The Analytic Hierarchy Process Involved in Air Defense Integrated Systems with SWOT Analysis

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Abstract: The main purpose of this paper is the achievement of research based on theoretical studies and experimental data processing in management solutions for choosing the best solution of SBADIS (Surface Based Air Defense Integrated Systems). The authors have in mind the integration of missile systems with short range of action in a flexible structure, taking into account the strengths, weaknesses, opportunities, and threats. Therefore we use the Analytic Hierarchy Process (AHP), a multi-criteria method in decision-making. The AHP is a very flexible and powerful tool because the scores, and therefore the final ranking, are obtained on the basis of the pairwise relative evaluations of both the criteria and the options provided by the user.

Key Words: Analytic Hierarchy Process (AHP), Eigen vector, Surface Based Air Defense Integrated Systems (SBADIS), SWOT analysis.

1. Introduction

The manifest advancement of research in the field of military technologies entitles us to consider that, in a short period of time from now on, the aerospace or cosmic power, through its technical and functional nature, will be redefined as the fourth dimension of warfare. Future military engagement will surely take place in space. Whoever will manage to control space, those will take control of everything.

The cruise missiles and the unmanned air vehicles, perceived as potential targets, represent a priority in establishing the rules of engagement, because they display similar characteristics with the unmanned air vehicles on radar screens.

In this context high capacity interception systems need to transmit real time data related to possible saturation attacks with numerous formations, by means of radar jamming at such distances from where means of air attack do not endanger own apparatus objectives. Meeting the basic requirements for the accomplishment of the action integration of forces whose specific mission is the air defense confers the air defense system the following characteristics:
- Organizational and structural modularity;
- Mobility;
- Flexibility;
- Action complementarity;
- Operational credibility;
- Sustainability.

The problematic of study the increased usage of processes in special integrated airspace systems is of tremendous relevance. In this area we intended to achieve a research based on theoretical studies and analysis of experimental data concerning modernization solutions of these systems.

The special airspace system represents an assembly of Surface-to-Air Missile (SAM) and Antiaircraft Artillery (AAA) nets that include groups of algorithms, technical and organizational means, whose specific mission is to survey the air space, to detect and identify enemy air targets and to destroy them.
2. Basics of AHP (Analytic Hierarchy Process) involved in the SWOT Analysis

In order to highlight the strengths and weaknesses of Surface Based Air Defense the SWOT analysis is preceded by the Analytic Hierarchy Process (AHP) an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker’s evaluations, thus reducing the bias in the decision making process.

AHP decides the best solution from a group of assessment criteria and a group of random options. It is good to emphasize that while some criteria can be put in opposition, it is not valid that broadly the best option is the one that optimizes every criterion, but rather the one that reaches the most suitable compromises from different criteria.

This method provides the weights for every assessment criterion according to the decision maker by comparing pairs of criteria. The general goal for a certain option is a weighed amount of the purposes regarding all the criteria.

AHP method consists of the action of three steps:

- The calculation of the vector with the weights of criteria;
- The calculation of the matrix to gain the results;
- The classification of the options.

Every step will be thorough presented in the next lines, taking into account a group of assessment criteria and a number of evaluated options. In addition we will check the reliability of the results. To calculate the weights for various criteria, AHP commence by creating a matrix of pairs’ comparison, symbolised by $A$. This is from $m \times m$ class, where $m$ is the amount of named assessment criteria.

Every entrance $a_{jk}$ of the $A$ matrix shows the importance of $j$ criterion in relation with $k$ criterion. If $a_{jk} > 1$, then $j$ criterion is more important than $k$ criterion whilst if $a_{jk} < 1$, than $j$ is less significant than $k$.

If two criteria have the same relevance, then the entry item $a_{jk}$ equals 1, where $a_{jk}$ and $a_{kj}$ perform the following conditions:

$$a_{jk} = \frac{1}{a_{kj}}$$  \hspace{1cm} (1)

Of course, $a_{jj} = 1$ for every $j$. The relevance between two criteria is measured on a 1 to 9 scale, according to 1 Table, where $j$ is more or at least equal important to $k$.

The studying of the columns from Table 2.1 is suggestive and it can be used by the decision maker to convert the qualitative assessment according to the significance between two criteria, in a quantitative evaluation by attaching numbers. Also, it is feasible that by using intermediate values there will be an improved accuracy.

The values from $A$ matrix are based on coherent pairs. On the other hand, the classification can generally contain small incoherences that do not cause serious problems AHP.

Each of these assessments correspond with a number from a scale, associated with, conclusions such as: „extremely significant”, „a lot more significant”, „as significant as”, and so on. The choose scale for this method is from 1 to 9 according to Fig. 1.

![Fig. 1. The Saaty Rating Scale](image)

Each of these judgments is assigned a number on a scale: absolutely more important (9), is very much more important (7), rather more important (5), as important, and so on down to very much less important, than attribute.

This method was applied to decide which of the four Surface Based Air Defense systems symbolized with $C_1$, $C_2$, $C_3$, and $C_4$ is the best taking into account some features.

Strengths:
- Camouflage ($S_1$);
- The identification possibility of enemy targets ($S_2$);
- Crew safety ($S_3$);
- Mobility ($S_4$);
- The number of targets shown on the screens ($S_5$).

Weaknesses:
- The lack of reconnaissance equipment ($W_1$);
- Target destruction on sun’s direction/night time ($W_2$);
- The chance of being detected by foe ($W_3$);
- The lack of proximity fire ($W_4$);
- The filling of fight capacity ($W_5$).

Opportunities:
- The presence of some types of profile with a rich experience in the defense field ($O_1$);
- A complete system’s presence of training the personnel who use the systems ($O_2$);
The existence of a firing range for the assessment of shootings using these systems (O₃).

Threats

- The bias of the decisional incoherence and interactions relating to the reattempting measures of the national defense institution, that damages directly and at once the maintenance of the defense system (A₁);
- They directly influence the financial instability and the direct negative effect of the crisis (A₂).

If one criterion from above is powerful than the other we settle its value on the chosen scale to the left or to the right.

The results are transferred in a 4x4 matrix where the diagonal always equals 1. We take into account the next rules:

- On the left there are the present complete results;
- On the left there are mutual values.

All the results of the criteria are positive ay > 0.

The next step is to build the (comparison) matrix corresponding to the pairwise comparisons. It will be a 4 (lines) by 4 (columns) matrix, and will be denoted by C. The diagonal elements of this matrix are always 1 as we mentioned before, and all we have to do is filling up the upper triangular matrix. In order to do this, we have to respect the following obvious rules (taking into account that we fill the rows of the matrix, i.e. we compare the Cᵢ characteristic with Cᵢ₊ᵢ, where i is the row index in the matrix):

A. If the attributed value (aᵢ,ᵢ₊ᵢ ∈ [1, 9]) on left of 1 (view the 2 tabel), that means Cᵢ is superior to Cᵢ₊ᵢ, in this case the value is introduced in the matrix.

B. If the attributed value (aᵢ,ᵢ₊ᵢ ∈ [1, 9]) on right of 1 (see the 2 tabel), that concludes Cᵢ₊ᵢ is superior to Cᵢ, then 1 is implemented in the matrix.

As Saaty theory says the next step implies the calculation of the priority vector, which is the normalised vector of the matrix, of the own maximum value.

The priority vector can be aproximately determined by the next method, with acceptable errors especially for a small dimensioned matrix. This is based on the normalization of every column from A matrix:

\[ a_{ij} \rightarrow \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \forall j = 1, n; \quad (n = 4) \quad (2) \]

The priority vector will be represented by the medium value of every line:

\[ w_j = \frac{1}{n}, \forall i = 1, n; \quad (n = 4) \quad (3) \]

Such level of about 10% it is thought to be quite high, hence we can conclude that the 6 x 6 comparison matrix 6 x 6 is not small enough to apply the approximative method.

Next it is studied the consistency of the survey, more exactly the consistency of the comparison matrix. In essence, a comparative judgement has consistency if it is respected the transitivitiy principle: According to this principle, if A is more significant than B, and the latter is more important than C, well, normally it means that A is more significant than C.

As these calitative judgements are converting into quantitative assessments, it is inferred that it can firstly be defined the consistancy of a mutual matrix.

Hence, a mutual matrix \[ \left( a_{ij} > 0; a_{ij} = \frac{1}{a_{ji}} \right) \] is formed only if:

\[ a_{jk} \cdot a_{kp} = a_{jp}, \quad \forall j, k, p \]

The next theory is being proven (Saaty):

A n x n mutual matrix is consistent only if its unique polinom has the next form:

\[ P(\lambda) = \lambda^n - n \cdot \lambda^{n-1} \]

3. Application: Possibilities analysis of choose the best system

The own value of such matrix (the equation solutions P(λ) = 0) will be 0 (multiple root of n – 1 times) and n (simple root). Here shows the selection of the own maximum matrix and of the proper vector as a priority vector. So, we can rate the consistancy of the survey through \[ \lambda_{max} = n \]. Theoretically, this should be zero. As it is little likely, after the comparisons between studied criteria there will be formed a consistent comparison matrix according to
the above definition, there are defined the following indicators of the consistency (Saaty):

The criterions $S_1$, $S_2$, $S_3$, $S_4$, and $S_5$

Taking into account Saaty’s scale the strengths for each four systems, are presented according to Table 3.1.

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Table 3.1

$$C = \begin{bmatrix} 1 & 1 & \frac{1}{8} & \frac{1}{8} \\ \frac{1}{8} & 1 & 8 & 1 \\ \frac{1}{8} & 1 & 8 & 1 \\ \frac{1}{8} & 1 & 8 & 1 \end{bmatrix} \Rightarrow W = \begin{bmatrix} 5.556 \\ 4.444 \\ 4.444 \\ 4.444 \end{bmatrix} \Rightarrow CR \approx 0$$

$$C = \begin{bmatrix} 1 & 1 & \frac{1}{8} & \frac{1}{8} \\ \frac{1}{8} & 1 & 8 & 1 \\ \frac{1}{8} & 1 & 8 & 1 \\ \frac{1}{8} & 1 & 8 & 1 \end{bmatrix} \Rightarrow W = \begin{bmatrix} 28.5 \\ 7.226 \\ 59.65 \\ 4.618 \end{bmatrix} \Rightarrow CR \approx 3.7\%$$

$$C = \begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{7} & \frac{1}{7} \\ \frac{1}{7} & 1 & \frac{7}{1} & \frac{7}{1} \\ \frac{1}{7} & \frac{7}{1} & 1 & \frac{7}{1} \\ \frac{1}{7} & \frac{7}{1} & \frac{7}{1} & 1 \end{bmatrix} \Rightarrow W = \begin{bmatrix} 43.75 \\ 6.25 \\ 43.75 \\ 6.25 \end{bmatrix} \Rightarrow CR \approx 0$$

$$C = \begin{bmatrix} 1 & \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & 1 & \frac{9}{1} & \frac{9}{1} \\ \frac{1}{9} & \frac{9}{1} & 1 & \frac{9}{1} \\ \frac{1}{9} & \frac{9}{1} & \frac{9}{1} & 1 \end{bmatrix} \Rightarrow W = \begin{bmatrix} 43.85 \\ 5.188 \\ 45.27 \\ 5.692 \end{bmatrix} \Rightarrow CR \approx 0.2\%$$
Also, taking into account Saaty’s scale the weaknesses for each four systems, are presented in Table 3.3.

\[
\begin{pmatrix}
1 & 1 & 1 & 1 \\
7 & 1 & 6 & 2 \\
1 & 1 & 1 & 3 \\
1 & 2 & 3 & 1 \\
\end{pmatrix} \Rightarrow W = \begin{pmatrix}
12,16 \\
57,36 \\
9,075 \\
21,4 \\
\end{pmatrix} \text{ si CR} \cong 6,7\%
\]

It is obvious that the three criteria will have the same weights as shown here: 33,33%.

It is obvious that the two criteria, threats will have equal weights as follows: 50% according to Table 3.4.

The SWOT analysis, including the weights for system C1 is shown in Fig 2.
3. Conclusions and contributions

This article has proposed an analysis of the Electronic counter measures capabilities (ECM) that influences single shoot kill probability, for a better understanding of the actual possibilities of upgrading the special integrated aerospace systems, characterized by high complexity. Understanding the factors that are involved, the risks, and proposed project costs is vital for the selection of this project, because in this case a complex set of constraints at the level of performances and costs is involved.

The importance, efficiency and effectiveness of the Air Defense System derived from its mission. Also it is important to understand the proper project management to obtain the proposed results in compliance with the performance requirements.

AHP has many strength points, the main ones being the following:

- The main advantage of AHP: it involves mathematical and logical reasoning to get the decision. In this way it turns into quantitative items the human qualitative judgments.
- AHP organizes data as a hierarchical structure and this is a human natural approach. In this way complex problems are transformed into several sub-problems to be solved sequentially. Psychological studies concluded that human beings can compare $7 \pm 2$ items simultaneously, and this fundament the Saaty’s scale.
- The AHP defines a procedure for making decisions, formalizing this process and placing it in a scientific context.

As a weak point of AHP, the possibility of getting an inconsistent comparisons matrix is the main one, especially when comparing a lot of items.

Using AHP method in the proposed application, the weights of criteria $S_1...S_5$; $W_1...W_5$; $O_1...O_3$ and $T_{1,2}$ were computed. It was shown in the framework of discussions an interesting analysis of the study consistency, namely the consistency of comparison matrix, based on the fact that comparative judgment is consistent only if respects the principle of transitivity.

The study results show that two of four criteria are influencing the systems choice tacking into account the strengths and weaknesses between 52-61%. It would be interesting a similar approach in the future, using AHP method, to other performance characteristics of special integrated aerospace systems.
References:


[16] Teece, D., (2005), "Dynamic capabilities: The causes, consequences and challenges of change", in J.Hazy (ed.), Comment at a Symposium at the Academy of Management Annual Conference, Tuesday, August 8, Honolulu, HI.


