PURCHASE OF A NEW AIR SUPERIORITY FIGHTER USING THE ANALYTIC NETWORK HIERARCHY PROCESS

Leila Paula Alves da Silva Nascimento*
Aeronautics Institute of Technology
São José dos Campos, SP, Brazil
leilapasn@gmail.com

Amanda Cecília Simões da Silva*
Aeronautics Institute of Technology
São José dos Campos, SP, Brazil
amanda@ita.br

Mischel Carmen Neyra Belderrain
Aeronautics Institute of Technology
São José dos Campos, SP, Brazil
carmen@ita.br

ABSTRACT

The F-X2 Project intends to define the purchase of new air superiority fighter for the Brazilian Air Force (BAF). The purpose of this work is to present a military-based application of the Analytic Network Process (ANP) method, adapting the F-X2 Project case to the use of fictitious data. The ANP stands out due to the fact that its characteristics provide realistic solutions. Specific literature has approached its theoretical aspects and its applications in real case and empirical studies.

Keywords: Multiple Criteria Decision Making, ANP, F-X2 Project.

http://dx.doi.org/10.13033/ijahp.v2i1.73

1. Introduction

The Multiple Criteria Decision Making methods (MCDM) help the evaluation of a set of alternatives in relation to a certain set of criteria. The MCDM has many effective methods to organize a complex problem into a structure that makes it possible to be analyzed such as, the Analytic Network Process (ANP) method.

The ANP is characterized by means of the decomposition of a decision-making issue in a network structure, with no hierarchical relationship among its elements. Actually, the ANP allows relationships of dependence and feedback among the elements. Taking into account that often in real world there is dependence among those criteria, the ANP provides a more realistic representation of the problem to the decision-maker.

The purpose of this work is to perform an application of the ANP method in a military decision environment, simulating the choice of a new air superiority jet fighter for the Brazilian Air Force (BAF). It is the so-called F-X2 Project, confidentially managed by BAF and by the Ministry of Defense. The project data included in this work were collected from media publications; therefore, it does not represent at all the completion of the process.

* Corresponding authors

The F-X2 Project is a complex decision-making issue that involves alternatives and multiple criteria and, at first, there might be dependent relationships among them. For this reason, a method which involves quantitative and qualitative criteria and that also allows dependent relationships becomes necessary to better approach the problem. The ANP complies with such requirements.

Thus, the present work is structured as follows: Section 2 is comprised of the ANP method. Section 3 outlines the application of the method to the addressed problem. Section 4 deals with final observations and last, the references used.

2. Theoretical Reference

"Decision–making issues may be difficult to solve, due to the complexity, the uncertainty inherent to the situation, the presence of multiple objectives and different perspectives, which might lead to different conclusions" (Clemen and Reilly, 2001).

A decision problem is considered multicriteria when it has, at least, one decision context, two conflicting evaluation criteria, a finite set of alternatives, a measure scale, decision matrixes and an accrual method of preferences.

The MCDM methods are meant to clarify the decision-making process above all, so they can help decision-makers evaluate and choose the alternatives to the problem. It is important to point out that the objective of MCDM methods is not to present to decision makers the optimum solution of the problem but instead to help them, bearing their preferences in mind.

2.1 Analytic Network Process (ANP)

First published by Thomas L. Saaty in 1996, the Analytic Network Process (ANP) is a discrete method of the MCDM American School. It is regarded as a generalization of the Analytic Hierarchy Process (AHP) and it utilizes a network (instead of hierarchy) with no need to specify levels, also allowing dependent relationships between elements. ANP overcomes the limitation of the linear hierarchical structure while contradicting the Axiom of Independence (Saaty, 2005). According to Saaty (1999), ANP "synthesizes the dependency effect and feedback inside and among sets (clusters) of elements".

In Figure 1, it is observed that a network is a non-linear structure expanding in all directions. It has non-organized clusters in a pre-defined order and presents influence (or dependence) relationships, which are transmitted in the same set of elements (inner dependence) and also among sets (outer dependence).

The dependence relationships among the elements of clusters C_4-C_2, C_4-C_3, C_1-C_4 e C_1-C_2 of Figure 1 represents some examples of outer dependence. The dependence relationship among the elements of clusters C_2-C_3 characterizes feedback. A loop in cluster C_1 indicates an inner dependence of its elements (Saaty, 2005).

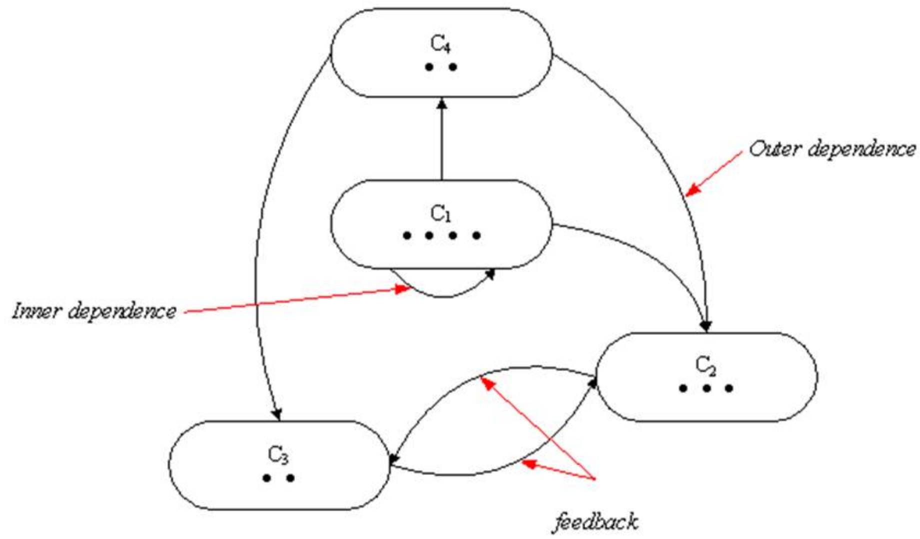


Figure 1. Network structure of the ANP (Source: Saaty, 2005)

As for the outer dependence relationships among clusters in network structure, they can be classified as shown in Figure 2, as: 1) source component, whose elements influence any elements of any other cluster, although they are not under any influence; 2) intermediate component, which is influenced and influences an element of another cluster; and, 3) sink component, which is influenced by the elements of another cluster (Saaty, 2005).

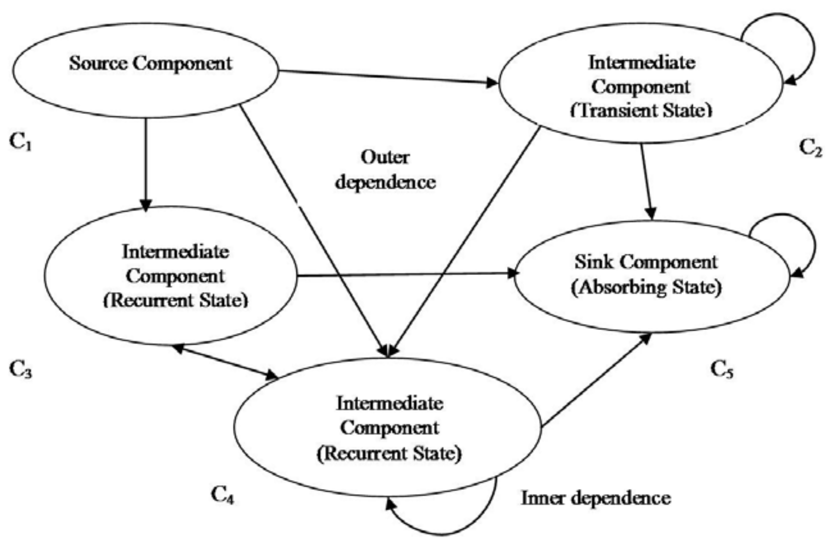


Figure 2. Connections in a Network (Source: Saaty, 2005)

Aiming to facilitate the understanding of the concept of ANP, a flow chart of the method is presented in Figure 3. The suggested flow chart identifies the following stages and the necessary steps to the application of the ANP:

Stage 1: Formulation of the decision problem

- Step 1 – Problem Structuring;
- Step 2 - Network construction.

Stage 2: Judgments

- Step 1 - Construction of global and local reachability matrices;
- Step 2 - Pairwise comparison of the elements and clusters;
- Step 3 - Verification of the consistency of judgment;
- Step 4 - Acquisition of eigenvectors and clusters weights matrix.

Stage 3: Algebraic Development

- Step 1 - Construction of Unweighted Supermatrix;
- Step 2 - Acquisition of the Weighted Supermatrix;
- Step 3 - Verification of the Weighted Supermatrix stochasticity;
- Step 4 - Acquisition of the Limit Matrix;
- Step 5 - Final Result.

More details about the ANP method may be found in Saaty (2005).

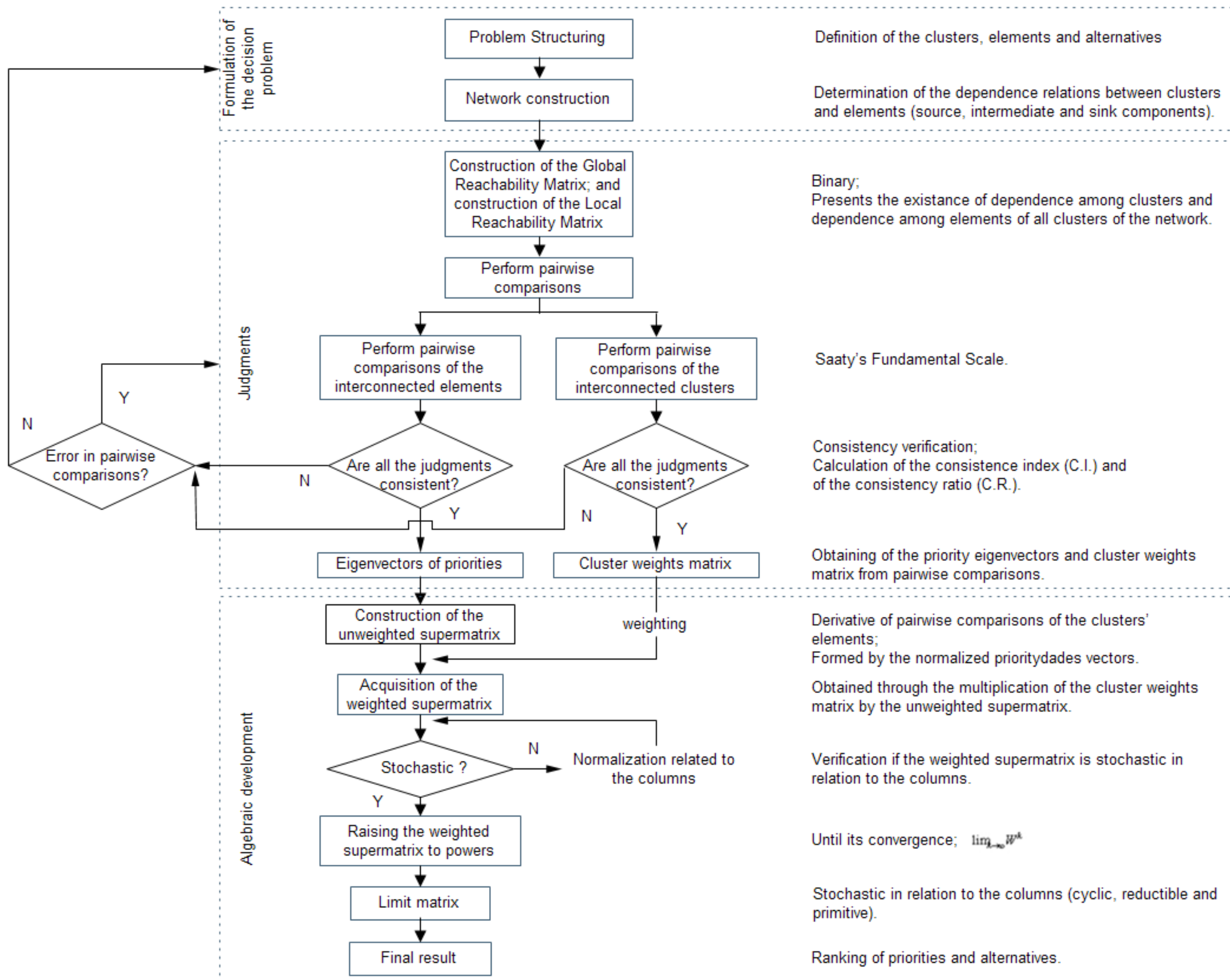


Figure 3. ANP method application flow chart: stages and steps followed in the ANP method (source: authors)

3. Application of ANP: The F-X2 Project Case

The F-X2, a project worth billions of Brazilian Reals, aims at re-equipping the BAF jet fighter fleet with fifth-generation supersonic aircraft. They will replace the current Mirage 2000 fighter planes initially, and afterwards, the F-5 fighters.

It is an old BAF project, started in 1998, during President Fernando Henrique Cardoso's term. Due to administrative reasons, the FX Project (or Phoenix Project) was not concluded. The F-X2, reactivated by the current president, has been dealt with on a confidential basis by both BAF and the Ministry of Defense, since it handles confidential warfare data of the countries involved.

In 2007, the re-edition of the BAF Directive DCA 400-6 (Aeronautical Systems and Materials Life Cycle) was approved by the Aeronautical Command, in view of "setting up the planning and execution of the necessary steps and main events of Aeronautical Systems and Materials Life Cycle" (DCA 400-6, 2007).

The Directive governs all of the Aeronautical Command systems and materials life cycle. It includes: the detection of an operational or logistics deficiency, technological or economic opportunity; the phase of creation; viability, definition, development/purchase, production, implementation, utilization, revival, modernization or improvement through its deactivation, when the life cycle is finished (DCA 400-6, 2007). Thus, the DCA 400-6 sets the guidelines for the process of acquisition of the BAF fighter planes.

The acquisition process will be "direct choice" which, in other words, means exemption of a bidding process. The Brazilian requirement is the commercial offset agreement, described as "one of the main focal points of the program, so as to provide qualification to the national industrial depot and also to allow an effective participation in future improvements and updates throughout the equipment life cycle" (O Estado de São Paulo, 2008).

Six international manufacturers of fighter planes models – JAS-39A Gripen, SU-35 E, RAFALE-C, F-18 E/F, F-35 Lightning and Typhoon – replied to the Request for Information (RFI) forwarded by Brazil, which was the first formal contact with the companies or interested governments. "The alternatives are analyzed upon evaluation of risks, timeline and cost-benefit relation and the strategical execution of various activities which the Systems and Materials Life Cicle is comprised of" (DCA 400-6, 2007). The purpose is to collect data to set forth Technical, Logistical and Industrial Requirements (TLIR) and to draw detailed technical specifications, which will be part of the agreements of development or acquisition.

After analyzing the manufacturers' replies to the RFI, the selection of three of the six initial fighter jets – RAFALE-C, F-18 E/F and JAS-39A Gripen – was announced. A Request for Proposal (RFP) was forwarded to these parties, having as its parameters the requirements set forth in TLIR. The F-X2 Project is currently in this step and, the Brazilian Government will soon announce the chosen manufacturer.

To illustrate an application of ANP method, fictitious data regarding the F-X2 Project were adopted. The intention of this work is to demonstrate that the ANP method can be applied in case of decision- making issues in many different areas, including the military environment.

The application will simulate the two phases (RFI and RFP) of the selection process, using ANP in both of them. First, the ANP will be applied to the six initial alternatives of fighter planes, selecting three of them. Upon a new application of the ANP, the final selection will be obtained.

In both phases, the ANP was reproduced in the free software SuperDecisions, available at www.superdecisions.com, considering the stages and steps included in the flow chart of Figure 3.

3.2 Illustrative Example of F-X2 Project

The problem is contextualized as follows: "selection of a supersonic aircraft manufacturer for the re-equipment of the BAF jet fighter fleet". Due to the fact that it is an illustrative example, only the criteria relevant to the authors were considered.

The existing dependency relationships, as well as the pairwise comparisons were also determined by the authors (decision-makers, in this case), without any knowledge of military issues. Nevertheless, some military personnel, who were not involved with the F-X2 Project were consulted and they were able to provide important data, such as elements, dependency and comparisons.

As previously explained, the selection of fighter planes occurred in two phases. In Phase 1, referred to as "Pre-Selection", resulting from RFI, macro criteria were used, that is, with no specific details. And, in Phase 2, named "Final Selection", resulting from RFP, the criteria included in the previous stage were further discussed, leading to more information and details than in the Pre-Selection Phase.

Phase 1: Pre-Selection – RFI

Stage 1: Formulation of the decision problem

- Step 1 – Problem Structuring: the objective, clusters, elements and alternatives must be defined. In this case, the objective is to select three manufacturers of fighter planes. There are two clusters to be considered: General Aspects and Alternatives, each one including its respective elements. The cluster General Aspects consists of the following elements: Costs, Offset, Performance, Weaponry, Airborne Systems (avionics and sensors) and Logistics. The cluster Alternatives consists of the following elements: JAS-39A Gripen, SU-35 E, RAFALE-C, F-18 E/F, F-35 Lightning and Typhoon.

- Step 2 - Network construction: the dependency relationships and feedback among the elements of clusters must be set forth. Figure 4 presents Phase 1 network. It is observed the inner dependence among the elements of the cluster General Aspects. Besides, its elements influence the ones of the cluster Alternatives and vice-versa, which characterizes a feedback.

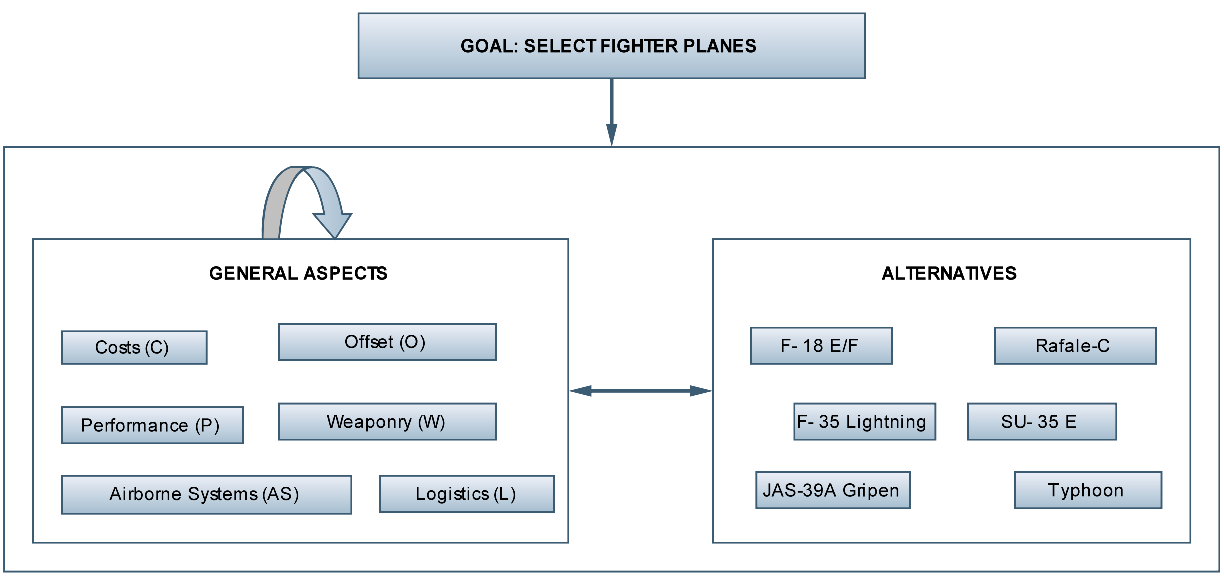


Figure 4. Network Structure to Phase 1

Stage 2: Judgment

• Step 1- Construction of global and local reachability matrices: to better view the existence of network dependence relationships, there must be constructed matrices of global and local range. Table 1 illustrates the global reachability matrix. Due to the fact that the elements of the cluster Alternatives were considered independently from each other, it is possible to observe the global reachability matrix at zero value, concerning the interaction among its elements. The other interactions receive a value 1, indicating that there is dependence among the elements.

Table 1. Global reachability matrix for the aircraft selection example

Clusters	Alternatives	General Aspects
Alternatives	0	1
General Aspects	1	1

Table 2 illustrates the local reachability matrix, which specifies the dependence relationship among the elements of the clusters. Value 1 is assigned whenever dependence occurs. If there is none, a zero-value is assigned.

Table 2. Local reachability matrix for the aircraft selection example

Elements	F-18	F-35	Gripen	Rafale	SU-35	Typhoon	W	O	C	P	L	AS
F-18 E/F	0	0	0	0	0	0	1	1	1	1	1	1
F-35 Lightning	0	0	0	0	0	0	1	1	1	1	1	1
JAS-39A Gripen	0	0	0	0	0	0	1	1	1	1	1	1
Rafale-C	0	0	0	0	0	0	1	1	1	1	1	1
SU-35 E	0	0	0	0	0	0	1	1	1	1	1	1
Typhoon	0	0	0	0	0	0	1	1	1	1	1	1
Weaponry (W)	1	1	1	1	1	1	0	0	0	0	0	1
Offset (O)	1	1	1	1	1	1	1	0	0	0	0	1
Costs (C)	1	1	1	1	1	1	1	0	0	1	1	1
Performance (P)	1	1	1	1	1	1	1	0	0	0	0	1
Logistics (L)	1	1	1	1	1	1	1	0	0	0	0	1
Airborne Systems (AS)	1	1	1	1	1	1	1	0	0	0	0	0

The construction of binary matrices is followed by paired comparisons, required to every connection existing on the network. In order to do that, Saaty's Fundamental Scale is used.

• Step 2 - Pairwise comparisons of the elements and clusters: such comparisons aim at obtaining eigenvectors of these elements and the weight of each cluster, respectively. The comparisons to be performed are the ones in which a single element of a cluster has a dependence relationship with a minimum of two elements of another cluster.

• Steps 3 and 4 - Verification of the consistency of judgment and acquisition of eigenvectors and clusters weights matrix: the verification consists of observing if the values of the Consistency Ratio (CR), obtained from the decision matrices are within the maximum limit of acceptance of 0.10. In this work, all of the decision matrices are consistent. Thus, both eigenvectors and clusters weights are registered. The registered eigenvectors are now called relative priority vectors of the judged elements. Once all the comparisons are performed and all of the consistencies are verified, the next stage is started.

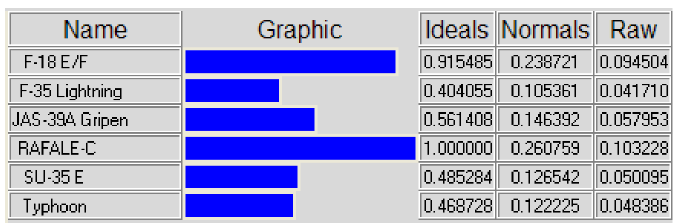
Stage 3: Algebraic Development

• Step 1 - Construction of Unweighted Supermatrix: from the accrual of the eigenvectors obtained at the paired comparisons among the elements of the previous stage.

• Steps 2 and 3 - Acquisition of the Weighted Supermatrix and Verification of its stochasticity: It is the result from multiplying the cluster weight matrix (which consists of the eigenvectors of the comparisons among clusters) with the Unweighted Supermatrix. This one shall be stochastic in relation to the columns (the total amount of the elements of the column shall be 1). If the Weighted Supermatrix is not stochastic, related to the columns, it should be normalized to make it stochastic.

• Step 4 - Acquisition of the Limit Matrix: obtained raising the Weighted Supermatrix to the powers until its convergence. The Limit Matrix shall also be stochastic in relation to the columns. The final result can be observed in it.

• Step 5 - Final Result: the final result is obtained with the aid of the alternatives priority ranking. In this case, the three fighter planes presenting the major ranking proportions (Figure 5) are: RAFALE-C > F-18 E/F > JAS-39A Gripen. Followed by SU-35 E > Typhoon > F-35 Lightning. Regarding the elements of the cluster General Aspects, the elements obtaining the major priorities were Costs and Offset, with priority levels of 0.26249 and 0.22276, respectively.



Name	Graphic	Ideals	Normals	Raw
F-18 E/F		0.915485	0.238721	0.094504
F-35 Lightning		0.404055	0.105361	0.041710
JAS-39A Gripen		0.561408	0.146392	0.057953
RAFALE-C		1.000000	0.260759	0.103228
SU-35 E		0.485284	0.126542	0.050095
Typhoon		0.468728	0.122225	0.048386

Figure 5. Final result of ANP to Phase 1.

Regarding the elements of the cluster General Aspects, the elements obtaining the major priorities were Costs and Offset, with priority levels of 0.26249 and 0.22276, respectively (Table 3).

Table 3. Elements of the cluster General Aspects priorities for the aircraft selection example

Elements	Normalized by Cluster	Limiting
Weaponry	0.029050	0.04809
Offset	**0.134575**	**0.22276**
Costs	**0.158576**	**0.26249**
Performance	0.134113	0.22200
Logistics	0.055435	0.09176
Airborne systems	0.092377	0.15291

Thus, Phase 2 begins with the three first fighter planes of the ranking (Figure 5) as alternatives to the decision-making issue.

Phase 2: Final Selection - RFP

Aiming to improve the model and attempting to imitate the reality, each element of the cluster General Aspects of the Pre-Selection Phase is now considered a cluster. The elements are associated to each one. Therefore, the following clusters and elements are created:

- Performance Cluster (P): range ratio, maximum speed, operational altitude, load capacity, take-off, landing, maneuver and climbing performances;

- Offset Cluster (O): industrial, commercial and technological;

- Costs Cluster (C): aircraft purchasing, maintenance and operation costs (flight hour);

- Airborne Systems Cluster (AS): radar, self-defense, data-link, helmet mounted display (HMD) and flight refueling;

- Logistics Cluster (L): maintenance and support equipment, technical publications, spare parts, staff training and contracted logistic support;

- Weaponry Cluster (W): cannons, missiles and intelligent bombs.

It is worth highlighting that Phase 2 followed the same procedure presented in the flow chart of Figure 3. However, the steps and stages are not shown here. Phase 2 network structure is shown in Figure 6.

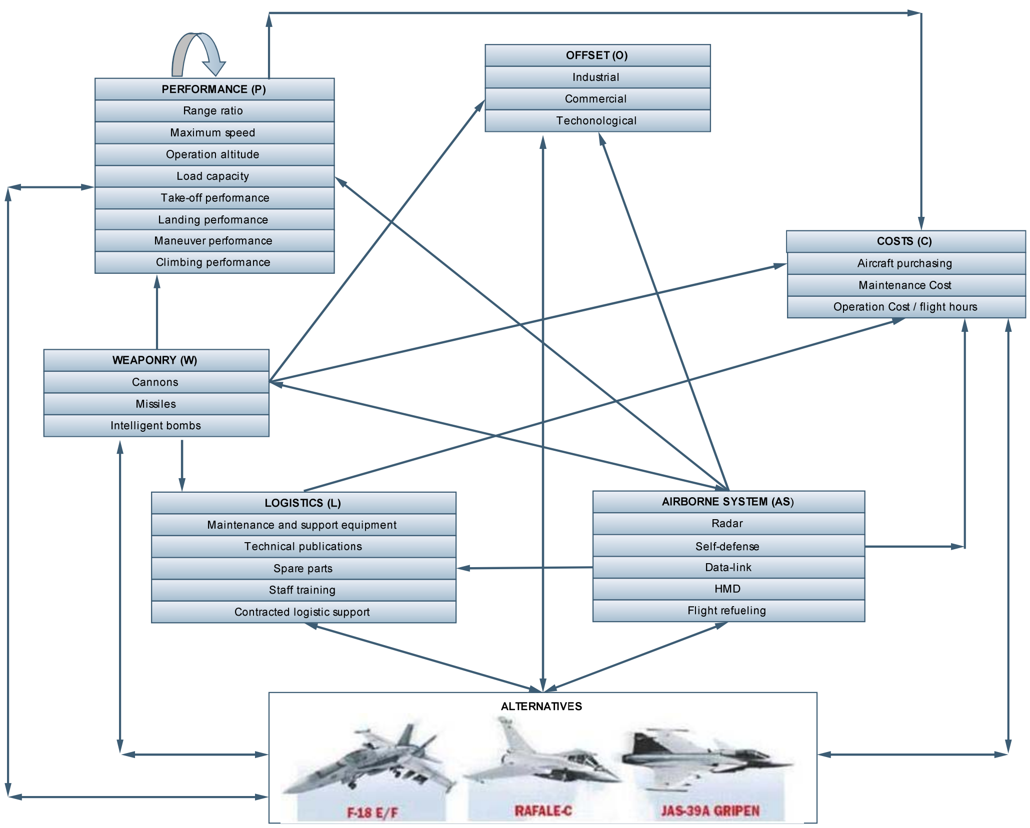


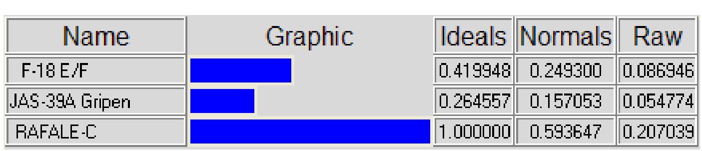
Figure 6. Network structure to Phase 2

Table 4 presents the priorities of the each element of the clusters. Among them, the ones with major priority are: Technological (from Offset Cluster) with a priority of 0.68296; and Aircraft purchasing cost (from Costs Cluster) with priority of 0.53766. Such result confirms the data obtained in Phase 1 and it shows that the Technological Offset and the Aircraft purchasing cost are critical to the selection of the fighter planes.

Table 4. Elements priorities for the aircraft selection example

Clusters	Elements	Normalized By Cluster	Limiting
Weaponry	Intelligent bombs	0.034823	0.32662
	Cannons	0.034831	0.32670
	Missiles	0.036961	0.34668
Offset	Commercial	0.005849	0.09409
	Industrial	0.013860	0.22295
	Technological	**0.042457**	**0.68296**
Costs	**Aircraft purchasing cost**	**0.101740**	**0.53766**
	Maintenance cost	0.054339	0.28716
	Operation cost	0.033147	0.17517
Performance	Load capacity	0.034256	0.23557
	Maneuver performance	0.012385	0.08517
	Climbing performance	0.015361	0.10563
	Take-off performance	0.010039	0.06904
	Landing performance	0.009913	0.06817
	Range ratio	0.029416	0.20229
	Operational altitude	0.011115	0.07643
	Maximum speed	0.022933	0.15770
Logistics	Maintenance and support equipment	0.014596	0.19169
	Spare parts	0.010063	0.13216
	Technical publications	0.013230	0.17375
	Contracted logistic support	0.014957	0.19643
	Staff training	0.023299	0.30598
Airborne systems	Self-defense	0.014900	0.20790
	Data-link	0.012167	0.16976
	HMD	0.007288	0.10169
	Radar	0.012274	0.17126
	Flight refueling	0.025041	0.34939

The final result of this phase of the illustrative example is shown in Figure 7, with the following alternatives priority ranking: RAFALE-C > F-18 E/F > JAS-39A Gripen.



Name	Graphic	Ideals	Normals	Raw
F-18 E/F		0.419948	0.249300	0.086946
JAS-39A Gripen		0.264557	0.157053	0.054774
RAFALE-C		1.000000	0.593647	0.207039

Figure 7. Final Result of ANP

Although it is only an illustrative example of the ANP application, the results obtained in both phases were satisfactory and coherent with what is published in the media.

4. Final observations

The Multiple Criteria Decision Making method (MCDM) has as its objective to evaluate and to provide a final ranking of the alternatives dealt with, including complex decision-making environments, involving external factors, such as, multiple decision-makers, conflicting judgment, cost criteria, among others.

Various methods of support to the decision-making process are discussed in the specific publications. In this work, the Analytic Network Process (ANP) method was used in this work. The ANP method has as its characteristics the inclusion of qualitative and quantitative criteria, structured in networks, in which the dependence relationships and feedback among the elements are allowed.

This work's intention was to present an application of ANP, adapting the F-X2 Project case, BAF's project of purchase of a new air superiority fighter to re-equip the Brazilian fleet. The criteria used as clusters and elements, as well as pairwise comparisons, were assigned by the authors and do not correspond to the real project.

Moreover, it is observed that the ANP method can be applied in case of decision-making issues involving military environment. The F-X2 Project could benefit from the use of Ratings and BOCR merits (Benefits, Opportunities, Costs and Risks).

There are many ways of evaluating and selecting fighter aircraft alternatives to the problem at hand. So, the involved parties should be the ones to decide and adapt the best method to the decision-making process, according to their specific demands.

REFERENCES

Clemen, R.T. & Reilly, T. (2001). *Making Hard Decisions*. Califórnia: Duxbury.

Ministry of Defense, Aeronautical Command, Logistic, BAF Directive DCA 400-6, (2007). *Aeronautical Systems and Materials Life Cycle*. [in Portuguese]

O Estado de São Paulo, July 2, 2008. *FAB dá Início a Processo para Definir Empresa que Venderá Caças ao País*. [in Portuguese]

Saaty, T.L., "Fundamentals of the Analytic Network Process". *Proceedings of the ISAHP V, Kobe, Japan, 1999, August 12-14*.

Saaty, T.L. (2005). *Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs and Risks*. Pittsburgh, PA: RWS Publications.

Saaty, R. W. (2003). Decision Making in Complex. The Analytic Hierarchy Process for Decision Making and The Analytic Network Process for Decision Making with Dependence and Feedback [Superdecisions Tutorial]. Retrieved Jun 01, 2008, from http://www.superdecisions.com.