ARTICLE

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Support for defense procurement decision: structuring multi-criteria problems using the Analytic Hierarchy Process (AHP)

Ayuda a la decisión sobre adquisiciones de defensa: estructuración de problemas multicriterio con el Proceso de Análisis Jerárquico (AHP)

Abstract: The procurement of products, systems and their defense components presents characteristics that make operational research particularly useful for solving problems about choosing materials for the Armed Forces, including the multi-criteria decision support theory. The problem about defense procurement fits this methodology, as it involves the use of decision criteria for the most satisfactory choice among a finite set of defense products, since the high technology and the large resources required for the production of these systems make the defense market restricted to a few developers and manufacturers. A multi-criteria method widely used in the defense industry is the Analytic Hierarchy Process (AHP), mainly due to its simplicity of validating expert's evaluations. The AHP calculation equations are described here and can be implemented in different pieces of software, including Excel, R, and Python, among others. A simulated application presented how data were collected and the sequence of AHP calculations for a problem about choosing three aircraft, evaluated under six criteria, indicating an expert's order of preference.

Keywords: defense procurement; support for multi-criteria decision; AHP.

Resumen: La adquisición de productos, sistemas y sus componentes de defensa presenta características que hacen que la investigación operativa sea especialmente útil para los problemas en la selección de material para las Fuerzas Armadas, incluyendo la teoría de ayuda a la decisión multicriterio. El problema de las adquisiciones de defensa se ajusta a esta metodología, ya que implica el uso de criterios de decisión para una selección más adecuada entre un conjunto finito de productos de defensa, puesto que la alta tecnología y los grandes recursos necesarios para la fabricación de estos sistemas hacen que el mercado de la industria de defensa esté restringido a algunos pocos desarrolladores y proveedores. Un método multicriterio ampliamente utilizado en el sector de defensa es el Proceso de Análisis Jerárquico (AHP), principalmente debido a su simplicidad de validar las evaluaciones de los especialistas. Aquí se detallan las ecuaciones para el cálculo del AHP, pudiéndose implementar en diferentes softwares, incluyendo Excel, R y Python, entre otros. La aplicación simulada mostró la forma de recolección de datos y la secuencia de cálculos del AHP para un problema de selección de tres aeronaves, evaluadas bajo seis criterios, indicando el orden de preferencia de acuerdo con un especialista.

Palabras clave: adquisición de defensa; ayuda a la decisión multicriterio; AHP.

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1 INTRODUCTION

The procurement of products, systems and their defense components involves complex and multidimensional analysis, in which several technical factors need to be evaluated, such as the adequacy to the gap in defense arsenal capabilities (CORRÊA, 2020; VIANELLO; MARTINS, 2019); the life cycle costs of possible solutions(SOUSA et al., 2021), and the maintenance and modernization capacity of the country's systems, and others (NEGRETE; SOUSA, 2018; PACHECO; PEDONE, 2016). The presence of these different evaluation criteria and a finite set of possible solutions to meet the Armed Forces' needs suggest the use of specific decision support methodologies, capable of offering a technical and satisfactory result.

In general, the process of choosing products, systems and their defense components that suit the Armed Forces' needs can be assisted by operational research methods, which are intended to support decision-making. Mathematical models produce results that give more objectivity to the process, providing a certain isolation in relation to other aspects which also are taking into consideration in decision-making, such as those of a political nature (KRUGER; VERHOEF; PREISER, 2019).

In a certain sense, it is possible to consider that the defense industry portfolio is limited with regard to the options available in the market for off-the-shelf procurement, or even for the generation of a research and development (R&D) project. This industrial sector increasingly depends on high technology, and, then, in order to remain state-of-the-art, there is need of trained human resources and financial amounts, which are restricted to a few developing and manufacturing countries worldwide (ABREU, 2015).Therefore, to deal with this finite set of possible solutions to the problem, operational research provides methodologies generically designated as Multi-criteria Decision Aid (MCDA) methods (ALMEIDA, 2013).

The MCDA methods, instead of seeking an optimal solution to the problem, seek a satisfactory one, because a finite set of possible solutions hardly includes that which presents the best performance in all decision criteria. If a solution with these characteristics is present in the set of possible solutions, there would be no need to model the problem, as the best answer would already be evident to decision makers. In general, the possible alternatives to the problem present irregular performances across criteria, sometimes performing as the best, sometimes as the worst, sometimes as intermediate in relation to the other alternatives. Under these conditions, there is no an optimal solution, but alternatives that are more satisfactory or more acceptable than others (ALMEIDA et al., 2019).

This article deals with the structuring of the essential elements of MCDA methods in problems about the procurement of defense products, their systems or system components. A practical application with the Analytic Hierarchy Process (AHP) is also presented, mainly because it is widely explored in problems about defense procurement (BELL; HOLODNIY; PAVLIN, 2016; BROWNE, 2018; CHO et al., 2022; GAVIÃO et al., 2020; GAVIÃO; DUTRA; KOSTIN, 2021; STERN; GROGAN, 2022).

The AHP presents a simple and intuitive logic, since it explores a specific scale for evaluations and presents an instrument for result validation, giving credibility and confidence to the process. This method was proposed by Thomas Saaty, in the early 1970s, and is widely supported in the scientific literature, with applications in the most varied areas of knowledge (SAATY, 1972; YU et al., 2021).

2 STRUCTURING THE MCDA MODELING

Modeling problems with MCDA methods involves three essential tasks: selecting alternatives to the problem, choosing the decision criteria, and evaluating the performance of each alternative in relation to the chosen criteria. These three elements configure the so-called problem decision matrix. Subsequently, this decision matrix needs to be submitted to some mathematical model to produce the expected result, which may be, for example, the order of preference of the finite set of solutions or the classification of solutions in clusters, among others (POMEROL; BARBA-ROMERO, 2012).

In defense procurement, these essential elements need to be surveyed and evaluated in line with the scenarios of employment of the Armed Forces (KRESS; MORGAN, 2018). Scenario prospecting is not analyzed in this article, despite being an important part of the process of choosing defense products, systems and components. The portfolio of defense products available to the Armed Forces should enable them to be employed in short, medium, and long term scenarios. Indeed, it is fair to assume that the contexts impact the experts' evaluations of the decision matrix, and it is possible that the same criterion or alternative will have different results depending on the situation presented.

2.1 Selection of problem alternatives

A finite set of alternatives capable of solving the problem has to be considered. In practice, these alternatives are defense products, their systems or components that were planned for acquisition or even R&D projects for construction in shipyards, factories and facilities of consortia established for this purpose. In the classic modeling system, it is assumed that the alternatives are different and that they comprise the entire set of decisions, with no possibility of choosing a mixed solution, composed of the union of alternatives or a portion of them. If the decision maker introduces a new alternative, then, in principle, the analysis process should be repeated with the newly formed set of choices (POMEROL; BARBA-ROMERO, 2012).

The set of alternatives should not be trivial, such as a set of only two alternatives where one clearly performs better. On the other hand, the set of alternatives should have a manageable size, avoiding the preliminary choice of dozens or hundreds of possible alternatives. One way to reduce the size of the set of alternatives is to eliminate those that are similar or that are clearly dominated by others. This dominance is characterized by better performance of one alternative in relation to the other in all criteria. Therefore, in this case, it makes no sense to proceed with the modeling and analysis of some less qualified alternative, which should be excluded from the initial set.

The alternatives considered for analysis have to be feasible as well, in the sense that they are viable from a financial and logistical point of view. It is necessary for the country, its defense industry and its Armed Forces to be able to acquire, operate, maintain, and dispose of the defense product at the end of its life cycle. This requires managerial capacity to structure the integrated logistics of new defense products and society's acquiescence in supporting a defense budget compatible with the life cycle costs of the new means. There are defense products that operate for decades, like some ships and submarines, which require massive resources to maintain them active and modernized for a long period, following the state of the art of other systems. These aspects need to be considered during the survey of the set of alternatives to the problem.

2.2 Choice of decision criteria

Criteria are special problem attributes or characteristics that the decision maker prefers in their choice. In managerial problems, it is common to use criteria related to purchase price, quality, material resistance, product appearance, and maintenance economy, among others. Some criteria are essentially quantitative, and are measured by numerical units and scales (weight, dimensions, and costs), while others are qualitative and measured by preference ordinal scales, which take into account the evaluator's perception rather than results or performances (quality, appearance, and risk).

According to Roy (1985), a criteria family is considered coherent if it satisfies three requirements:

- Integrity: none of the relevant attributes to discriminate the alternatives was forgotten. The full use of the most relevant criteria for searching a solution to the problem would not allow, in theory, the existence of pairs of alternatives having the same score, in such a way that the decision maker can state, without hesitation, the preference ratio between them.
- Consistency: the decision maker's final preferences have to be consistent with the preferences in each criterion. This means that if "a" and "b" are two alternatives between which the decision maker is indifferent, reaching, for example, the same score for each criterion, then the improvement of "a" in one criterion and/or the degradation of "b" in another criterion implies, in fact, that "a" should be preferable to "b" for the decision maker.
- Non-redundancy: two criteria must not be similar in the sense of evaluating the same performance variables. The existence of two or more criteria with this characteristic unbalances decision-making, as a common attribute will have been considered more than once for the result. Special attention must be given to the use of indices for criteria, as they are generally composed of variables that may be common to other criteria. A coherent criteria family that satisfies the integrity

and consistency requirements is not redundant if the removal of a single criterion compromises the remaining set to just these requirements.

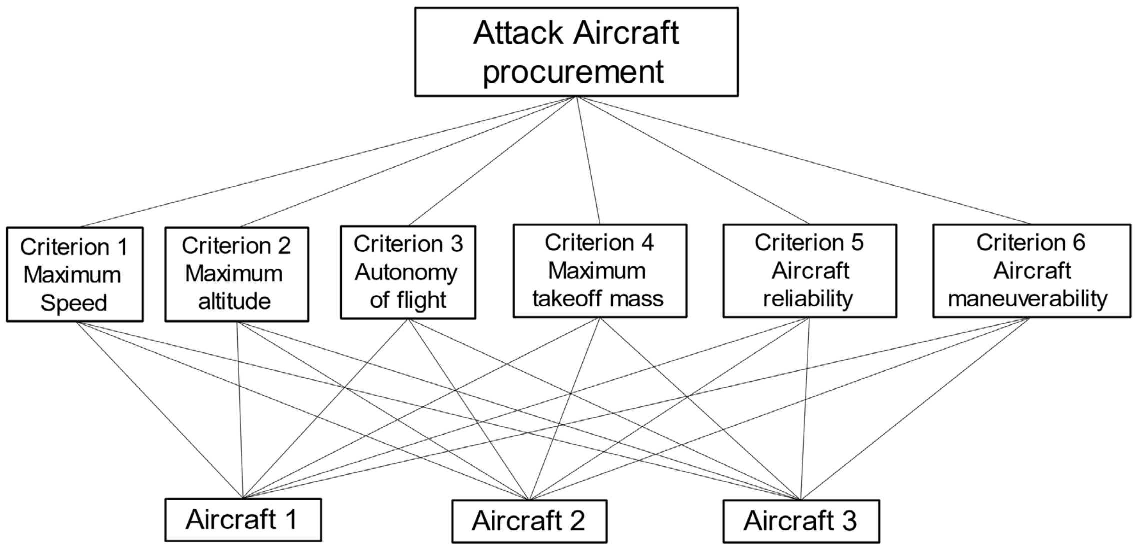
When modeling the problem, Pomerol and Barba-Romero (2012, p. 313) warn that integrity should be the priority requirement when choosing the criteria, as a rational decision maker, experienced and knowing about the problem, tends to select the criteria that should effectively be considered for choosing the most satisfactory alternative. Integrity has a positive impact on the consistency and non-redundancy requirements of the criteria family. Those authors also recommend that the MCDA modeling should avoid a high number of criteria (more than seven), but if this is absolutely necessary, a hierarchical structure should be built at different criteria and sub-criteria levels This comment reinforces the indication of the AHP method, which uses this type of structure to search for the most satisfactory solution.

In problems about procurement of defense products, some criteria are usually explored. Operational performance, for example, is critical to success on the battlefield, whatever the operating environment. For a weapon system, fire accuracy and rate (number of shots per time) are relevant requirements. Another set of important criteria refers to logistics, expressed through reliability and maintainability characteristics. Reliability affects system readiness. The more reliable your components are, the less frequent the breakdowns and the more educed the need to stop for repair services, in addition to reduction in spare parts costs. Such a criterion is quantitative and is usually measured by the mean time between failures (MTBF). Maintainability is an attribute that portrays the ease (or difficulty) of maintaining the system. A modular component that allows maintenance with the help of a plug-and-play system is more sustainable than one that is interconnected by wires, or one that requires the disassembly of system components in order to reach the damaged component. Similar to reliability, the maintenance structure of an item can be measured with the help of the repair and maintenance service time (KRESS; MORGAN, 2018).

Finally, it is also worth highlighting the criteria related to life cycle costs and the risks inherent to R&D projects for a new system. The costs related to future expenditures on the operation and maintenance of the systems are more uncertain than the R&D costs for an item in an advanced stage of development, or the purchase price of an off-the-shelf item. There are pessimistic estimates that operation and support costs can represent more than 80% amount needed for the entire life cycle of a defense product (GAVIÃO et al., 2018). The risk may be related to delays in development and production schedules, or even to rising planned costs, exceeding the desired budget (KRESS; MORGAN, 2018).

In summary, items 2.1 and 2.2 show the essential elements for modeling an MCDA problem and, simultaneously, for building the hierarchical structure for the AHP use. Figure 1 illustrates the hierarchical tree used by Ardil (2021) to choose an attack aircraft. Despite the author's concern about evaluating essentially operational aspects, this structure is sufficient to demonstrate the AHP methodology use, even without applying logistics, reliability, and maintainability criteria.

Figure 1 – Hierarchical structure of a problem



Source: adapted from Ardil (2021)

2.3 Selection of experts

Defense procurement involves a significant portion of government, defense industry, and academic-scientific sectors (GAVIÃO et al., 2020). These sectors bring together the parties interested in the procurement process and are called stakeholders. Because they represent different interests, points of view, agendas and goals, stakeholders are potential experts to be consulted for data collection (SUN et al., 2008). In other words, combatants (the future users of the item) can focus on the effectiveness of the system and its compatibility with the platforms currently used by the Armed Forces. System developers may take a broader view and will be concerned about issues of force structure and other strategic considerations. Technical experts will focus on the scientific aspects of engineering and, in particular, potential technological challenges that may affect the risk criterion. Finally, budget managers will naturally pay a greater attention to programmatic aspects associated with the financial capacity of system development, production, operation, and maintenance. In this context, it is interesting to gather evaluations that cover the stakeholders' areas of knowledge, so that the AHP result reflects a balanced solution in relation to different points of view and interests.

2.4 Performance evaluation

The evaluation of the alternatives in each criterion of Figure 1 allows configuring the problem decision matrix. Each line of the matrix (Figure 2) expresses the performance (*a*) of the (*m*) alternatives "A" in relation to the (*n*) criteria considered "C." Each column presents the evaluations of all the alternatives adopted by the decision maker, relative to a specific criterion.

Figure 2 – Decision matrix

$$\begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_n \end{array} \\ \begin{pmatrix} a_{11} & \dots & a_{1n} \\ \dots & \dots & \dots \\ a_{m1} & \dots & a_{mn} \end{pmatrix} \end{array}$$

Source: Adapted from Pomerol and Barba-Romero (2012, p. 19)

In the particular case of the AHP, the decision matrices are different from Figure 2, as they gather the pairwise evaluation in relation to each variable of the immediately higher hierarchical level. For the problem about choosing an attack aircraft (Figure 1) with the AHP method, for example, seven evaluation matrices per expert would be necessary: one 6x6 (six rows and six columns) matrix for the pairwise evaluation between criteria, and six 3x3 matrices (three rows and three columns) for aircraft evaluations in relation to each criterion, as shown in Figure 3.

Figure 3 – AHP matrices

Objective

$$\begin{array}{c|cccccc} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \\ \hline C_1 & 1 & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ C_2 & c_{21} & 1 & c_{23} & c_{24} & c_{25} & c_{26} \\ C_3 & c_{31} & c_{32} & 1 & c_{34} & c_{35} & c_{36} \\ C_4 & c_{41} & c_{42} & c_{43} & 1 & c_{45} & c_{46} \\ C_5 & c_{51} & c_{52} & c_{53} & c_{54} & 1 & c_{56} \\ C_6 & c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & 1 \end{array}$$

Criterion 1

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Criterion 2

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Criterion 3

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Criterion 4

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Criterion 5

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Criterion 6

$$\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & a_{12} & a_{13} \\ A_2 & a_{21} & 1 & a_{23} \\ A_3 & a_{31} & a_{32} & 1 \end{array}$$

Source: Elaborated by authors, 2023

For this evaluation, a nine-point scale proposed by Saaty (1977), described in Chart 1, is used.

Chart 1 – Saaty's evaluation scale

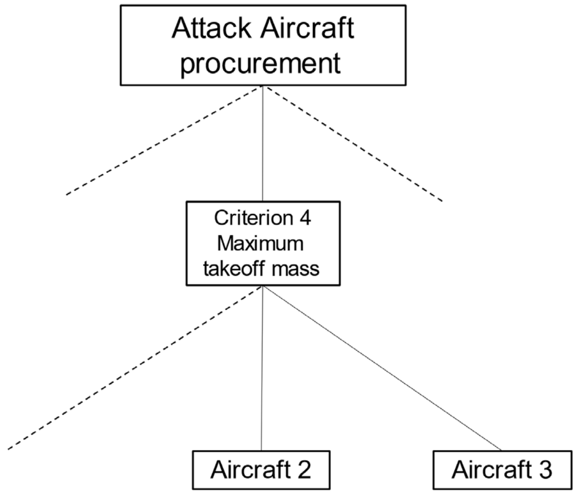
Intensity of pairwise ratio	Scale score	Description of pairwise evaluations
Equivalent	1	Two criteria are equivalent with respect to the objective Two alternatives are equivalent with respect to a criterion
Moderate	3	One criterion is slightly more important than another with respect to the objective One alternative is slightly more important than another with respect to a criterion
Strong	5	One criterion is more important than another with respect to the objective One alternative is more important than another with respect to a criterion
Very strong	7	One criterion is much more important than another with respect to the objective One alternative is much more important than another with respect to a criterion
Extreme	9	One criterion is extremely more important than another with respect to the objective One alternative is extremely more important than another with respect to a criterion
Intermediate	2, 4, 6, 8	Ratio scores by the nine-point scale intermediate values

Source: Adapted from Saaty (1977, p. 246)

The internal elements of the AHP matrices (Figure 3) indicate the values corresponding to the intensity of the ratio between two criteria or two alternatives. As in the comparison between aircraft 2 and aircraft 3, regarding criterion 4 (Figure 4), it is possible to assume that the expert considers the first alternative more important than the second. Therefore, element a_{23} of the evaluation matrix, in relation to criterion 4, would receive value 7, as this value is equivalent to the *much more important* expression in Saaty's scale. By reciprocity, element a_{32} would receive value 1/7 in the same matrix. In this way, the other matrices are assembled according to the expert's evaluations. The main diagonal of matrices is always composed of values 1, as each variable is equivalent to itself; thus, aircraft 3, for example, is equivalent to aircraft 3 in relation to any criterion.

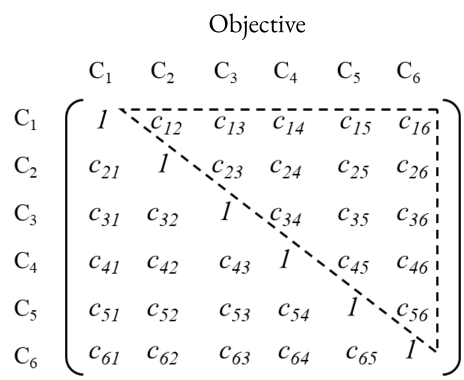
Generalizing the evaluations for n variables, the decision matrix should be composed of elements n^2, due to the structure of n rows and n columns. Regarding these elements, n of the main diagonal have to assume the value 1, as each variable is equivalent to itself. There would then be elements n^2-n to be filled in. However, half of this remainder is also obligatorily the inverse value of its reciprocal element (for example, the reciprocal element of a_{15} is the element a_{51}). In summary, it is only necessary to fill in the elements included in the dotted triangle in Figure 5 for each matrix.

Figure 4 – Extract of the hierarchical structure



Source: Elaborated by authors, 2023

Figure 5 – Evaluations required in an AHP matrix



Source: Elaborated by authors, 2023

3 AHP CALCULATION METHODOLOGY

AHP calculations originate from linear algebra, as it explores a database in matrix form and uses the concepts of eigenvector and eigenvalue of matrices. Equations (1) to (6), in the appendix of this article, are used for these calculations, as detailed in Liu and Lin (2016). The calculations in this research were performed on Excel software, but others are usually used, such as R and Python, including AHP-specific libraries (CHO, 2019; FANG; PARTOVI, 2021).

The logical consistency of the evaluations is also measured, with up to 10% of inconsistency being admitted by the evaluator (LANE; VERDINI, 1989). For example, an expert judges that A is more important than B and B is more important than C. By logic, it is not accepTable that A is equivalent to or less important than C. For three variables, this logical inconsistency is noticeable, but for a greater number of pairwise comparisons, it is common for the evaluator to make this type of mistake.

Depending on the hierarchical structure of the problem, an evaluator can devote considerable effort and time to carry out the evaluations, which can increase the probability of logical inconsistency of their judgments. This problem occurs in situations that demand flat hierarchical structures, that is, characterized by a significant number of variables at each level. To mitigate this AHP vulnerability, the scientific literature records some techniques to simplify data collection, reducing the effort/time spent by the expert and ensuring the process logical consistency. In the illustration of the problem about the attack aircraft procurement, with the 6-criteria structure (Figure 1), the simplified model proposed by Gavião, Lima and Garcia (2021) would require the evaluator to make only five judgments for this level, instead of the 15 foreseen in the original AHP model. This article does not delve into these procedures for simplifying AHP data collection, but it is possible to find different solutions in the literature (ÁGOSTON; CSATÓ, 2022; ALRASHEEDI, 2019; GAVIÃO; LIMA; GARCIA, 2021; LEAL, 2020; ZHOU et al., 2018).

4 APPLICATION AND RESULTS

To illustrate the AHP application to the problem in Figure 1, a database created by an expert was simulated, according to the pairwise evaluations in Figure 6, which are equivalent to the matrices in Equation (1) format. Thus, the expert should complete seven matrices of pairwise evaluations.

Figure 6 – Data collection by expert

$$
\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array}
\begin{array}{c}
\begin{array}{cccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 \end{array} \\
\begin{bmatrix}
1 & 3 & 2 & 1/4 & 1/3 & 6 \\
1/3 & 1 & 1/2 & 1/6 & 1/5 & 4 \\
1/2 & 2 & 1 & 1/5 & 1/4 & 5 \\
4 & 6 & 5 & 1 & 2 & 9 \\
3 & 5 & 4 & 1/2 & 1 & 8 \\
1/6 & 1/4 & 1/5 & 1/9 & 1/8 & 1
\end{bmatrix}
\end{array}
$$

Criterion 1

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 3 & 2 \\ A_2 & 1/3 & 1 & 1/2 \\ A_3 & 1/2 & 2 & 1 \end{array}
$$

Criterion 2

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 1/3 & 1 \\ A_2 & 3 & 1 & 3 \\ A_3 & 1 & 1/3 & 1 \end{array}
$$

Criterion 3

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 4 & 1/2 \\ A_2 & 1/4 & 1 & 1/5 \\ A_3 & 2 & 5 & 1 \end{array}
$$

Criterion 4

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 1/2 & 2 \\ A_2 & 2 & 1 & 3 \\ A_3 & 1/2 & 1/3 & 1 \end{array}
$$

Criterion 5

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 1/3 & 4 \\ A_2 & 3 & 1 & 6 \\ A_3 & 1/4 & 1/6 & 1 \end{array}
$$

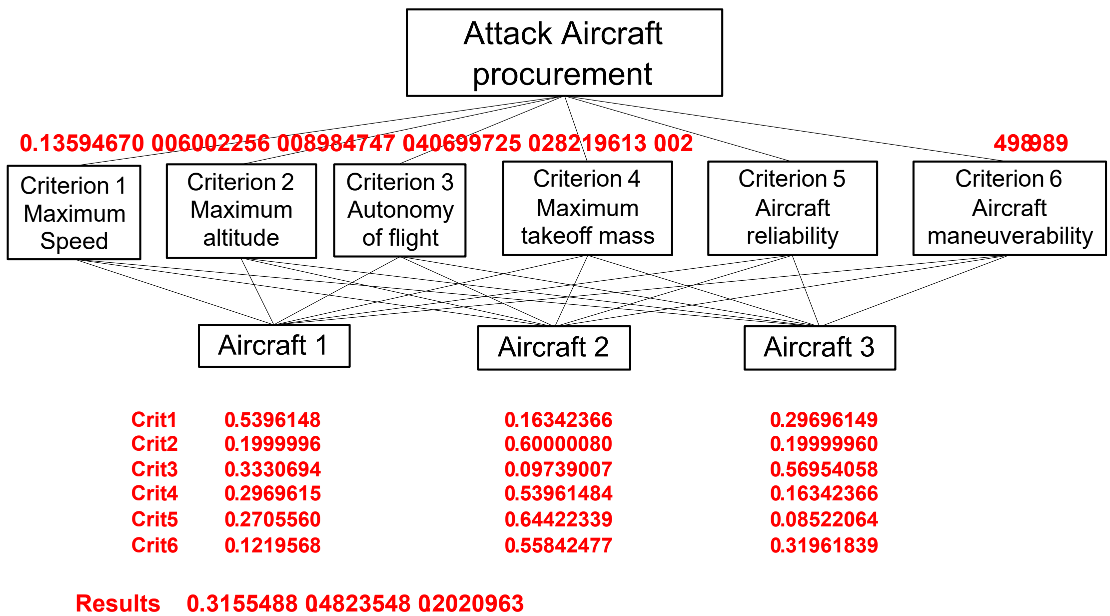
Criterion 6

$$
\begin{array}{c|ccc} & A_1 & A_2 & A_3 \\ \hline A_1 & 1 & 1/4 & 1/3 \\ A_2 & 4 & 1 & 2 \\ A_3 & 3 & 1/2 & 1 \end{array}
$$

Source: Elaborated by authors, 2023

In the sequence of calculations, Equation (2) allows obtaining the weights of the variables of each matrix. Therefore, the matrix of pairwise evaluations of the six criteria produces their weights and each aircraft evaluation matrix produces the weights in relation to each criterion, as shown in Figure 7. By way of illustration, the criteria evaluation matrix indicated that the expert's preference as to criterion 4 had the highest weight among the others (40.69%), while criterion 6 was considered the least important for the choice of aircraft (2.49%). Below the aircraft level, Figure 7 shows their weights in relation to each criterion.

Figure 7 – Weights of each evaluation matrix



Source: Elaborated by authors

Then, Equations (3) to (6), in the appendix of this article, are applied to generate the CR of each matrix, allowing validation of the expert's preferences or indication of the need for a new round of evaluations. Table 1 presents the results of these calculation steps, and it is possible to identify that they are less than 10%, which validates the consistency of the expert's evaluations.

Table 1 – CR calculation sequence

Matrix	Criteria	Aircraft Criterion 1	Aircraft Criterion 2	Aircraft Criterion 3	Aircraft Criterion 4	Aircraft Criterion 5	Aircraft Criterion 6
λ max	6.2544	3.0092	3	3.0246	3.0092	3.0536	3.0183
CI	0.0509	0.0046	$5.56.\ 10^{-12}$	0.0123	0.0046	0.0268	0.0091
RI	1.24	0.58	0.58	0.58	0.58	0.58	0.58
CR	0.0412	0.0079	$9.58.\ 10^{-12}$	0.0212	0.0079	0.0462	0.0158

Source: Elaborated by authors, 2023

The results of final preferences as to each aircraft correspond to a weighted sum of the weights obtained at the different levels. For aircraft 1, for example, the result is equivalent to the sum of the portions (0.5396148 x 0.13594670) referring to weighting of criterion 1 (0.1999996 x 0.06002256), to criterion 2, (0.3330694 x 0, 08984747), to criterion 3, and so on, until criterion 6. For this reason, Table 2 presents the final preference as to the aircraft, which reflects the consulted expert's judgments. For him, aircraft 2 should be chosen, as it obtained the highest result, 48.23%.

Table 2 – Final weights

Alternatives	Final weight	Order of preference
Aircraft 1	0.3155488	2
Aircraft 2	0.4823548	1
Aircraft 3	0.2020963	3

Source: Elaborated by authors, 2023

5 CONCLUSION

This article aimed to address decision support in defense procurement problems, showing how to structure it through the multi-criteria method, specifically presenting the AHP method. The problem about defense procurement fits the multi-criteria decision theory, as the attributes of products, systems and their components can be selected according to decision criteria and, in general, the set of possible solutions to the problem is finite (ARDIL, 2021). The high technology and the major resources required for the production of these systems make the defense market restricted to a few manufacturers. These characteristics allow adjusting the problem to the multi-criteria decision support methods available in operational research.

The AHP has been frequently used in defense procurement problems, mainly due to its simplicity, logic, and the possibility of validating the experts' evaluations (GAVIÃO; DUTRA; KOSTIN, 2021). The use of a scale of perceptions to make a variable pairwise comparison facilitates the evaluators' judgment, as it avoids the need to use performance measures that are often non-existent or unfeasible to experts. In addition, the evaluators' logical consistency can be easily verified with the help of calculations from linear algebra, indicating whether the judgments are within an acceptable range or whether they need to be redone or even discarded. The AHP calculation equations can be implemented in different pieces of software, including Excel, R, and Python, among others (FRANEK; KRESTA, 2014; LIU; LIN, 2016).

This article brought a simulated application in order to show how data collection and AHP calculations should occur. The problem showed the evaluations of a single expert, but it is important – and desirable – that other stakeholders participate in the process. Thus, it is possible to obtain different points of view, resulting from personal or interesting sectoral experiences. Results from different experts can, for example, be aggregated by arithmetic means, indicating a general idea of preferences. In the model explored here, three aircraft were evaluated under six criteria, indicating the order of choice of the simulated expert.

APENDIX

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \quad (1)$$

A: matrix of pairwise evaluations of one expert
aij: pairwise evaluation value corresponding to the Saaty's scale
n: number of criteria/alternatives

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}} \quad (2)$$

wi: matrix eigenvector (weights of the criteria matrix or of alternatives)
i: matrix row indicator
j: *i*: matrix column indicator
Σ: sum
Π: product

$$A^s = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1' \\ w_2' \\ \vdots \\ w_n' \end{bmatrix} \quad (3)$$

As: product matrix of evaluations and eigenvector (*w*)

$$\lambda_{\max} = (1/n)\times(w_1'/w_1 + w_2'/w_2 \cdots + w_n'/w_n) \quad (4)$$

λmax: maximum eigenvalue of the reciprocal matrix

$$IC = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

CI: Consistency Index (Table 1)

$$RC = \frac{IC}{IR} \quad 6.$$

RC: Consistency Ratio (evaluator logic)
RI: Random Index, calculated based on Table 1

Table A1 – AHP Random Index Values

Number of matrix variables	1	2	3	4	5	6	7	8	9
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: Adapted from Liu and Lin (2016)

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