s-1}, \tag{2}$$

$$CR = \frac{IC}{RI}, \tag{3}$$

where IC– consistency index; δ(max) – is the maximum eigenvalue of the matrix; *s* is the order of the matrix; RI is a random index (Fig. 1).

Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Fig. 1. Random index

The condition under which the results of the survey (comparison) will be considered consistent is the following calculation, according to which the value of the coefficient of consistency is in the range from 0 to 0.10 (10 %).

Microsoft Excel was used to create matrices of pairwise comparisons and other calculations (Figs. 2–5).

Ranking	Benefit	1	2	3	4	5	6	7	8	SUM	GEAOMEAN	PR	λmax	IK	CR
0,290	1	1,00	9,00	3,00	7,00	1,00	5,00	9,00	9,00	44,00	4,07	0,31	8,362	0,052	0,037
0,033	2	0,11	1,00	0,17	1,00	0,13	0,25	2,00	0,33	4,99	0,37	0,03			
0,155	3	0,33	6,00	1,00	5,00	0,17	3,00	4,00	4,00	23,50	1,72	0,13			
0,031	4	0,14	1,00	0,20	1,00	0,11	0,25	1,00	1,00	4,70	0,40	0,03			
0,303	5	1,00	8,00	6,00	9,00	1,00	5,00	8,00	8,00	46,00	4,39	0,34			
0,117	6	0,20	4,00	0,33	4,00	0,20	1,00	4,00	4,00	17,73	1,16	0,09			
0,028	7	0,11	0,50	0,25	1,00	0,13	0,25	1,00	1,00	4,24	0,37	0,03			
0,044	8	0,11	3,00	0,25	1,00	0,13	0,25	1,00	1,00	6,74	0,47	0,04			
1,000	SUM	3,01	32,50	11,20	29,00	2,85	15,00	30,00	28,33	151,89	12,95				

Fig. 2. Ranking of the list of "Benefits" criteria

Ranking	Opportunities	1	2	3	GEAOMEAN	PR	λmax	IK	CR
0,134	1	1,000	0,500	0,250	0,500	0,136	3,018	0,009	0,016
0,255	2	2,000	1,000	0,333	0,874	0,238			
0,611	3	4,000	3,000	1,000	2,289	0,625			
1,000	SUM	7,000	4,500	1,583	3,663	1,000			

Fig. 3. Ranking of the list of criteria "Opportunities"

Ranking	Costs	1	2	3	SUM	GEAOMEAN	PR	λmax	IK	CR
0,162	1	1,000	0,500	0,333	1,833	0,550	0,163	3,009	0,005	0,008
0,309	2	2,000	1,000	0,500	3,500	1,000	0,297			
0,529	3	3,000	2,000	1,000	6,000	1,817	0,540			
1,000	SUM	6,000	3,500	1,833	11,333	3,367				

Fig. 4. Ranking of the list of criteria "Costs"

Ranking	Risks	1	2	3	4	GEAOMEAN	PR	λmax	IK	CR
0,072	1	1,000	0,200	0,333	0,333	0,386	0,075	4,101	0,034	0,037
0,501	2	5,000	1,000	3,000	4,000	2,783	0,541			
0,244	3	3,000	0,333	1,000	2,000	1,189	0,231			
0,183	4	3,000	0,250	0,500	1,000	0,783	0,152			
1,000	SUM	12,000	1,783	4,833	7,333	5,141				

Fig. 5. Ranking of the list of criteria "Risks"

According to the calculations shown in Figs. 1–4, the coefficients of consistency range from 0 to 0.10 (10 %): for the Benefit group, the coefficient of consistency is 0.037; for the Cost group, 0.008; for the Risks group, 0.037; and for the Opportunities group, 0.016.

Therefore, the coefficients of consistency for all groups of criteria are within the permissible limits.

The next step is to rank the criteria, and the results of the criteria ranking are shown.

Group "Benefits":

Price – 0.290;

Maximum possible volume of a single delivery – 0.033;

After-sales service – 0.155;

Packaging quality – 0.031;

Product quality and compliance with technical specifications – 0.303;

Product shelf life – 0.117;

Environmental sustainability of production – 0.028;

Ukrainian production – 0.044.

Group "Costs":

Communication costs and other related expenses, including time costs – 0.162;

Transportation, documentation, and insurance costs (if needed) – 0.309;

Availability of spare parts for the product (item) – 0.529.

Group "Opportunities":

Payment terms – 0.134;

Supplier experience in similar operations – 0.255;

Availability of material resources and specialists at the supplier – 0.611.

Group "Risks":

Supplier's location and transportation difficulties – 0.072;

Possible defect rate – 0.501;

Supplier instability and negative cooperation experience – 0.244;

Delivery timeframes – 0.183.

The next step is to test the AHP method on data. To test the AHP method on the test data, three suppliers (names: Supplier1, Supplier2, and Supplier3) were formed to supply a certain product with certain characteristics, and evaluation matrices were created according to certain criteria.

One of the last steps of the Analytic Hierarchy Process (AHP) involves calculating a vector of global priorities for the alternatives and selecting the best one. This step synthesises the scores for all the criteria to determine the most appropriate option. To do this, a local priority matrix is built, where each element reflects the relative importance of the alternative according to a particular criterion. The global priority vector is determined by multiplying the local priority matrix of alternatives by the local priority vector of criteria.

In this context, the local priorities of the alternatives describe their performance on each individual criterion, while the local priorities of the criteria indicate the relative importance of each criterion in the overall decision. The product of these two matrices yields a global priority vector that ranks the alternatives according to their overall score across all criteria. The alternative with the highest value in the global priority vector is identified as the best choice (Fig. 6).

Title	Benefits	Costs	Opportunities	Risks
Supplier1	0,605	0,589	0,645	0,642
Supplier2	0,286	0,298	0,242	0,245
Supplier3	0,109	0,113	0,113	0,113

Fig. 6. Results of calculating the global vector for three suppliers

The final step is to calculate the BOCR score and build a hierarchical diagram. The optimal option is the one with the highest BOCR score.

The BOCR formula is used to evaluate alternatives by considering four key factors: Benefits (B), Opportunities (O), Costs (C), and Risks (R). The calculation is performed using the following formula:

$$BOCR = (B * O) / (C * R) \quad (4)$$

This approach allows for a comprehensive assessment of each alternative by taking into account both positive aspects (benefits and opportunities) and negative ones (costs and risks). Benefits represent the advantages an alternative provides, while opportunities reflect its potential for growth or improvement. Costs encompass the resources required to implement the alternative, and risks denote uncertainties and threats associated with the decision.

Alternative	BOCR
Supplier1	1,033
Supplier2	0,946
Supplier3	0,963

Fig. 7. Results of calculating alternatives using the BOCR methodology

The analysis of the hierarchical diagram of the BOCR assessment of alternatives allows us to draw conclusions. Supplier 1 received the highest BOCR score of 1.033, which indicates the efficiency and stability of this supplier, as well as its ability to provide high quality services and products at minimal risks and costs. Supplier1 is the best alternative among the three considered suppliers.

Discussion and conclusions

Based on a comparison of the advantages and disadvantages of the methods, the AHP method was chosen to solve the supplier selection task. This method allows breaking down a complex task into simpler components, integrating different types of criteria into a single model, and assigning weights to the criteria according to their importance. Since the calculations used test judgements, which were subsequently displayed in the form of a pairwise comparison matrix, the matrix consistency coefficient was first calculated to ensure that the estimates were consistent. All the results were positive and allowed for further calculations. The analysis of the BOCR hierarchy diagram allows us to conclude that Supplier1 is the best alternative among the three suppliers considered. This supplier provides an optimal balance of benefits, opportunities, costs and risks, which makes it the most attractive for further cooperation. The developed model of decision support for budget managers based on the AHP method contributes to the maximum satisfaction of users' needs through a transparent decision-making process, taking into account various criteria and expert assessments.

Authors' contributions: Serhiy Dyachenko – data validation, writing (revision and editing); Oleksandr Artiushenko – conceptualisation, formal analysis, software, methodology, writing (original draft).

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ЗАСТОСУВАННЯ МЕТОДУ АНАЛІТИЧНОЇ ІЄРАРХІЇ У СФЕРІ УПРАВЛІННЯ ОБОРОННИМИ ВИДАТКАМИ

В с т у п . ***Оптимізація оборонних видатків критично важлива для забезпечення боєздатності військових формувань та підтримки національної безпеки. Україна збільшує витрати на озброєння та військову техніку, що вимагає ефективного управління бюджетними ресурсами для досягнення максимальної віддачі. Ефективне управління бюджетними ресурсами має вирішальне значення не лише для забезпечення боєздатності військових формувань, а й для підтримання національної безпеки.***

М е т о д и . ***У статті використано метод AHP із застосуванням парних порівнянь та шкали Сааті для оцінювання критеріїв у межах концепції BOCR (вигоди, витрати, можливості, ризики).***

Р е з у л ь т а т и . ***У межах дослідження було розроблено модель прийняття рішень на основі концепції AHP, яка допоможе в оцінюванні та виборі постачальників. Модель оцінює постачальників за допомогою набору критеріїв, згрупованих у чотири категорії: вигоди, витрати, можливості та ризики (BOCR). Кожному критерію, такому як: ціна, якість продукції, час доставки та надійність постачальника, було присвоєно вагу за допомогою матриці попарних порівнянь за шкалою Сааті. Підхід AHP дозволив інтегрувати як кількісні, так і якісні критерії в процес прийняття рішень. Після оцінювання трьох постачальників, Постачальник 1 був визначений як найбільш підходящий варіант з найвищим показником BOCR 1,033.***

В и с н о в к и . ***Проведене дослідження показало, що модель прийняття рішень на основі методу AHP є ефективним інструментом оптимізації оборонних видатків та вдосконалення закупівельних процесів. Завдяки застосуванню концепції BOCR модель збалансовує позитивні та негативні фактори, забезпечуючи прозорий та ефективний процес прийняття рішень. Використання попарних порівнянь забезпечує узгодженість суджень і дозволяє особам, які приймають рішення, систематично ранжувати альтернативи. У дослідженні вказано на адаптивність моделі до різних операційних середовищ: для аналізу та впровадження даних використовується Microsoft Excel, але також можна використовувати мови програмування. Результати дослідження демонструють, що методи багатокритеріальної оптимізації, такі як AHP, є цінними інструментами для оптимізації у сфері управління оборонними видатками, у тому числі вибору постачальників товарів, робіт та послуг.***

К л ю ч о в і с л о в а : ***бюджет, оборонні видатки, планування бюджету, методи оптимізації, ефективність видатків, економіко-математичне моделювання.***

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