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The Multi-Criteria Method for the Evaluation of Combat Capabilities of Surface to Air Missile Systems for the NAREW Program

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Abstract

The selection of weapon systems involves a number of activities to choose the best system in relation to the predefined operational requirements and other vital criteria. In the case of surface to air missile systems competing for the NAREW program, attempts are being made to obtain an asset that will be capable of engaging a spectrum of air threats, under specified conditions, with a predefined high degree of probability. In order to make the right choice, it is necessary to analyze information on performance and combat capabilities. Thus, the aim of this article is to develop a preliminary method of evaluating the capabilities of surface to air missile systems offered under the NAREW program. The theoretical foundation of the empirical study was provided by the method of literature content analysis. Using the methods of comparison and generalization, the author obtained data on the combat capabilities of surface to air missile systems expressed through their tactical and technical parameters. Among the empirical methods, the author applied the algorithm of a multi-criteria analysis and an assessment of the capabilities of surface to air missile systems based on the use of matrix calculus. The diagnostic survey, conducted by means of the questionnaire technique, made it possible to prioritize the adopted evaluation criteria and, consequently, to conduct proper research. The formulation of the final conclusions and establishing the links between the theoretical and empirical part of the study was achieved by means of a synthesis. The results obtained in such a manner may constitute a valuable information database, showing the directions that should be considered when selecting a short-range surface to air missile (SAM) system for Poland. The evaluations and suggestions included in this study can be used for prospective solutions and research conducted in a similar area.

Keywords:

air defense, combat capabilities, multi-criteria analysis, NAREW program, surface to air missile (SAM) system

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1. Introduction

The majority of surface to air missile systems operated by Polish armed forces are obsolete. The post-Soviet systems, although modernized, are not capable of effectively engaging contemporary air threats. High speeds, low observability, altitude changes or resistance to electronic interference have become standards for modern air and missile threats (Bużantowicz & Pietrasieński, 2018). This can be seen in the hypersonic missiles, developed by such military powers such as Russia, China India and the United States (Lee, 2019). With the ability to change their flight path or with speeds exceeding the speed of sound multiple times, surface to air missile systems are able to penetrate even a well-organized, multilayered air and missile defense in a relatively short time. It is assumed that in the event of a high-intensity conflict on NATO's eastern flank, a potential aggressor may use a range of unmanned and manned aircraft performing combat, reconnaissance and support tasks for its own long-range missile and artillery assets. It is to be expected that at least some of them, such as Grom, Piorun or Poprad, will launch stand-off attacks, outside the effective range of the Polish very short-range air defense systems (Cieślak, 2020).

Bearing in mind the urgent defense needs of the state, on September 17, 2013, a multiyear program was established by a resolution of the Council of Ministers,[1] in which priority tasks of technical modernization were defined under separate programs. It included essential expenditures and key tasks that were intended to provide the Polish Armed Forces with the required and desired operational capabilities in the long run. From the perspective of air defense operational requirements, the program for the development of the Polish air defense system, the implementation of which is due by the year 2022, is worth noting. The program called for fielding medium-range surface to air missile systems under WISŁA program, which would be capable of engaging both air and tactical ballistic missile threats. Another important element of the modernization program was the plans to aquire short-range surface to air missile systems under the NAREW program. The modernization of the air defense systems was also meant to introduce the Poprad vehicle-mounted surface into air missile systems, Grom/Piorun man-portable air defense systems (MANPADS), along with short-range anti-aircraft missile and artillery systems for the PILICA program. The program also includes the plans for the deployable Soła/Bystra 3D radars.

While the majority of the above-mentioned plans are being implemented without major disruptions, the NAREW program has been significantly delayed, and the Polish military is still working on the concept of developing a short-range air defense system. The problems related to the NAREW program seem complex, with a number of concerns related to technology transfer, cooperation with the Polish Armaments Group, or compatibility with existing and prospective air defense command, control and communication systems.[2]

Bearing in mind the aim of this article, the author aims at developing a preliminary method for assessing the capabilities of surface to air missile systems competing for the NAREW program. The article includes the findings of research carried out with various research methods. The theoretical methods included analysis, synthesis, generalization

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[1] Resolution No. 164 of the Council of Ministers of 17 September 2013 on the establishment of the multiannual program *"Priority Tasks of Technical Modernization of the Armed Forces of the Republic of Poland within the framework of operational programs"*, Warsaw, 4 October 2013, p. 7.

[2] such as the proposed Polish C2-class command system or the American IBCS (Integrated Air and Missile Defense Battle Command System).

and inference. Within the empirical methods, the algorithm of a multi-criteria analysis based on the use of matrix calculus and the method of a diagnostic survey based on the questionnaire technique was applied.

2. The combat capabilities of surface to air missile systems

In order to determine the ability of a given component to perform a task and to achieve predefined objectives in combat, it is necessary to determine the combat capabilities of air defense units and assess the performance of weapon systems. A number of indicators are used for this purpose in air defense troops so as to relate an air defense system / forces (weapon systems, battery, battalion, regiment) to a space and time framework while assessing the effectiveness of their combat employment. The Lexicon of Military Knowledge (1979) defines combat capabilities as a set of quantitative and qualitative indicators characterizing the ability of a unit (subunit) to perform tactical tasks. Spatial indicators determine the environment in which combat tasks can be executed. Time indicators refer to the intensity and duration of the operations. Combat effectiveness indicators provide information on the ability to cover troops and facilities and to engage aerial threats. The main tangible indicators of combat capabilities relate to reconnaissance, fire and mobility (Kuriata, 2005).

The elements of combat capabilities that are considered to be the most important while assessing a particular surface to air missile system include the zone of engagement, and for various tactical scenarios, degree of mobility and ability of conducting autonomous operations (Andruszkiewicz & Głowiński, 2008). Bearing this in mind, it may be concluded that the combat capabilities of air defense troops will largely depend on the tactical and technical characteristics of the reconnaissance, command and fire control, and effector subsystems of their surface to air missile systems, along with skills of their operators. Moreover, available literature on the subject discusses other factors that influence the combat capabilities of air defense units, such as tactics applied by air threats, the strength of their own air defense troops in accordance with the tables of organization and equipment (TOE), and combat service and combat service support available.

The combat capabilities of troops equipped with surface to air missile systems are expressed by their ability to conduct combat operations and defend against air threats in various tactical scenarios (Zdrodowski et al. 1996). Depending on the adopted criteria, they may be expressed by air reconnaissance, fire capabilities, mobility and logistic capabilities.

Air reconnaissance capabilities are defined as the ability to obtain information about air threats and analyzing and processing it. They define the ability of a surface to air missile system as detecting, assessing, identifying and tracking an aerial object. They are conditioned by air reconnaissance elements of the surface to air missile system, the means of relaying information and the ability to obtaining information from other sources. An important factor that affects air reconnaissance involves the technical characteristics of radiolocation and optoelectronic sensors.

Fire capabilities are defined by the ability of an effector component of a surface to air missile system to perform the task of engaging an aerial threat within a specified time and space using a dedicated number of missiles. Some of the most important indicators describing fire capabilities are firing efficiency and combat effectiveness. It is assumed that the parameters expressing the firing effectiveness are such determinants as the probability of engaging aerial threats (kill probability) and the expected number of destroyed air threats. On the other hand, combat effectiveness characterizes the ability of a surface to air missile system (subunit) to perform its tasks. It is expressed by the ratio (quotient) of the number of targets engaged (the expected number of air threats) to the number of targets entering the engagement zone of a surface to air missile system (subunit). Fire capabilities of a surface to air missile system might also be assessed by calculating a segment of airspace protected against enemy air attacks. It may be defined as the radius around protected assets in which there is a possibility of continuous fire. Employing surface to air missile systems in this manner allows for engaging of aerial threats before they can execute their mission. Assessing the fire capabilities of a surface to air missile system (subunit) takes into account time needed for combat readiness expressed by the time required to start firing sequence. It is characterized by the readiness to fire at a target at maximum range, taking into account the delay in obtaining information from air reconnaissance sources. Mobility is characterized by the ability of surface to air missile systems (subunits) to move from the march to firing position (or vice versa), mobility on the roads and in a specific area, and the ability to engage other air targets (maneuver by fire). The logistic and combat supply capabilities of a surface to air missile system (subunit) are defined by, among others, the ability to carry a specific stock of missiles at a required time and place and in a specified state of readiness.

3. The methodology of a multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems

The analysis and evaluation of the combat capabilities of military equipment consists of a number of activities aimed at selecting the best weapon option for the assumed operational capabilities. These capabilities result from specific operational needs. The operational requirements may result in modifying tactical employment of weapons systems or acquisition of new ones. The selection process of a new weapon system can be divided into four basic phases:

1. Analyzing and defining threats;
2. Analyzing and defining the operational capabilities to be achieved by the armed forces;
3. The way in which operational capability is achieved by the armed forces;
4. Evaluating and selecting a weapon system (Miszalski &Mitkow, 2011).

Phase four is the most extensive part related to the selection of a weapon system. As a result of this phase, a final selection of a specific system is made to facilitate a specific operational capability and thus to give the armed forces and the military security system the ability to respond to a specific threat. In the case of surface to air missile systems, a crucial element of this stage is an analysis of tactical-technical parameters characterizing the indicated combat capabilities (Figure 1).

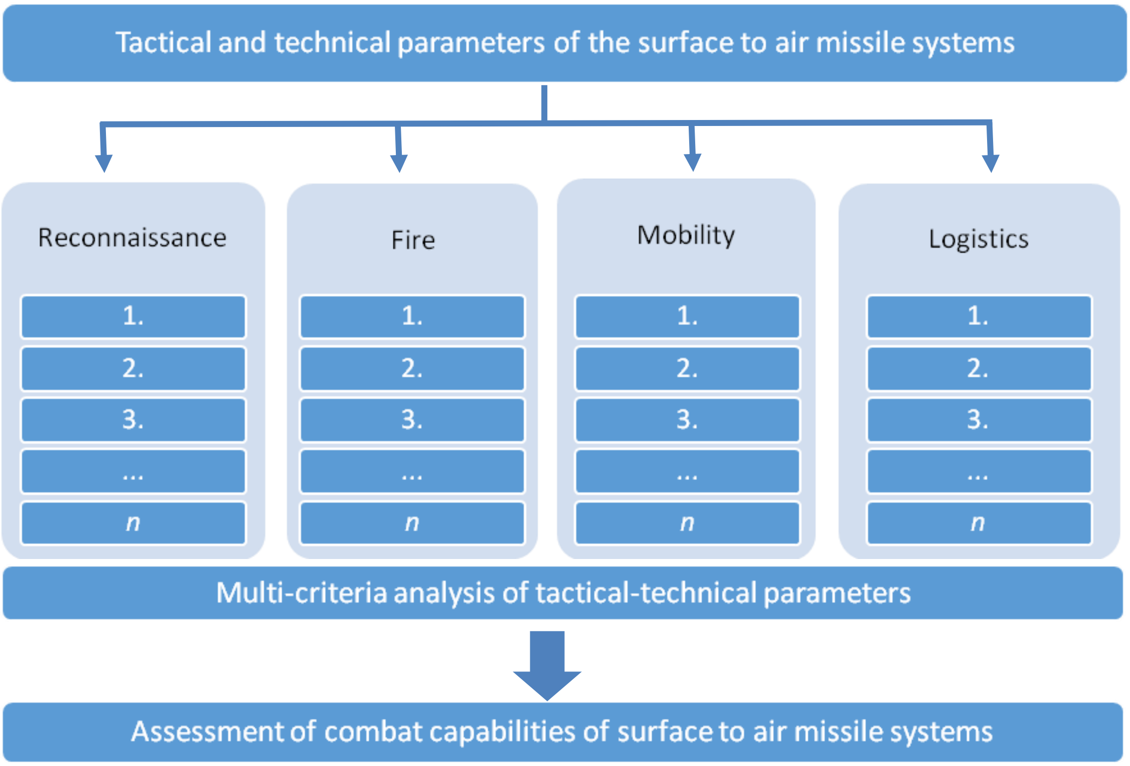

Figure 1. The multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems. Author's own work adapted from: "Analiza wielokryterialna w procesie wyboru dostawcy systemu uzbrojenia" by S. Mitkow. Copyright 2013 by Polskie Wydawnictwo Ekonomiczne.

A multi-criteria approach was used to analyze and evaluate the combat capabilities of surface to air missile systems. When analyzing any issue, in the first place, the objectives of the analysis are defined, which can be described by means of corresponding criterion functions, in short - criteria. When making a comparative analysis of a selected type of armament, many decision-makers are guided by an assessment of the tactical and technical parameters that characterize their combat capabilities. Given a choice of several similar surface to air missile systems, it is difficult to immediately identify the best one, as even the simplest decisions involve several criteria. Quite frequently, the decisions taken are conflicting, as the indication may not fully meet the initial objectives. A multi-criteria discrete optimization may resolve this type of a problem.

Making a decision is usually associated with accepting a compromise on achieving the formulated objectives. It is usually not possible to make a decision so that the best values are achieved simultaneously for all of the criteria considered. It is assumed that in view of the practical impossibility of finding an optimal solution simultaneously for all criteria (i.e. a dominant solution), a multi-criteria solution is accepted as the one which is non-dominated. A non-dominated solution is one for which there is no decision variant, in which the value of a criterion could be improved without the necessity to reduce a value of another criterion. A set of non-dominated solutions forms a boundary efficiency.

Multi-criteria comparative analysis methods are designed to compare (evaluate) objects characterized by multiple features (parameters, decision variables) of an identical or similar functional purpose. The main objective of a multi-criteria comparative analysis is a prioritization of objects and their sets in a multi-dimensional feature space from the point of view of some characteristic that cannot be directly measured.

The basis for making comparisons is always a certain value-criterion system, which is a function of the relevant features of the objects compared. There are distinctive stages in the multi-criteria comparative analysis procedure. It starts with identification of compared objects and their parameters (quality features). Then the parameters are standardized. The next step involves the aggregation of parameters of the objects compared into a comprehensive quality indicator using additional information on the preferences of the decision-maker (Górny, 2004).

Bellinger's method is part of a group of methods for a multi-criteria comparative analysis, uses a simple algorithm that does not require complicated calculations. As a result, Bellinger's method was adopted for the evaluation of the combat capabilities of surface to air missile systems. Due to its interdisciplinary nature, it can be analyzed in different areas of activity and science, thus supporting the decision-making process in the area chosen by a concerned organization or a person. The essence of the method relies on putting analyzed objects in an order on the basis of the total evaluation value, determined from a set of partial criteria, which should be previously reduced to the form of additive values (Górny, 1999). For each criterion of a given decision variant, the most and least desirable state and the direction of change of this state (i.e. stimulants and destimulants) are determined. The assessment of each criterion in this range for a given object is a fraction of the total distance, being the difference between the above states. The best decision-making option becomes the object which obtains the highest value in the total evaluation (after summing up the evaluations of all criteria of a given object). Each criterion to be evaluated is assigned a significance for further weighting. Its size depends on the relevance of a given criterion for the decision-maker and the impact of the criterion on the overall decision-making situation. It is important that all of the weights of the individual criteria be evaluated to be selected in such a way that their sum is equal to unity. However, the way in which the weights are recorded is arbitrary.

Figure. 2 shows the algorithm of stages in the adopted method of a multi-criteria analysis of the combat capabilities of surface to air missile systems.

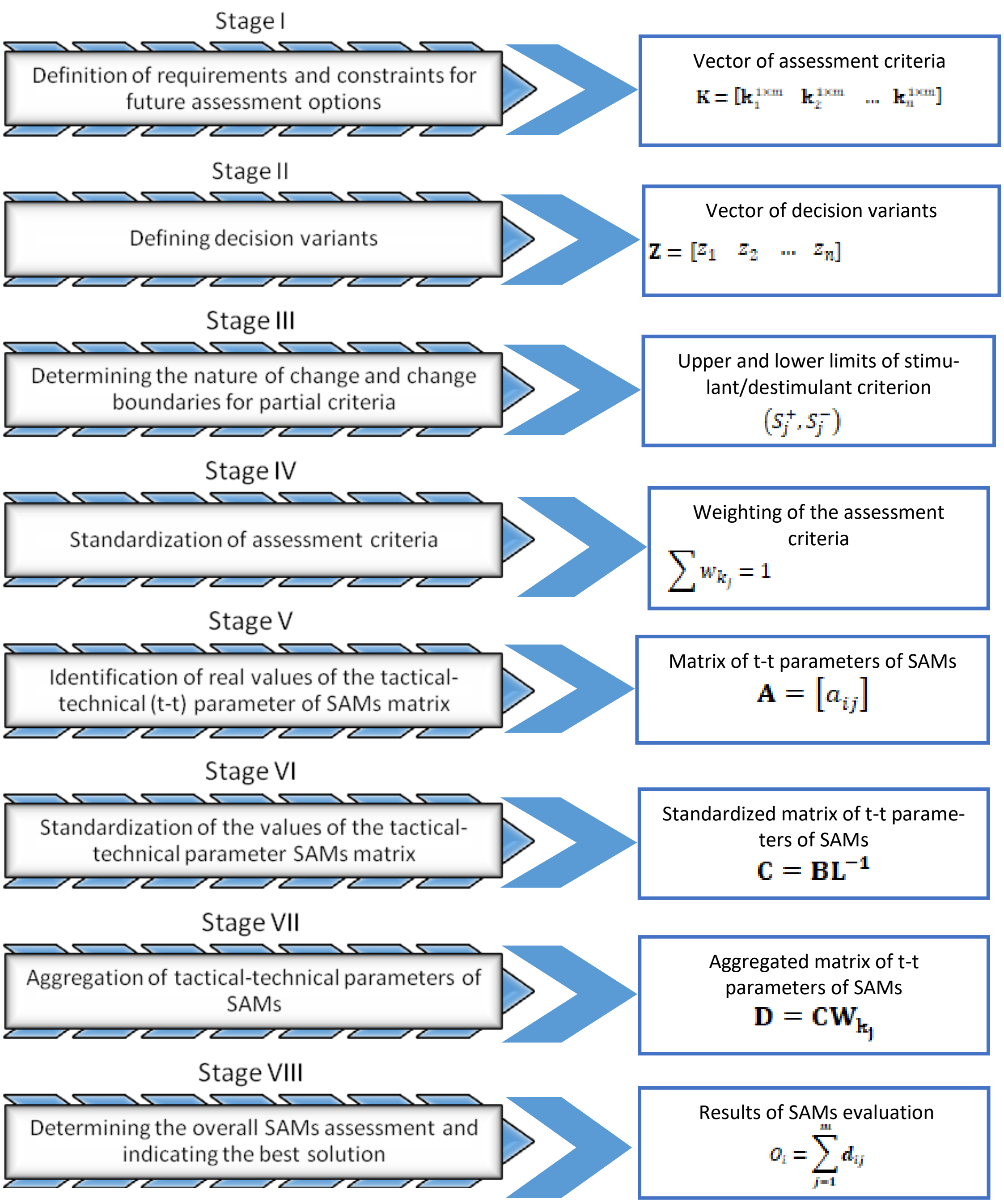

Figure 2. Algorithm of the multi-criteria analysis and evaluation of combat capabilities of surface to air missiles systems by means of Bellinger's method. Own work.

Stage one consists of identifying the requirements and constraints for future solution variants. In this phase, the criteria against which the analysis will be conducted, are defined. The evaluation criteria will be characterized by a vector as follows:

$$\mathbf{K} = [\mathbf{k}_1^{1\times m} \quad \mathbf{k}_2^{1\times m} \quad \dots \quad \mathbf{k}_n^{1\times m}] \tag{3.1}$$

Stage two consists of specifying decision alternatives, i.e. determining a set of surface to air missile systems to be analyzed, which will be characterized by a vector expressed as:

$$\mathbf{Z} = [z_1 \quad z_2 \quad \dots \quad z_n] \tag{3.2}$$

Stage three entails a detailed definition of the assessment criteria, the units of measurement, as well as the desired direction of change of the given criteria, i.e. stimulants indicating a preferable increase in values or destimulants indicating their decrease, together with boundary values of acceptable changes.

During this phase, the difference of the current value of the surface to air missiles systems parameter in relation to the most desirable value is also calculated. In order to determine it, it is necessary to calculate the arithmetic mean $X_j$of the values of particular variants in relation to particular sub-criteria:

$$X_j = \frac{1}{n}\sum_{i=1}^{n} a_{ij} \tag{3.3}$$

where: a_{ij}- the value of the *i-th* variant under *j-th* criterion.

This is followed by determining the boundary values of desirable S_j^+ and undesirable values S_j^-:

$$\text{If } z_j = \text{max} \text{then } S_j^+ = X_j \text{and } S_j^- = 0 \tag{3.4}$$

$$\text{If } z_j = \text{min} \text{then } S_j^+ = 0 \text{and } S_j^- = X_j \tag{3.5}$$

The obtained values allow the determination of the total distance L_j:

$$L_j = S_j^+ - S_j^- \tag{3.6}$$

Stage four is the stage in which the adopted evaluation criteria are prioritized by assigning them appropriate weights w_{k_j}in accordance with the following conditions:

$$w_{k_j} \geq 0 \tag{3.7}$$

$$\sum_{i=1}^{n} w_{k_j} = 1 \tag{3.8}$$

In stage five, the matrix **A**is created containing the actual values of the tested variants in relation to the individual criteria.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} \\ a_{12} & a_{22} & \cdots & a_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \tag{3.9}$$

where: *aij* - the value of the *i-th* variant under *j-th* criterion.

Stage six describes the elements of the matrix **A** as a percentage of the difference in the value of the actual state in relation to the most desirable one. For this purpose, matrix **B** is created, in which the calculated differences are placed. Next, matrix **C** is created, in which the elements of matrix **B** are presented as a percentage of the distance of the value of the actual state in relation to the most desired one.

$$\mathbf{B} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1j} \\ b_{21} & b_{22} & \cdots & b_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ b_{i1} & b_{i2} & \cdots & b_{ij} \end{bmatrix} = \begin{bmatrix} (a_{11} - S_1^-) & (a_{12} - S_2^-) & \cdots & (a_{1j} - S_j^-) \\ (a_{21} - S_1^-) & (a_{22} - S_2^-) & \cdots & (a_{2j} - S_j^-) \\ \cdots & \cdots & \cdots & \cdots \\ (a_{i1} - S_1^-) & (a_{i2} - S_2^-) & \cdots & (a_{ij} - S_j^-) \end{bmatrix} \tag{3.10}$$

$$\mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1j} \\ c_{21} & c_{22} & \cdots & c_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ c_{i1} & c_{i2} & \cdots & c_{ij} \end{bmatrix} = \begin{bmatrix} \frac{100b_{11}}{L_1} & \frac{100b_{12}}{L_2} & \cdots & \frac{100b_{1j}}{L_j} \\ \frac{100b_{21}}{L_1} & \frac{100b_{22}}{L_2} & \cdots & \frac{100b_{2j}}{L_j} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{100b_{i1}}{L_1} & \frac{100b_{i2}}{L_2} & \cdots & \frac{100b_{ij}}{L_j} \end{bmatrix} \quad (3.11)$$

In stage seven, matrix **D** is created, in which the products of matrix **C** elements with corresponding weights are described w_{kj}.

$$\mathbf{D} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1j} \\ d_{21} & d_{22} & \cdots & d_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ d_{i1} & d_{i2} & \cdots & d_{ij} \end{bmatrix} = \begin{bmatrix} c_{11}w_{k_1^1} & c_{12}w_{k_2^1} & \cdots & c_{1j}w_{k_j^i} \\ c_{12}w_{k_1^2} & c_{22}w_{k_2^2} & \cdots & c_{2j}w_{k_j^i} \\ \cdots & \cdots & \cdots & \cdots \\ c_{i1}w_{k_1^i} & c_{i2}w_{k_2^i} & \cdots & c_{ij}w_{k_j^i} \end{bmatrix} \quad (3.12)$$

In the last stage, stage eight, the overall assessment O_i for the analyzed development variants is determined, which is the sum of the partial assessments of the individual variants from the considered criteria.

$$O_i = \sum_{j=1}^{m} d_{ij} \quad (3.13)$$

On the basis of the value of the cumulative assessment, the armament variant with the best tactical and technical parameters is identified.

4. The multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems

The analysis and evaluation of the combat capabilities of surface to missile systems, meeting the initial requirements of NAREW program, begins with the selection of their characteristic features in terms of reconnaissance, fire capabilities and mobility without considering the logistic capabilities.

The following designations for the vectors of the tactical and technical parameters of the surface to air missile systems' combat capability assessment have been adopted:

- **k1**- vector of tactical-technical parameters for the evaluation of reconnaissance capabilities;
- **k2**- vector of tactical-technical parameters of fire capabilities assessment;
- **k3**- vector of tactical-technical parameters for the assessment of mobility.

The set of evaluation criteria **K** will be characterized by a vector in the following form:

$$\mathbf{K} = [\mathbf{k}_1^{1\times2} \quad \mathbf{k}_2^{1\times4} \quad \ldots \quad \mathbf{k}_n^{1\times2}] \quad (4.1)$$

for the assumed vector **K** , formula (4.1.), the criteria and the tactical-technical parameters characterizing them are summarized in Table 1.

Table 1.
Criteria and their characteristics adopted to assess the combat capabilities of surface to air missile systems.

Criterion of assessment			Features: tactical-technical parameters		Nature of criterion change*
Combat capabilities	Reconnaissance	$\mathbf{k_1}$	k_1^1	The maximum range of target detection [km]	S
			k_1^2	Number of simultaneously tracked targets	S
	Fire	$\mathbf{k_2}$	k_2^1	Spatial dimensions of engagement zone [km]	S
			k_2^2	Maximum engagement altitude [km]	S
			k_2^3	Missile velocity [m/s]	S
			k_2^4	Number of missiles in a launcher [missiles]	S
	Mobility	$\mathbf{k_3}$	k_3^1	Reaction time [s]	D
			k_3^2	Maximum mobility of SAM vehicles [km/h]	S

* S - stimulants; D - destimulants

For the purpose of the conducted analysis, it is assumed that the combat capabilities of the surface to air missile system will be expressed by three numerical tactical-technical parameters characterizing each of the features of the surface to air missile system.

Under the NAREW program, the Polish Armed Forces are to acquire several surface to air missile batteries of short-range SAM systems capable of engaging aerial threats at distances of up to 25 km. Israeli, British and Norwegian-American corporations have offered Poland the following products: Diehl Defense Holding (IRIS-T missile), MBDA Missile Systems (VL MICA and CAMM-ER missiles), Thales (VT-1 missile), Rafael Advanced Defense Systems (Derby and Python-5 missiles), Israel Aerospace Industries (Barak-8SR missile), Aselsan (AIHSF missile), Raytheon Company (AMRAAM and Stunner missiles) and Kongsberg Group (NASAMS II missiles). Each of the proposed systems features different combat capabilities.

A six-element vector was analyzed $\mathbf{Z} = [z_1 \quad z_2 \quad z_3 \quad z_4 \quad z_5 \quad z_p]$ in the configuration shown in Table 2, and the corresponding tactical and technical parameters have been summarized in Table 3. A vector $\mathbf{Z}$ is a set of five systems selected for the analysis of the systems. The SA-6 surface to air missile system (2K12 KUB),[3] which is in the inventory of the Polish Armed Forces, has been used for comparative purposes.

Table 2.
The hardware configuration of the analyzed SAM systems

	NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	SA-6 KUB
Effector (missile)	AIM-120 C-8 AMRAAM-ER	BARAK MRAD	MICA FR/IR	IRIS-T	CAMM-ER	3M9M3E
Sensor	3D radar AN/MPQ64F1 Sentinel	M-2084 Multi Mission AESA 3D Radar	Radar TRML-3D/32	SAAB Giraffe AMB Radar	SAAB Giraffe 4A Radar	SURN 1S91 (SSWN)

3 The 2K12 KUB system exploited in Poland has been used only for reference purposes.

Table 3.
A summary of parameter values of the evaluation criteria and their limits of change

Criterion of assessment			Parameter values						Auxiliary calculation values	
			NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	KUB		
			Z1	*Z2*	*Z3*	*Z4*	*Z5*	Z_p	X_j	L_j
Combat capabilities	**k₁**	k_1^1	120	470	200	180	280	65	219	219
		k_1^2	60	1100	400	200	800	100[4]	443	443
	k₂	k_2^1	40	35	20	40	40	24	33	33
		k_2^2	14	20	9	20	10	7[5]	13	13
		k_2^3	1,350	680	1,360	1,100	1,020	950	1,077	1,077
		k_2^4	6	8	4	8[6]	8	3	6	6
	k₃	k_3^1	1,200	120	600	600	1,200	420	690	-690
		k_3^2	60	60	60	60	60	50	58	58

In the next stage of the analysis, the adopted evaluation criteria were prioritized by assigning appropriate weights to them. The weight values of the individual evaluation criteria were determined on the basis of the experts' preferences during a survey with a total of thirty respondents, who were academic teachers from military universities working on air defense issues as well as officers serving in air defense units. The standardized weighting values for the individual assessment criteria are shown in Table 4.

Table 4.
A summary of the weighting values of the individual evaluation criteria

Weighting of the assessment criterion	$w_{k_1^1}$	$w_{k_1^2}$	$w_{k_2^1}$	$w_{k_2^2}$	$w_{k_2^3}$	$w_{k_2^4}$	$w_{k_3^1}$	$w_{k_3^2}$
Weight value	0.165	0.118	0.147	0.154	0.132	0.088	0.150	0.046

The input data for the evaluation of the combat capabilities of surface to air missile systems is matrix **A**, whose form for the actual quantities listed in Table 3, are as follows:

$$\mathbf{A} = \begin{bmatrix} 120 & 470 & 200 & 180 & 280 & 65 \\ 60 & 1100 & 400 & 200 & 800 & 100 \\ 40 & 35 & 20 & 40 & 40 & 24 \\ 14 & 20 & 9 & 20 & 10 & 7 \\ 1350 & 680 & 1360 & 1100 & 1020 & 950 \\ 6 & 8 & 4 & 8 & 8 & 3 \\ 1200 & 120 & 600 & 600 & 1200 & 420 \\ 60 & 60 & 60 & 60 & 60 & 50 \end{bmatrix}$$

4 Value adopted on the basis of expert interviews.
5 With Rega-Łowcza system (without K1 cabin).
6 Initially the system was mounted on the Polish manufactured Jelcz undercarriage and displayed during the International Exhibition of Defense Industry held in Kielce in 2015.

The final form of matrix **C**, in which its individual elements constitute a percentage of the distance of the actual state values of the parameters in relation to the most desired value, equals:

$$\mathbf{C}=\begin{bmatrix}\frac{100b_{11}}{L_1} & \frac{100b_{12}}{L_2} & \cdots & \frac{100b_{1j}}{L_j}\\ \frac{100b_{21}}{L_1} & \frac{100b_{22}}{L_2} & \cdots & \frac{100b_{2j}}{L_j}\\ \cdots & \cdots & \cdots & \cdots\\ \frac{100b_{i1}}{L_1} & \frac{100b_{i2}}{L_2} & \cdots & \frac{100b_{ij}}{L_j}\end{bmatrix}=\begin{bmatrix}55 & 214 & 91 & 82 & 128 & 30\\ 14 & 248 & 90 & 45 & 180 & 23\\ 121 & 106 & 60 & 121 & 121 & 72\\ 105 & 150 & 68 & 150 & 75 & 53\\ 125 & 63 & 126 & 102 & 95 & 88\\ 97 & 130 & 65 & 130 & 130 & 49\\ -74 & 83 & 13 & 13 & -74 & 39\\ 103 & 103 & 103 & 103 & 103 & 86\end{bmatrix}$$

The final form of matrix **D**, which is the product of the elements of matrix **C** and the corresponding weights $w_{k_j^i}$ equals:

$$\mathbf{D}=\begin{bmatrix}c_{11}w_{k_1^1} & c_{12}w_{k_2^1} & \cdots & c_{1j}w_{k_j^i}\\ c_{12}w_{k_1^2} & c_{22}w_{k_2^2} & \cdots & c_{2j}w_{k_j^i}\\ \cdots & \cdots & \cdots & \cdots\\ c_{i1}w_{k_1^i} & c_{i2}w_{k_2^i} & \cdots & c_{ij}w_{k_j^i}\end{bmatrix}=\begin{bmatrix}9 & 35 & 15 & 14 & 21 & 5\\ 2 & 29 & 11 & 5 & 21 & 3\\ 18 & 16 & 9 & 18 & 18 & 11\\ 16 & 23 & 10 & 23 & 12 & 8\\ 17 & 8 & 17 & 13 & 13 & 12\\ 9 & 11 & 6 & 11 & 11 & 4\\ -11 & 12 & 2 & 2 & -11 & 6\\ 5 & 5 & 5 & 5 & 5 & 4\end{bmatrix}$$

The total assessment O_i for the analyzed surface to air missile systems, which is a sum of partial assessments of particular systems out of the considered criteria, is presented in Table 5 and depicted in Figure 3.

Table 5.
The cumulative assessment values of the analyzed armament alternatives.

NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	SA-6 KUB
63	140	74	91	89	52

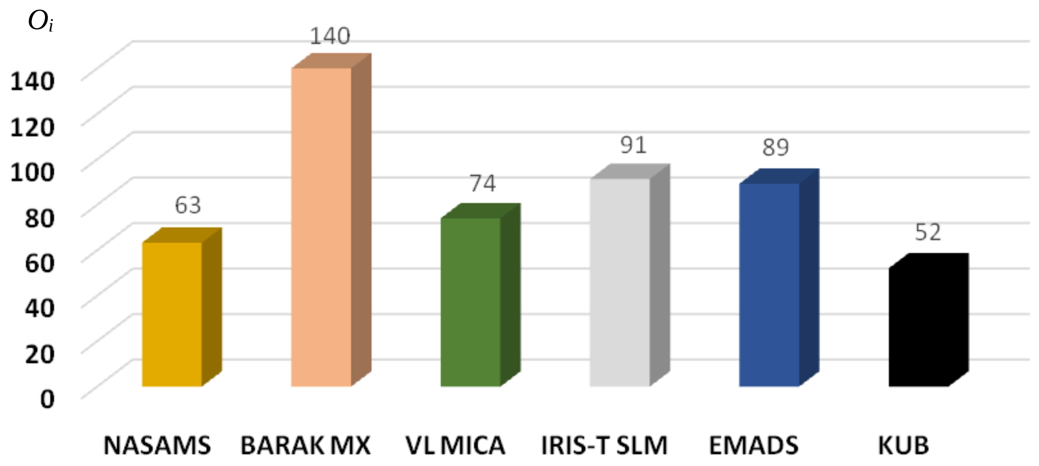

Figure 3. The overall evaluation of the combat capabilities of the examined armament variants. Author's own work.

The intermediate results of the discussed variants for the evaluation criteria under scrutiny have been illustrated in the bar diagrams in Figure 4.

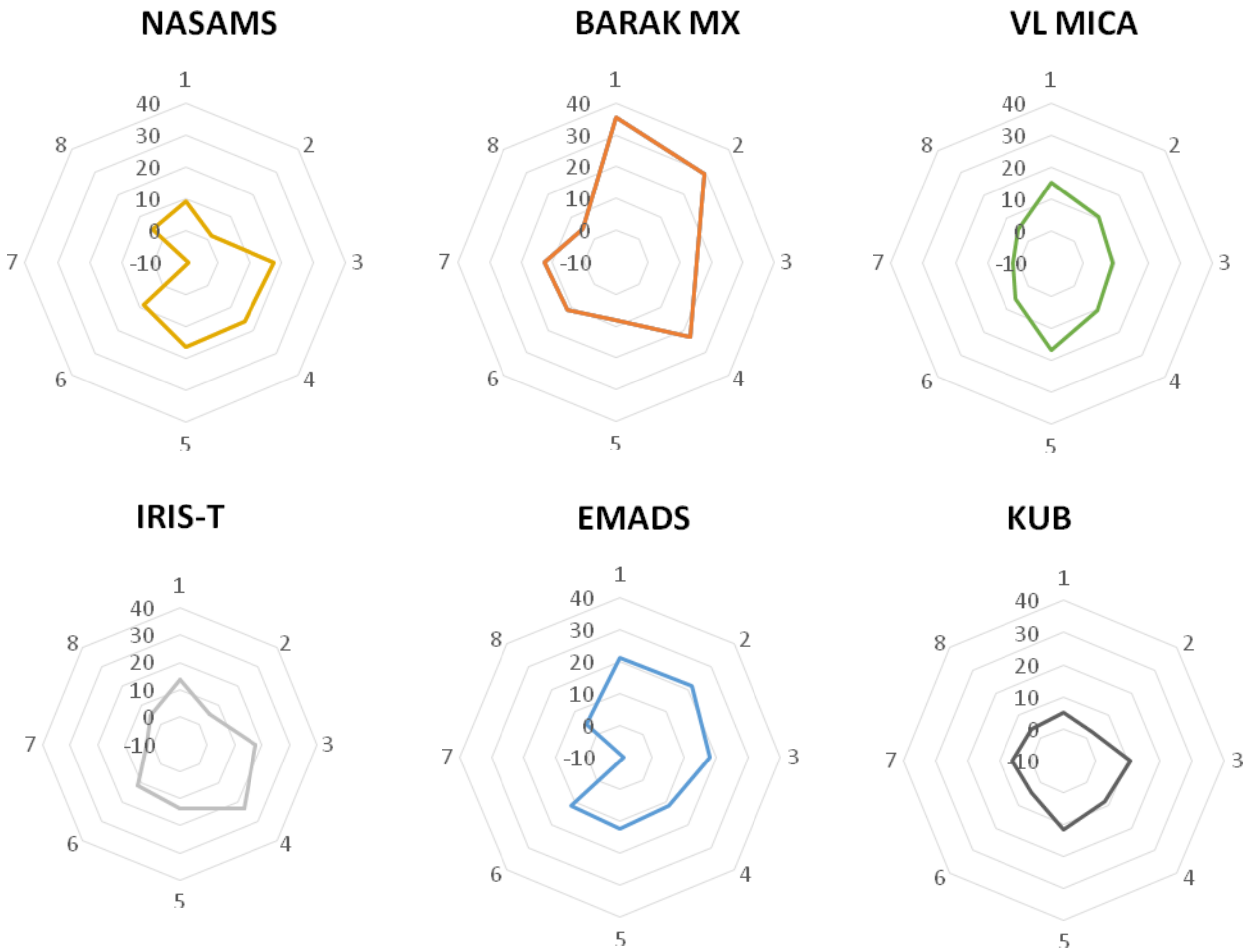

Figure 4. The detailed characteristics of combat capabilities of the analyzed SAMs variants (adopted axes labeling: 1 - k_1^1; 2 - k_1^2; 3 - k_2^1; 4 - k_2^2; 5 - k_2^3; 6 - k_2^4; 7 - k_3^1; 8 - k_3^2) (author's own development)

5. Conclusions

Based on the obtained findings, it can be observed that for each indicator of the combat capabilities features, the highest values were determined for the BARAK MX surface to air missile system. When analyzing the graph showing the comparison of values of the synthetic quality indicator of the systems, it can be concluded that the BARAK MX system is the most effective among the examined surface to air missile systems. In contrast, the lowest values for the adopted indicators of combat capabilities are featured by the SA-6 (KUB) system. However, it should be noted that the technical parameters of the surface to air missile systems used in the calculations are taken from generally available sources and do not necessarily reflect the systems' current technical characteristics. Consequently, the results obtained are representative since only a few parameters out of many others were compared in the conducted study. For the purpose of the conducted study,, certain criteria had been adopted. The author does not intend to select the best or the worst surface to air missile system for the NAREW program. His deliberations are to encourage discussion about making such choices. The adopted manner of reasoning and the presented method for evaluating the combat capabilities of surface to air missile systems are intended to indicate one of the possible directions in their selection. If more input data are used, and the criteria are expanded, the result of the combined combat capability assessment may give a more comprehensive picture of the analyzed surface to air systems, and their selection may prove easier.

Knowledge and practical consideration of the indicators of the combat capabilities of surface to air missile systems form the basis for making rational decisions on their combat employment. This, in turn, allows for a rational approach to planning for tactical employment, the formation of a combat task force, and coordination with other elements of the integrated air defense system. Due to less expensive missiles and a higher number of launchers than the PATRIOT system, the surface to air missile systems planned for the NAREW program will be better suited for providing effective air defense for critical zones and areas such as land forces troops 'groupings, air bases and logistic support assets or command posts. Taking into account the combat capabilities of such current surface to air missile systems, including SA-8 OSA, SA-6 KUB, and SA-3 NEWA, it is not difficult to notice that on today's battlefield, the ability to engage and destroy a one air threat at a time is not a solution. Therefore, there is a real need for surface to air missile systems that are capable of simultaneous engagement of multiple air threats, such as aircraft, helicopters, UAVs, cruise missiles, and loitering munitions. It is important that such surface to air missile systems are compatible with national and allied command and control systems, air reconnaissance assets and other weapon systems. Moreover, new surface to air missile systems planned for the NAREW program should be capable of acquiring and exchanging information on the air threats. In addition, they also have the ability to simultaneously engage several air targets with a high probability of kill. Hence, every effort should be made to ensure that the surface to air missile systems acquired within the framework of the NAREW program will, on one hand, possess appropriate combat capabilities and, on the other hand, become an integral element of the Polish air defense system, enabling its reliable and effective operations.

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