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Decision Support Model in the Strategic Management of the Portuguese Air Force Alpha Jet Fleet

António Abreu[1]
Rúben Piedade[2]

[1]*ISEL- Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Portugal Uninova Institute, Centre of Technology and Systems, Portugal*
Email: ajfa@dem.isel.ipl.pt Tel (+351) 218 317 000
[2]*ISEL- Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Portugal*
Email: rubenmspiedade@gmail.com Tel (+351) 218 317 000


(Corresponding Author)

Abstract

Based on exploration criteria, the Phase-Out of an asset comprises the operation end of that asset. However, given the high cost of some assets, decision makers are faced by the dilemma of developing policies that allow them to extend the exploration period or find alternative scenarios for their use. With the aim of creating value, in terms of maintenance planning, this paper proposes a decision support model based on a multi-criteria approach, with the objective of selecting the best alternative. The proposed model analyzes the exploration extension scenario of an asset, identifying the actions necessary to guarantee its operational availability in relation to other alternative scenarios. The model developed was applied to the Alpha Jet fleet of the Portuguese Air Force, which is in Phase-Out period and will cease to operate in January 2018, and there is no definite decision for its use.

Keywords: Asset management, Operational availability, Maintenance planning, Risk analysis, Multiple criteria decision making.

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Contents

1. Introduction

The maintenance function, has long since ceased to be considered a "necessary evil" and a Costs Center, to take a leading position for business success, with features that generate profits for organizations in the so-called First World countries.

It is in these terms that the maintenance has gained a greater importance in the organizations, having as main focus the profitability of the organization, through the increase of the maintenance effectiveness, more properly the increase of availability, increase of reliability, increase of quality, increase of personal safety and reduced downtime (Muchiri *et al.*, 2011; Arslankaya and Atay, 2015). In terms of maintenance planning, reliability is a very efficient variable for analyzing the likelihood of the adequacy of the functioning of components and systems, guaranteeing high safety standards (Kinnison, 2012) and thus optimizing the management of aircraft maintenance.

Reliability Centered Maintenance (RCM) becomes an ideal, efficient, and cost-effective planning methodology to help close the resource gap. In the aeronautical industry, the methodology used in the development of maintenance programs with the objective of maximizing the reliability of the assets is called MSG-3 (*Maintenance Steering Group-3*), this methodology incorporates the principles of RCM, could these two methodologies be seen as similar (Ahmadi *et al.*, 2010). The two methodologies use asset risk analysis tools, identifying those most susceptible to failure, in particular the MSI tool (Maintenance Significant Items) in MSG-3, and the FMEA tool (*Failure Mode and Effects Analysis*), in the RCM. However, an assessment at the strategic level of an organization, in terms of aircraft operation, will require efficient and multi-criteria decision making, so the adoption of Multicriteria Decision Analysis Methods is justified by the purpose of providing a complex decision of greater transparency and clarity (Ishizaka and Nemery, 2013) so that it can be taken closer to the ideal.

In this context, exploring the different possibilities of value creation for an aircraft fleet, based on different criteria, this paper proposes the development of a decision support model using a multicriteria approach to evaluate the extent of the operation of the Alpha Jet fleet of the Portuguese Air Force, however, the application of the proposed model is not restricted to the aeronautical maintenance industry, allowing a strategic evaluation and management according to the condition of the assets, in another industry.

2. Maintenance Management

Ensuring the maximum operational availability of an asset is one of the challenges that any maintenance manager faces in his day-to-day life. Availability is the ability of a good to perform its required function at a given time or during a given time interval under certain conditions (Tont *et al.*, 2008). As shown in Figure 1, the operational availability of goods depends on two variables, intrinsic availability, which is imposed by the reliability (probability of non-failure) and maintainability (ease of repair) of the good or system, and the operating variable, the maintenance organization that can maximize operational availability with its maintenance policy.

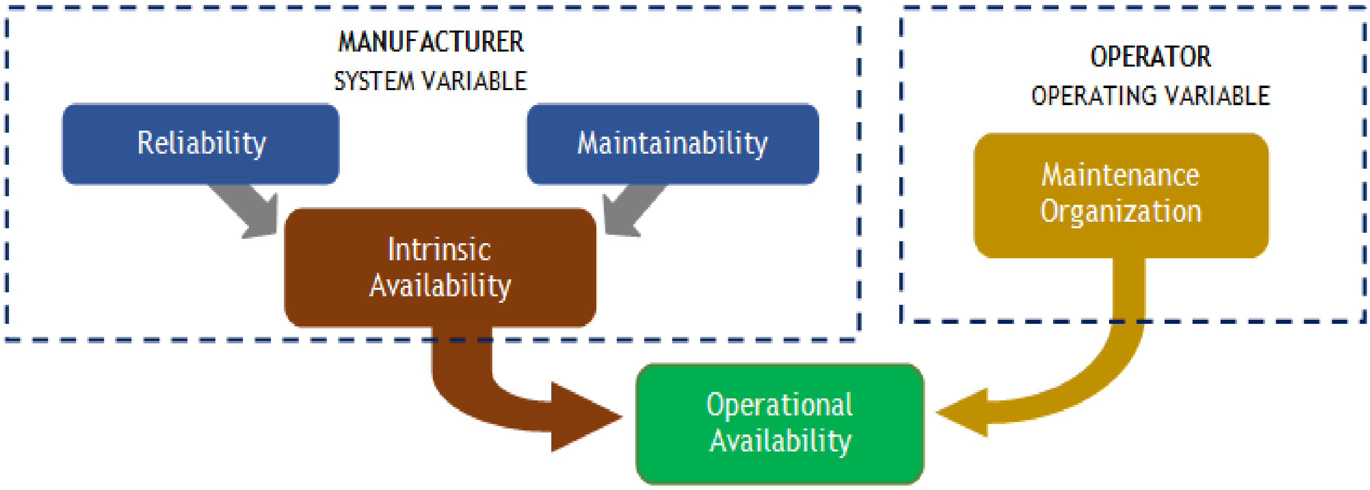

Figure-1. Factors influencing operational availability)

Source: adapted from Bussel and Zaaijer (2001)

Thus, in the 1970s the RCM methodology was developed, it is a management process that seeks to define the best operational maintenance policies for each asset, based on the preservation of the function of the assets, avoiding or reducing the consequences of the failures (Nowlan and Heap, 1978) and to maximize the reliability and security of goods (Ahmadi *et al.*, 2010).

The implementation of the RCM is based on the response to seven key questions, using as a guide the standards IEC 60300-3-11, SAE-JA1011, SAE-JA1012 (Emovon *et al.*, 2016): What are the functions and performance standards of the equipment, in the context of operation? In what ways is an equipment incapable of carrying out its functions? What are the causes of each functional failure? What are the effects of each functional failure? What is the importance of each failure (criticality and costs)? What can be done to predict or prevent each failure? What should be done if the appropriate preventive task or procedure is not identified?

In order to address these key issues, the FMEA is normally used (Moubray, 1997).

FMEA is a structured method that allows the visualization and evaluation of all cause-and-effect relationships among the various components of a system and, as a result, allows the identification of failures and malfunctions in a system by studying its failure modes and effects on the various system components, as well as to determine effects mitigation tasks (Ahmed *et al.*, 2007). The method application stands out in the areas of chemistry, aerospace, military, automotive, electronics, mechanics and semiconductors (Maheswaran and Loganathan, 2013). The FMEA has a qualitative and quantitative objective (Pillay and Wang, 2003). Qualitative because it predicts the probability of certain types of system failures and quantitative because it aims to identify the components whose failures could lead to accident, injury and loss of property. However, when applied in an isolated way there are some limitations, for example: the three risk factors: Failure Mode Severity, Failure Mode Occurrence Probability and Failure Mode Detection Probability are usually difficult to evaluate; the relative importance between the three risk factors is not taken into account; the RPN (Risk Priority Number) determination is questionable: It ignores the relative importance of the three risk factors; the assessment is imprecise; a low RPN value is obtained when, multiplying the three risk factors, two of the risk values have low values and the third value is high; the interdependence between various failure modes and effects is not taken into account (Emovon *et al.*, 2016); (Maheswaran and Loganathan, 2013).

However, the maintenance management process will only be effective if capable of responding in an integrated way to the three decision levels in an organization (Figure 2): Strategic, Tactical and Operational.

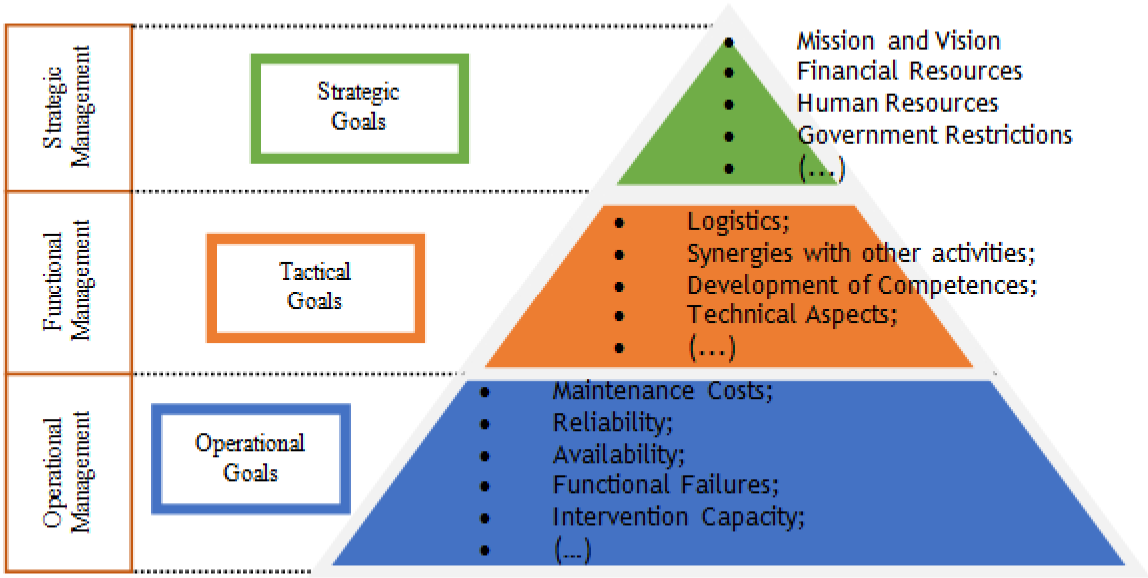

Figure-2. Organizational Levels of Maintenance by Goals
Source: adapted from Horenbeek and Pintelon (2014)

3. Maintenance Planning Model – MSD-GECA

In order to mitigate some of the limitations of the FMEA and develop a decision support model that allows to respond to the three levels of organizational decision, the MSD-GECA (Decision Support Model in the Strategic Management of Asset Condition) was developed, whose implementation goes through the use of the FMEA tool and the application of Multicriteria Decision Making (MCDM) Methods.

However, when applying the Ishikawa Diagram, as a risk identification tool that breaks down a problem into its possible causes, allied to the FMEA (Arvanitoyannis and Varzakas, 2009) it reveals a greater ease in the FMEA application and in the perception of the variants of a problem.

Based on the literature (Goossens and Basten, 2015) the AHP (*Analytic Hierarchy Process*) is the most appropriate multicriteria decision method for risk analysis through the definition and subjective quantification of risk factors, according to the overall goal. However, for greater effectiveness, validity and consistency in the evaluation and selection of the maintenance strategy, it is necessary to integrate AHP with TOPSIS (*The Technique for Order Preference by Similarity to the Ideal Solution*), allowing the hierarchization and selection of the best alternative according to various criteria, whether they are imprecise or ambiguous (Emovon, 2016); (Ioannis and Nikitas, 2013).

In this context, and although both methods allow the hierarchization of alternatives, the AHP will assign values to criteria, while the TOPSIS will select the maintenance plan (Emovon, 2016) thus allowing to raise the results at a strategic level.

The MSD-GECA model comprises the following steps (Figure 3):

I. Problem Identification: Identification of the object of study, through the Ishikawa Diagram, and definition of goal (s);
II. Risk Analysis: FMEA analysis of critical components and corrective actions;
III. Response Strategy: Definition and weighting of criteria and alternatives, through AHP analysis, hierarchization of alternatives and selection of the answer to the problem in question, through the TOPSIS analysis.

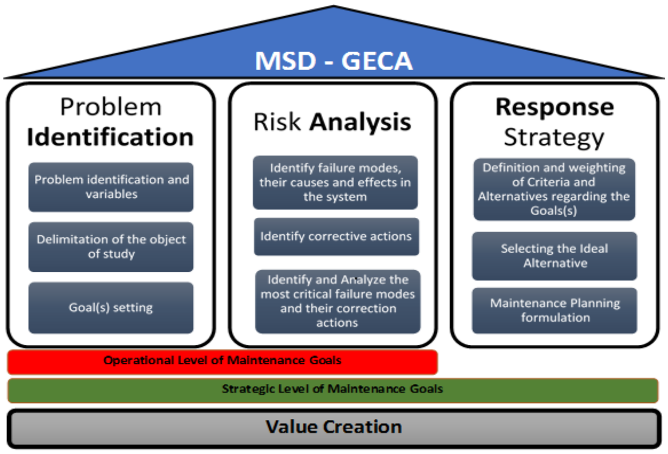

Figure-3. Pillars of the Maintenance Planning Model MSD-GECA

The maintenance planning model will be applied to an aircraft maintenance organization that is in the degradation period that will, in particular, allow an assessment of the most critical components of an aircraft fleet, in terms of available potential and corrective actions, in order to occur a more correct evaluation of the various alternatives that could give a more viable future to the fleet of aircraft, aiming at the continuity of operation.

4. Case Study - Application of the Proposed Model

The Case Study has the objective of applying the proposed maintenance planning model, more specifically to the Alpha Jet fleet, operated by the 103 Squadron of the Portuguese Air Force's. The specific plan developed, by the Portuguese Air Force, states that it should be exploited to the point of exhaustion, the Phase-Out, assuming that after January 2018, the fleet will no longer operate. However, there are no solutions proposed so far.

The Alpha Jet aircraft is a light fighter-bomber, whose function covers the offensive air support, surface support and advanced operational instruction areas. Due to these capabilities and to the mission, of generating airpower, of the Portuguese Air Force, the mission assigned to 103 Squadron is the one of instruction, forming combat pilots that could be assigned to the operational squadrons, 201 and 301, in which the F16 aircraft operates.

4.1. Application of the Model MSD-GECA

I. **Problem Identification:** Identification of fleet exploitation limitations.

Respecting the operational support plan, it was decided that the fleet will cease to operate in January 2018, leaving 5 operational aircraft with a remaining potential of 237 FH (Flight Hours). So far, no solution has been defined for the end of the fleet, however, exploring the solution of extending the operation of the fleet beyond 2018, Figure 4 illustrates the main sources and causes of the problem in question:

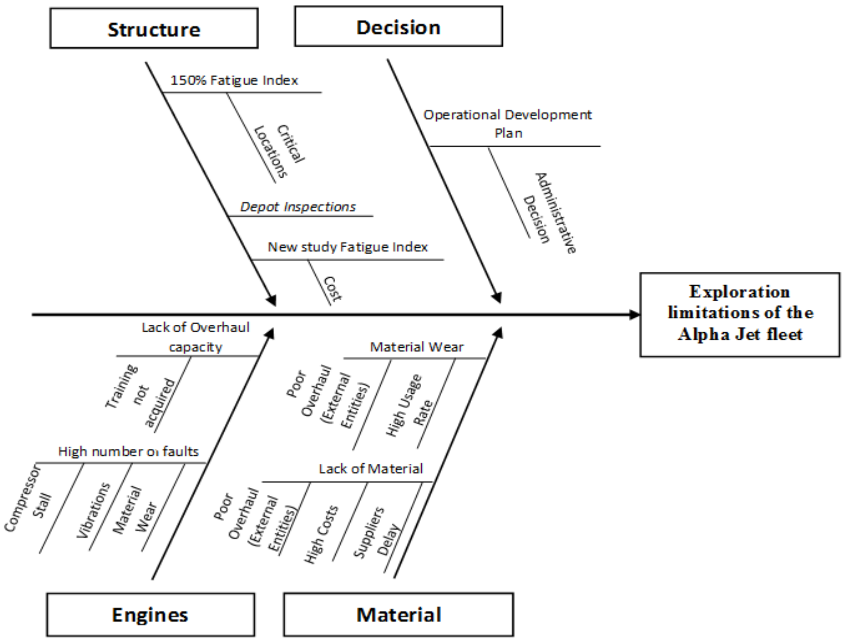

Figure-4. Ishikawa Diagram applied to the Case Study

The Phase-Out period has influenced the shortage of available material due to the high price and delay in material supply, affecting the aircraft availability and rotatable wear.

The structures or cells of the aircraft suffered a fatigue life extension in 2010, allowing them to operate up to a limit of 150% of Fatigue Index. This extension of life allows to control 27 critical locations, however the most limiting identified was the location WS 54/55, which corresponds to the bores of the wing-engaging sections in the fuselage. This more critical location allows an 1818 FH of operation (up to the 2nd half of 2020), from January 2018, up to the 150 % of Fatigue Index.

These 1818 FH (already included the 237 FH), are, however, limited by the engines that equip these aircraft, the Larzac 04 C20 engines, consisting of a modular structure of eight modules. This limitation is due to the lack of proper maintenance to these modules, due to the poor capacity of maintenance intervention in these modules, allowing only their replacement, which, consequently, has been degrading them, in terms of performance, reliability and material fatigue. The overhaul is no longer a solution due to the end of the maintenance contract with the engines manufacturer.

Taking into account critical engine systems, the MSD-GECA aims to evaluate alternatives that could allow the creation of value to the fleet, in the event of an extension of operation or not, considering the associated costs and the maintenance load to be performed.

II. Risk Analysis

II.1 FMEA

In order to quantify the risk that the potential failure modes may be causing to the fleet operation, two time samples were defined, for which the RPN will be calculated, the first time sample was defined between January 1st, 2010 and August 31st, 2014, of which 3778 FH were performed, 133 faults were registered, being the second time sample defined between January 1st, 2015 and December 31st, 2016, of which 1365 FH were performed, 54 faults were recorded. In the scope of the case study, it was necessary to adapt the scales of the index severity, occurrence and detectability. The Severity Index table was adapted to the level of maintenance depth and consequent downtime to perform this maintenance. The Occurrence Index table was defined by the failure rate (considered constant) in the two time samples. The Detection Index table was based on the immobilization times for the failure mode detection actions.

Finally, it should be noted that not all failure modes have the same criticality or urgency to be minimized or mitigated, in order to reduce the risk associated with each failure mode. Therefore, three ranges of values are defined by which the FMEA analysis will be guided (Table 1), in terms of which failure modes should be prioritized.

Table-1. RPN classification applied to the Case Study

Risk Priority Number Classification (RPN)		**Urgency of Corrective Actions**
High Risk	RPN ≥ 200	Immediate and urgent action
Moderate Risk	120 ≤ RPN < 200	Deferred and non-urgent action
Low Risk	1 ≤ RPN < 120	Non-urgent action

Table-2. Critical RPNs Summary and recommended actions

System	**Subsystem**	**Component**	**Function**	**Potential Failure Mode**	**Severity 10-14**	**Severity 15-16**	**Occurrence 10-14**	**Occurrence 15-16**	**Detectability 10-14**	**Detectability 15-16**	**RPN 10-14**	**RPN 15-16**	**Recommended Action**
3rd Module	4-Stage Rotor-Stator Set		Compress the air mass from the low pressure compressor, heat it and send it to the combustion chamber	Compressor Insufficiency Pressure	**10**	**10**	**4**	**7**	**6**	**7**	240	490	**Module Replacement or Overhaul**
				Compressor Insufficiency Rotation	**10**	**10**	**4**	**7**	**2**	**2**	80	140	
5th Module	1-Stage High Pressure Stator Set	Stator vanes	Direct the hot air mass flow from the combustion chamber	Wear of the vanes	**10**	**10**	**5**	**4**	**5**	**5**	250	200	**Vanes Replacement**
	1-Stage Rotor	Rotor blades	Transform kinetic energy of the air mass from the combustion chamber, moving the high pressure compressor	Wear of the blades	**10**	**10**	**6**	**5**	**6**	**7**	360	350	**Module Replacement or Overhaul**
	1-Stage Low Pressure Stator Set	Stator vanes	Direct the remaining hot air mass from the high pressure turbine to tap the blades of the low-pressure turbine, moving it	Fractures in the vanes	**10**	**10**	**6**	**2**	**5**	**5**	300	100	**Vanes Replacement**
				Abnormal engine operating vibrations	**8**	**8**	**3**	**5**	**6**	**7**	144	280	**Module Rotation**
6th Module	1-Stage Rotor	Rotor blades	Transform the kinetic energy of the remaining air mass of the high pressure turbine into mechanical energy	Wear of the blades	**10**	**10**	**1**	**2**	**5**	**6**	50	120	**Module Replacement or Overhaul**

Analyzing Table 2, the systems identified as being the most critical are the 3rd (High Pressure Compressor) and 5th (High Pressure Turbine) Modules, occasionally the 6th Modules (Low Pressure Turbine) which is one of the sources of vibrations in the engine. It should be noted that there is a severe increase and a slight decrease in the 3rd modules and in the 5th modules criticality, respectively, however, it can be seen that, to a large extent, the insufficiency of power and vibrations in the engines are originated in the 3rd modules and in the 5th modules, respectively. It verifies that the solution would be to replace or overhaul these three modules, however, there are no 3rd and 5th modules with sufficient potential or reliability for use, to minimize these failure modes, in addition to those installed in operational aircraft, that is, the recommended action of the 3rd and 5th modules replacement is not feasible. In the case of the 6th modules, the replacement solution is still feasible, as there are still some modules with some reliability and potential to be able to minimize the increasing risk of these failure modes. The overhaul solution of the 3rd and 5th modules is not feasible since 2009, with the end of the contract with the engine manufacturer, much due to the small annual budget allocated to the fleet. According to the above, and from the most critical failure modes, it can be concluded that the systems that most compromise the operational availability of the fleet are the 3rd and 5th modules, due to the lack of proper maintenance due, in large part, to the budget cuts.

So, the next step of the MSD-GECA has the main goal of selecting the maintenance strategy that will allow the creation of value to the fleet, that is, to identify and evaluate other alternatives that make it possible to extend the operationality of the fleet or minimize degradation, and eventual loss, of the national heritage, using a multicriteria approach that allows the evaluation of the variables obtained in FMEA analysis, at the operational level of maintenance, and other variables or criteria that allow to extend the evaluation of MSD-GECA to a strategic organizational level of maintenance.

III. Respond Strategy

III.1 AHP

The hierarchy defined, in Figure 5, is based on the experience of the researcher of the present scientific research work:

- Level I: Definition of the Global Goal of Value Creation;
- Level II: Criteria influencing the different decision scenarios (C1, C2, C3, C4, C5);
- Level III: Decision alternatives or scenarios (AP, AM, AV, AR).

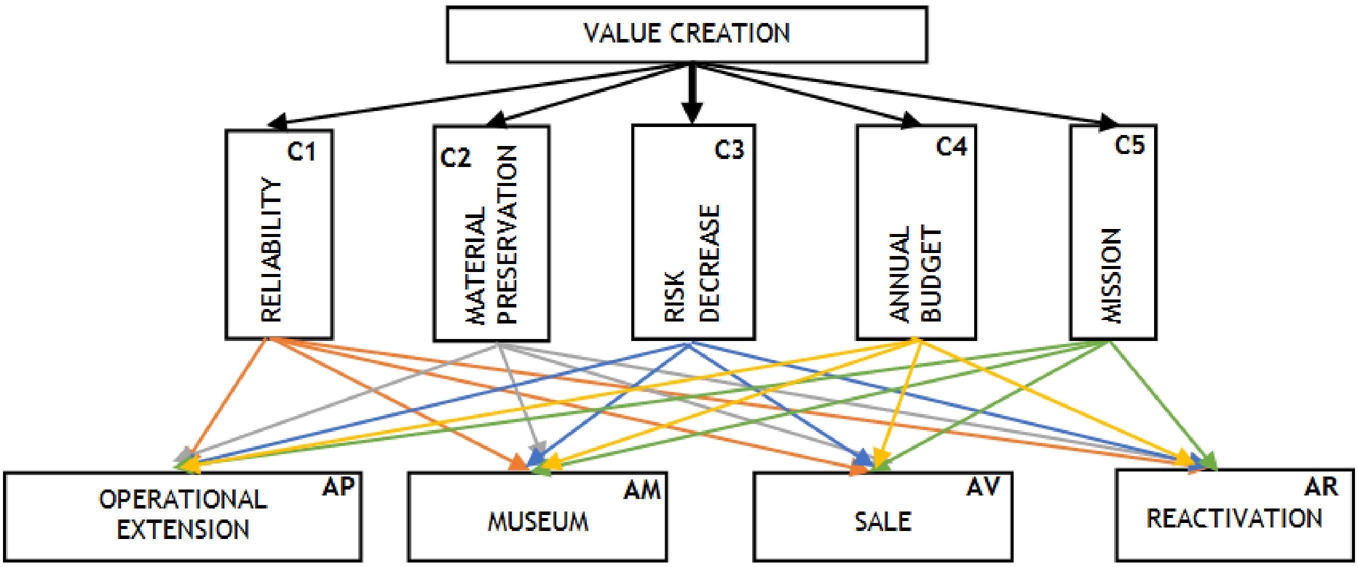

Figure-5. Hierarchical Structure of the Operationality Extension Evaluation Decision

Table 3, used the Saaty scale (Ioannis and Nikitas, 2013); (Gurung and Phipon, 2016) represents the pairwise comparison matrix (A) between the criteria in relation to the Global Goal, the priority vector (C_i) and the consistency vector (X_i):

Table-3. Priority Vector (C_i) and Consistency Vector (X_i)

Criteria	C1	C2	C3	C4	C5	Priority Vector (C_i)	Consistency Vector (X_i)
C1	1	1/7	1/3	1/6	1/2	0,0529	0,2852
C2	7	1	1/2	1/2	3	0,2207	1,1919
C3	3	2	1	1/2	6	0,2881	1,6302
C4	6	2	2	1	2	0,3432	1,8684
C5	2	1/3	1/6	1/2	1	0,0951	0,4941

The comparison of preference between criterion *i* (row) and criterion *j* (column), is obtained from:

Criteria *i* 9 7 5 3 1 3 5 7 9 Criteria *j*

- If the numerical judgment between criterion i and j falls to the left side of the value 1, the value will be the value selected in the Saaty scale, a_{ij};
- If the numerical judgment between criterion i and j falls to the right side of the value 1, the value will be $a_{ji}=1/a_{ij}$.

Then, the values are normalized by dividing each element by the sum of its column and, finally, the vector C_i is calculated by the average of each line. The vector X_i is calculated by the multiplication between the pairwise comparison matrix (A) and the vector C_i.

Table 4 represents the relative weight of each criterion relating to each alternative and the Overall Weight of each alternative relating to the Global Goal:

Table-4. Overall weight of the Alternatives

Criteria	C1	C2	C3	C4	C5	Overall Weight
AP	0,4258	0,0352	0,4285	0,2635	0,3411	0,2766
AM	0,0347	0,2231	0,0364	0,0365	0,0788	0,0816
AV	0,2047	0,3066	0,1633	0,5951	0,1998	0,3488
AR	0,3349	0,4351	0,3718	0,1049	0,3803	0,2930

As was done previously in the calculation of the vector C_i, each column of Table 4 represents the vector C_i, the preference of each criterion in relation to the alternatives. The Overall Weight is obtained by multiplying the priority vector for each alternative, expressed in Table 4, and the main priority vector (C_i), expressed in Table 3. The Overall Weight allows to conclude that the AHP hierarchy places the Sale alternative (AV) as the most preferred, with 34.88%, and Museum alternative (AM) as the least preferred, with 8.16%.

The calculation of the judgments consistency is carried out by the following steps:

- Principal Eigen Vector (eigenvalue), is the measure of consistency of the pairwise comparisons for the five criteria (n = 5): $\lambda max = (1 / n) \times \sum (x_i / C_i) = 5{,}4181$;
  - x_i is the consistency vector and C_i is the main priority vector (Table 3).
- Consistency Índex: $CI = (\lambda max - n) / (n - 1) = 0{,}1045$;
- Consistency Ratio: $CR = CI / RI = 0{,}0933$, the inconsistency is acceptable, because the premise $CR \leq 0{,}1$ is verified.

Note: RI is the Random Consistency Index, which is obtained from the table of values of Random Consistency Index in relation to the order of the matrix (n) (Ishizaka and Nemery, 2013).

III.2 TOPSIS

According to Gurung and Phipon (2016) a scale is developed (Table 5) that evaluates the relation of conformity between each criterion and each alternative, and then this conformity assessment is expressed (Table 6), that is, each criterion will be evaluated according to its suitability to each alternative:

Table-5. Criterial Attributes Scale

Values	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
1	Nonexistent	Unnecessary	Unnecessary	Does not	Disregarded
3	Low	Little needed	Little needed	Little favors	Little
5	Moderate	Moderately	Moderately	Moderately	Moderately
7	High	Required	Required	Favors	Considered
9	Very High	Much needed	Much needed	Favors a lot	Highly

Table-6. Decision Matrix D

Alternatives	Criteria				
	C1	**C2**	**C3**	**C4**	**C5**
AP	5	5	9	1	3
AM	3	9	3	7	5
AV	5	7	3	9	5
AR	5	9	5	5	5
Importance	0,0529	0,2207	0,2881	0,3432	0,0951

Note: The w_i values represent the main priority vectors (C_i), obtained in AHP.

Table 7 shows the PIS and NIS values, as well as their separation measures, finally the relative closeness values (C_i*) to the ideal solution (PIS) of each alternative and its hierarchy:

Table-7. Separation measures between PIS and NIS of the Weighted-Normalized Matrix V and Relative Closeness values (C_i*) to the ideal solution

Alternatives	Criteria					D_i^+	D_i^-	C_i*	Hierarchy
	C1	C2	C3	C4	C5				
AP	0,0289	0,0718	0,2329	0,0275	0,0311	0,2699	0,0586	0,1784	4
AM	0,0173	0,1293	0,0776	0,1923	0,0519	0,0804	0,2274	0,7389	2
AV	0,0289	0,1006	0,0776	0,2473	0,0519	0,0288	0,2717	0,9043	1
AR	0,0289	0,1293	0,1294	0,1374	0,0519	0,1344	0,1528	0,5321	3
PIS (v^+)	**0,0289**	**0,0718**	**0,0776**	**0,2473**	**0,0519**				
NIS (v^-)	**0,0173**	**0,1293**	**0,2329**	**0,0275**	**0,0311**				

From Table 6, the following values are calculated in Table 7:

- Normalized Decision Matrix R is obtained by dividing each element of Table 6 by the square root of the squared sum of the respective column : $r_{ij} = x_{ij} / \sqrt{(\sum x_{ij}^2)}$;
- Weighted-Normalized Decision Matrix V is calculated by multiplying the importance w_i and the elements of the Normalized Decision Matrix R : $v_{ij} = w_i \times r_{ij}$;
- PIS (v^+) are the highest benefit values and the lowest non-benefit values of each column of the Weighted-Normalized Decision Matrix V;
- NIS (v^-) are the lowest benefit values and the highest non-benefit values of each column of Weighted-Normalized Decision Matrix V. Cost is a non-benefit, represented by C2 and C3;
- The calculation of the separation measures (Euclidean distance) of each alternative from the Positive Ideal Solution PIS: $D_i^+ = \sqrt{(\sum (v_{ij} - v_j^+)^2)}$;
- The calculation of the separation measures (Euclidean distance) of each alternative from the Negative Ideal Solution NIS: $D_i^- = \sqrt{(\sum (v_{ij} - v_j^-)^2)}$;
- The Relative Closeness values: $C_i^* = D_i^- / (D_i^+ + D_i^-)$, where the closest solution to the ideal solution will be the one closest to $C_i^* = 1$.

It is concluded that, taking into account the current state of the Alpha Jet fleet and its dependent variables, the closest solution to the ideal one for the creation of value to it, among the available alternatives, is the Sale of the fleet.

5. Conclusion

The presented model of decision support using a multicriteria approach to value creation, concludes that an operation extension of the Alpha Jet fleet is the least preferred solution. Being the Sale alternative the most preferred, however, it is advised that an aircraft preservation planning should be applied to this fleet, since the timing of the purchase is unknown, but also to avoid a more rapid degradation of its materials and components due to the non-use and to reduce, as much as possible, the buyer maintenance effort to return the fleet to the airworthy state.

The FMEA analysis allows a more in-depth assessment of failure modes, revealing the ones that most compromise the operation of the engines. As expected, the FMEA results only allow decisions to be taken at the operational level, but its hybrid application with the multicriteria decision analysis tools, AHP and TOPSIS, has successfully brought the decision-making to a strategic level through hierarchization and selection of the best alternative according to the most varied criteria, whether they were imprecise or ambiguous.

The hierarchy developed by the AHP and TOPSIS tools allows the MSD-GECA to have some consistency and validity, in terms of results, since both have obtained the same alternative with the most preference (Sale), although the other alternatives have registered a slight change in their hierarchy of preference.

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