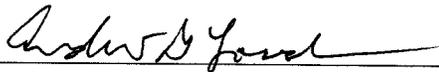


**COMPARING AND PRIORITIZING AIRCRAFT REQUESTS IN THE BRAZILIAN
AIR FORCE**

by

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Submitted to the
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of
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In Partial Fulfillment of
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of
Master of Science
Systems Engineering

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Comparing and Prioritizing Aircraft Requests in the Brazilian Air Force

A thesis submitted in partial fulfillment of the requirements for the degree of Master of
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DEDICATION

This work is dedicated to my wife Eleanor and to our four months old daughter Lara, the two pillars of my happiness.

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LIST OF ABBREVIATIONS

A/A	Air-to-air
ACFT	Aircraft
AFCS	Air Force Chief of Staff's Office
A/G	Air-to-ground
AI	Additive Independent
A/S	Anti-submarine
AWX	All Weather Capability
BAF	Brazilian Air Force
BRIC	Brazil, Russia, India, China
DM	Decision Maker
EW	Electronic Warfare
GDP	Gross Domestic Product
HF	High Frequency
LDW	Logical Decisions for Windows
MAWS	Missile Attack Warning System
MBPS	Megabits per Second
MD	Ministry of Defense
MUI	Mutual Utility Independent
NM	Nautical Miles
NSD	National Strategy of Defense
OCR	Operational Capabilities Request
OPS	Operational Projects Sub-section
PI	Preferential Independent
POR	Preliminary Operational Requirements
RWR	Radar Warning Receiver
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defense
SPJ	Self Protection Jammer
SPR	Semi Prepared Runway
UHF	Ultra High Frequency
UI	Utility Independent
USD	United States Dollars
VHF	Very High Frequency

ABSTRACT

COMPARING AND PRIORITIZING AIRCRAFT REQUESTS IN THE BRAZILIAN AIR FORCE

Alessandro Sorgini D'Amato, M.S.

George Mason University, 2011

Thesis/Dissertation Director: Dr. Andrew G. Loerch

Brazil is a huge country with vast natural reserves, mainly located in the Amazon region and the South Atlantic. In the last decade its economic growth and increasing importance in the global stage, have motivated Defense policies focused on the enhancement and strengthening of the Brazilian Armed Forces' operational capabilities. In the Brazilian Air Force (BAF), these policies are reflected mainly by the acquisition of new aircraft systems, which must be carefully selected according to the specific tasks and scenarios expected to be faced in the future. Hence, it is mandatory for the BAF to identify the required capabilities needed to accomplish the strategic objectives of the organization. The main purpose of this research is to develop a model composed of both a qualitative and a quantitative component, capable to function as a tool to compare how well different aircraft systems contribute to the accomplishment of the BAF's objectives and help decision makers to rank alternatives and define priorities among them.

1. BACKGROUND

1.1 Brazil's Natural Resources

Brazil is the fifth largest country in the world, both in terms of territory (8.5 million km²) and of population¹ (estimated 191 million inhabitants in 2010).² Brazil is also the biggest country in South America (see fig. 1) and has several different kinds of mineral resources that spread across a land with different physical characteristics.

The Amazon rainforest, located in the North region of the Brazilian territory, occupies 49.29% of the country's area³ and is rich in biodiversity and mineral resources like gold, silver, manganese, copper, bauxite, zinc, nickel, chromium, tin, niobium, uranium and tungsten.⁴

¹ "CIA - The World Factbook," <https://www.cia.gov/library/publications/the-world-factbook/geos/br.html> (accessed November 30, 2010).

² "IBGE :: Instituto Brasileiro de Geografia e Estatística," http://www.ibge.gov.br/home/presidencia/noticias/noticia_visualiza.php?id_noticia=1766&id_pagina=1 (accessed December 1, 2010).

³ "IBGE : Instituto Brasileiro de Geografia e Estatística," http://www.ibge.gov.br/home/presidencia/noticias/noticia_visualiza.php?id_noticia=169 (accessed December 1, 2010).

⁴ Luiz Augusto Bizzi et al., eds., *Geology, Tectonics and Mineral Resources of Brazil* (Brasília, Brasil: CPRM, 2003), 365, <http://www.cprm.gov.br/publique/media/abertura.pdf>.



Figure 1. Map of South America.⁵

Recently, the oil and gas shelf won a new dimension after the discovery of the Tupi field, in the Santos Basin (South Atlantic Ocean).⁶ If the forecasts prove accurate, these fields will transform Brazil into exporter of these energy resources, increasing the strategic importance of the South Atlantic to the country and also in the global context.

⁵ “CIA - The World Factbook -- References :: Regional Maps,” <https://www.cia.gov/library/publications/the-world-factbook/docs/refmaps.html>.

⁶ “Petrobras / Pre-salt,” <http://www.petrobras.com.br/minisite/presal/en/questions%2Danswers/> (accessed December 1, 2010).

1.2 Brazil in the World Stage

A strategic report by the European Commission states that in recent years, “Brazil has been implementing an increasingly assertive foreign policy, playing an active role in multilateral fora and positioning itself as a representative of emerging countries.”⁷ It also emphasizes that Brazil has been “lobbying intensively for a permanent seat on the United Nations (UN) Security Council”⁸ and is leading the UN peacekeeping force in Haiti since 2004.

At regional level, the Brazilian Government has aimed at strengthening the country’s role as a protagonist in South America, through the support of regional stability and integration processes in the subcontinent.

Throughout the early 1990s, Brazil lived through a period marked by economic instability and high inflation. In 1994 Brazil adopted the Plano Real and succeeded in controlling inflation. The following years of economic stability rendered Brazil a place in the so called BRICs, a group that refers to the developing countries of Brazil, Russia, India and China.

Recent economic performance provided Brazil with an upper middle income Gross Domestic Product (GDP) of US\$1.58 trillion and a GDP per capita of US\$8,040.00 in 2009.⁹ In present day, Brazil is seen as a “key emerging world economic power, which

⁷ European Commission, *Brazil - Country Strategy Paper 2007-2013* (European Union, 2007), 7, http://eeas.europa.eu/brazil/csp/2007_csp_en.pdf.

⁸ European Commission, *Brazil - Country Strategy Paper 2007-2013*.

⁹ “Brazil - Data,” <http://data.worldbank.org/country/brazil?display=map> (accessed December 1, 2010).

- according to recent estimates - could constitute one of the world's biggest economies by 2050"¹⁰ (see fig. 2).

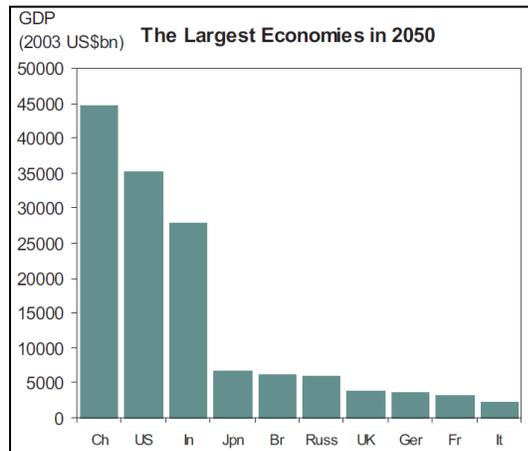


Figure 2. Largest Economies in 2050.¹¹

Brazilian Minister of Defense, Nelson Jobim, emphasizes that Brazil was able to “consolidate its position in the world, based on the economic and political stability conquered recently.”¹² He also states that this scenario provided the country, the opportunity for a bigger participation in the international arena, requiring new Defense policies.¹³

¹⁰ Dominic Wilson and Roopa Purushothaman, *Dreaming with BRICs: The Path to 2050*, Paper (Goldman Sachs, 2003), <http://www2.goldmansachs.com/ideas/brics/book/99-dreaming.pdf>.

¹¹ Ibid.

¹² Nelson Jobim, “A Defesa na Agenda Nacional: O Plano Estratégico de Defesa,” *Revista Interesse Nacional*, 2008, 9.

¹³ Ibid.

1.3 Current Defense Structure and the Brazilian Air Force (BAF)

The Brazilian Ministry of Defense (MD), created in 1999, is the federal agency in charge of the upward direction of the Armed Forces, comprised of the Navy, the Army and the Air Force. One of its main tasks is to establish policies related to defense and security of the country and is the “main initiator of actions involving more than one singular force.”¹⁴

The MD is responsible for a wide and diverse range of subjects, some of which are of great sensitivity and complexity, for example, military operations, the defense budget, military policy, military strategy, and military service.

Subordinated to the MD, the BAF performs a wide array of activities in order to pursue the achievement of its constitutional duties. They include “formulating strategic planning and performing actions for the defense of the country in the aerospace field, and being always able to act in the full spectrum of operations envisaged in the Military Doctrine of Defense.”¹⁵

In order to accomplish its role, the BAF must contribute with other services and federal agencies by exercising the “control of sensitive airspace areas; defending airports, aviation facilities and others considered of interest; providing the necessary air

¹⁴ “Ministério da Defesa,” <https://www.defesa.gov.br/index.php/o-que-e-o-md.html> (accessed December 1, 2010).

¹⁵ Comando da Aeronáutica, *ICA 11-1 Missão da Aeronáutica* (Brasília, Brasil: Comando da Aeronáutica, 2007), 11.

transportation to others organizations involved; and supporting logistic, intelligence, communications and instruction activities, upon request.”¹⁶

The BAF’s attributions previously described lead to the definition of its ultimate mission, which should guide all its activities:

“Keep the sovereignty in national airspace in order to protect the Motherland.”¹⁷

To accomplish this mission, the BAF needs to maintain the required readiness levels of its forces in order to keep an effective capacity to monitor, control and protect the airspace over the sensitive areas of the country with “detection, interception and destruction resources.”¹⁸

1.4 Vulnerabilities

The previous description of Brazil’s natural and economic wealth, along with its growing political importance in the global and regional stage, leads to the conclusion that the country needs a Defense structure compatible with its greatness.

But, according to the National Strategy of Defense (NSD), published in 2008 by the MD, there are vulnerabilities in the current Brazilian Defense structure caused, among others, by:¹⁹

¹⁶ Ibid.

¹⁷ Comando da Aeronáutica, *ICA 11-1 Missão da Aeronáutica*, 17.

¹⁸ Ibid.

¹⁹ Ministry of Defense of Brazil, *National Strategy of Defense* (Brasilia, Brazil: Ministry of Defense of Brazil, 2008), 42.

- Lack and discontinuity in the allocation of budget resources for defense (see fig. 3 and 4).
- Obsolescence of most of the equipment of the Armed Forces.
- Absence of a unified direction for the acquisition of these products.

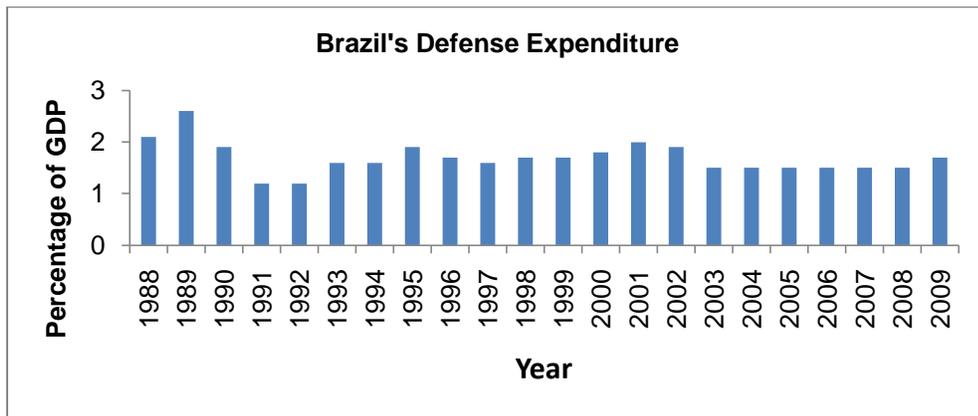


Figure 3. Brazil's Defense Expenditure - Percentage of GDP.²⁰

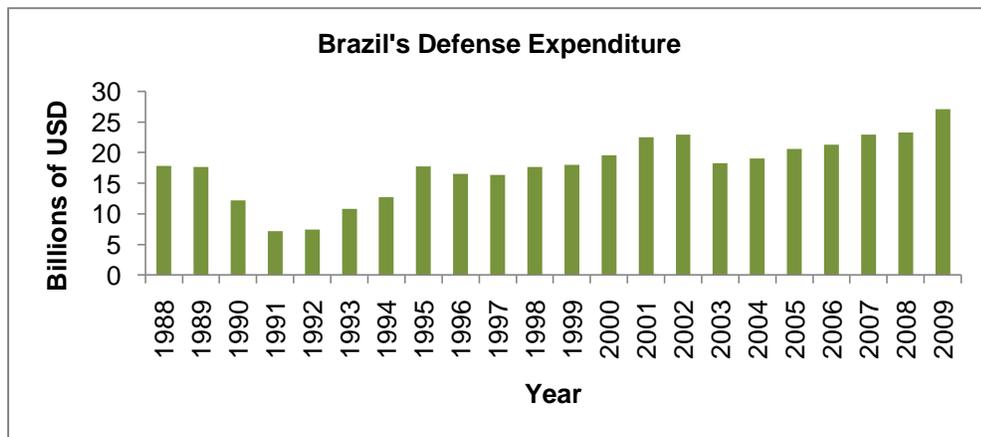


Figure 4. Brazil's Defense Expenditure - Billions of USD.²¹

²⁰“SIPRI Publications,” *Stockholm International Peace Research Institute*, <http://milexdata.sipri.org/result.php4> (accessed December 1, 2010).

²¹ *Ibid.*

Jobim points out that the lack of resources destined to the defense budget in the past, caused among other issues, the loss of the operational capacity of the Brazilian armed forces.²² Specifically in the BAF, this scenario led to an aging fleet, which caused the majority of the aircraft inventory to become obsolete, in face of the rapid evolution of new technologies and doctrines.

The NSD aims to address this issue by listing specific actions that should be taken in order to build new capabilities, directly related to the tasks that the Brazilian armed forces expect to face in the coming decades.

Some of the recommended actions to address this situation are:²³

- The Ministry of the Defense will propose to the President a “National Defense Equipment and Organization Bill.”
- Regularity and continuity in the allocation of defense budget resource to increase investments and ensure the financing of the Armed Forces.
- The Ministry of Defense, shall establish a legal proceeding to guarantee the continuous allocation of specific financial resources to make viable the integrated development and the completion of national defense-related projects, emphasizing the development and production of, among others:
 - fighters and transport aircrafts.
 - unmanned aerial vehicles.
 - electronic warfare equipment and platforms.

²² Jobim, “A Defesa na Agenda Nacional: O Plano Estratégico de Defesa,” 9.

²³ Ministry of Defense of Brazil, *National Strategy of Defense*, 51-56.

- airlift helicopters for the enhancement of tactical mobility, and reconnaissance and attack helicopters.

It becomes clear that there is a government policy intended to increase military expenditure and acquire or develop new aircrafts in order to replace obsolete ones. This is an unusual situation for the BAF, since large acquisitions of new aircrafts were not common in the last decades.

2. PROBLEM DESCRIPTION

2.1 Systems Life Cycle in the BAF

The BAF's official documents state that the Life Cycle of a system starts with the identification of an operational necessity and ends with the deactivation of the system. It is comprised by the following phases: conception, viability, definition, development or acquisition, production, implementation, use, modernization and deactivation.²⁴

This research was focused only on the Conception Phase, in which the identification of an operational deficiency occurs and an Operational Capabilities Request (OCR) is generated.

The OCRs are documents requesting the acquisition of a new system or the modernization of an existing one. They can be elaborated by any BAF's unit that identifies an operational deficiency or the lack of an operational capability needed to the accomplishment of its missions, caused by the obsolescence or lack of a specific aeronautical system.

There are three situations in which a BAF organization can generate an OCR:²⁵

²⁴ Comando da Aeronáutica, *DCA 400-6 Ciclo de Vida de Sistemas e Materiais na Aeronáutica* (Brasília, Brasil: Comando da Aeronáutica, 2007), 24.

²⁵ *Ibid.*, 16.

- The deficiency is caused by material shortages and not by poor training or deficient use of doctrines, tactics or processes.
- Due to technological innovations that can provide a new capability or more efficiency in the accomplishment of a current one.
- Market opportunities that favor the substitution of obsolete equipment in an economic way.

Moreover, the OCRs must provide information, as detailed as possible, of the following aspects related to the requested system:²⁶

- Description of the operational deficiency.
- Description of the intended uses, and in which scenarios.
- Required performance, described as complete as possible.
- Suggestions of systems already in use in the internal/external market that could be used as a reference.
- Logistic necessities.
- Requested quantity of systems.
- Expected results and benefits.

After an OCR is generated, it follows the chain of command until it gets to the Air Force Chief of Staff's Office (AFCS) in order to be analyzed. The accepted OCRs are used to generate a Preliminary Operational Requirements document (POR), which describes in greater detail the desired characteristics and applications of the requested

²⁶Comando da Aeronáutica, *ICA 400-14 Confecção de Necessidade Operacional - NOP* (Brasília, Brasil: Comando da Aeronáutica, 2003), 18.

system. The generation of a POR constitutes the end of the first phase (Conception Phase) in the life cycle of a new system (see fig. 5).

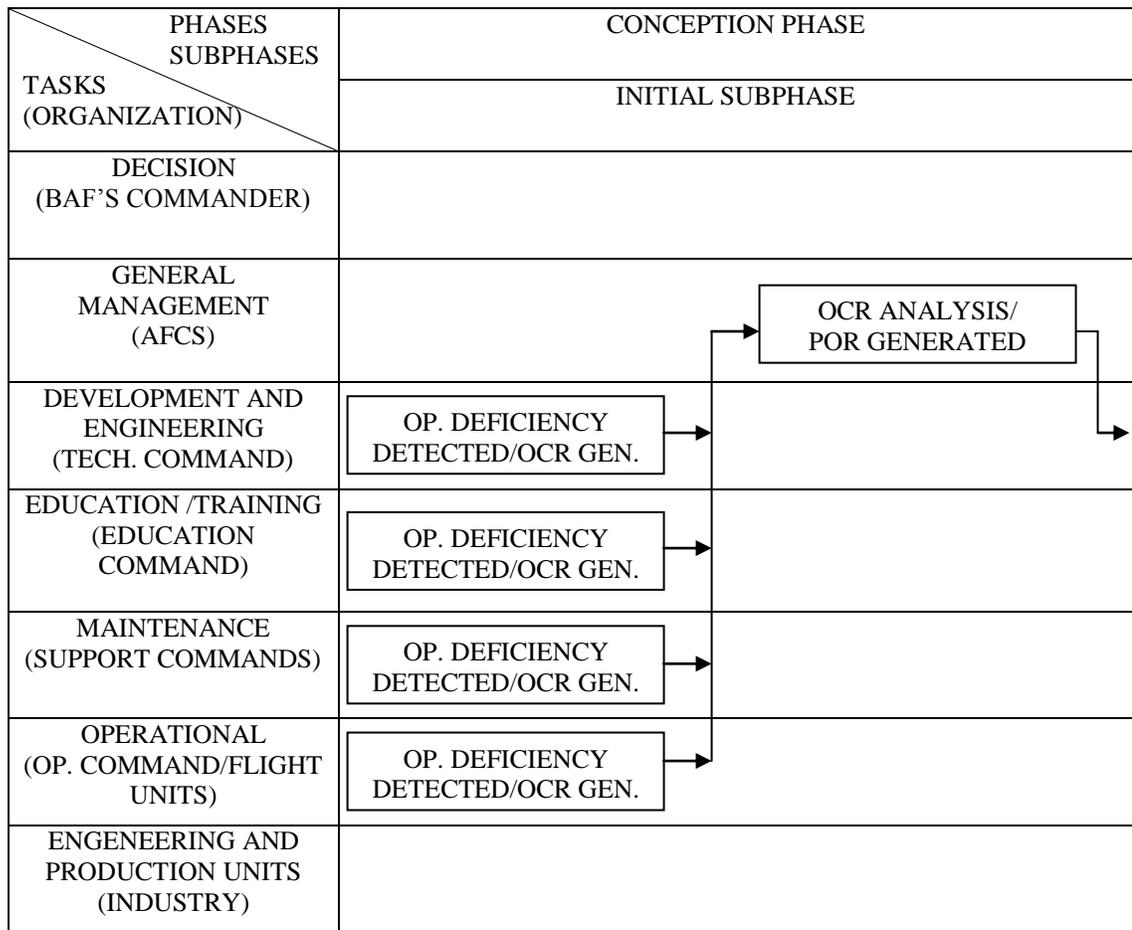


Figure 5. Systems Life Cycle in the BAF - Conception Phase.²⁷

²⁷ Comando da Aeronáutica, *DCA 400-6 Ciclo de Vida de Sistemas e Materiais na Aeronáutica*, 56.

2.2 The Role of the AFCS

One of the key organizations within the BAF's administrative structure is the AFCS, directly subordinated to the BAF's Commander. As defined in its regiment, the mission of the AFCS is to execute strategic planning of the highest level and to advise the BAF's Commander on subjects of interest to the organization. Among the most important tasks performed by the AFCS are:²⁸

- Formulate the strategic objectives and doctrines that must be pursued by the BAF.
- Develop the Aeronautical Military Policy, the BAF's Military Strategy and the BAF's Strategic Plan, overseeing its execution.
- Establish standards of efficiency and management indicators for the activities of the BAF.
- Formulate the annual budget plan for the BAF.
- Perform analysis related to the necessity of substitution and/or acquisition of aircrafts and armament.
- Determine the operational requirements of aeronautical systems.

The organizational structure of the AFCS is divided into six main Sections (see fig. 6), each one responsible for a specific set of tasks. The Operational Projects Sub-

²⁸ Comando da Aeronáutica, *RICA 20-8 Regimento Interno do Estado Maior da Aeronáutica* (Brasilia, Brasil: Comando da Aeronáutica, 2007), 9.

section (OPS) is subordinated to the Third Section (3SC) and has, among its attributions, the task to perform the analysis of the OCRs and decide which ones will generate a POR.

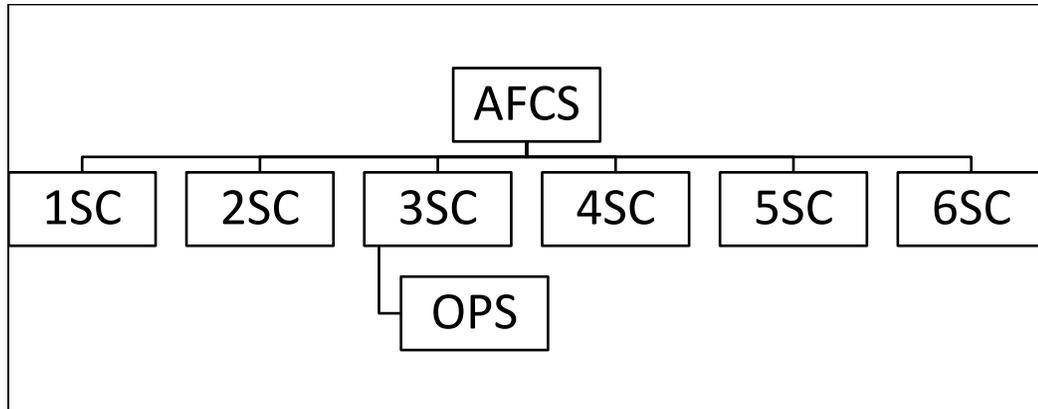


Figure 6. AFCS Simplified Structure.

The OPS' analysis must be made considering the strategic, political and budgetary scenarios.²⁹ Moreover, priorities must be established among the OCRs and the impact of the requested system to the BAF must be assessed.³⁰

The importance of this analysis can't be overlooked, once it is in line with the statement made by Jobim, during the studies for the release of the NSD. He emphasized that Brazil should clearly define what it wants from its Armed Forces. According to him, this query will be answered by, among other things, defining what kind of equipments are

²⁹ Comando da Aeronáutica, *ICA 400-14 Confecção de Necessidade Operacional - NOP*, 9.

³⁰ Comando da Aeronáutica, *ICA 400-5 Confecção de Requisitos Operacionais Preliminares -ROP* (Brasília, Brasil: Comando da Aeronáutica, 2003), 11.

needed, which ones should be acquired or developed and what is the priority among them.³¹

2.3 Issues with the Current Methodology

Currently, the analysis of the OCRs is based solely on the experience of the OPS's staff and there is no systematic method in place to guide the prioritization of the requests. Hence, it is a challenging task to evaluate and compare the contribution of each system to the BAF's operational capability.

The lack of an integrated performance measurement and management model makes it difficult for the OPS's analysts to choose which OCRs will be accepted (generate a POR) and which ones will be rejected. This scenario can lead to a non optimal budget allocation, leaving vulnerable areas without the needed resources and important programs unfunded.

In addition to that, the performance indicators currently in use to evaluate the OCRs are not necessarily designed using the strategic documents as a guide. This situation might lead to the use of the wrong indicators, not directly related with the strategic plan.

³¹ Jobim, "A Defesa na Agenda Nacional: O Plano Estratégico de Defesa," 10.

According to Ralph Keeney, the strategic objectives are

intended to guide all decision-making and should provide common guidance to all decisions and to all the decision opportunities. If these strategic objectives are not carefully defined and communicated, the guidance is minimal and some separate decisions simply won't make sense in the larger context of the organization's affairs.³²

In summary, the lack of standardized performance metrics defined based on the BAF's strategic objectives makes it difficult to establish a coherent long term acquisition policy and to justify to the taxpayer the choice of a specific portfolio of systems to be procured. This problem becomes even more important due to the current NSD, which aims to improve the BAF's operational capability by, among other things, replacing obsolete aircraft systems.

2.4 Problem statement

The scenario described in the previous sections leads to the explicit definition of the problem addressed by this thesis:

Given,

- A set of OCRs, each one related to a different type of aircraft.
- Estimated acquisition cost of each aircraft.

³² Ralph L. Keeney, *Value-Focused Thinking: A Path to Creative Decisionmaking* (Harvard University Press, 1996), 41.

The problem is to:

- Develop a methodology to compare different types of materials (aircraft), in the Conception Phase of their life cycle, in order to support decision makers to establish priorities between the alternatives.

By choice of:

- Accepted OCRs.

Subject to:

- Doctrines, policies and strategic documents related to the BAF.

3. THEORETICAL FOUNDATIONS AND METHODOLOGY

3.1 Value Focused Thinking

As Keeney points out, “values are what we care about”³³ and thus, they should guide the decision making process. Unfortunately, this approach is not common among most of the decision makers, who usually see a decision problem according to the alternatives available. This type of attitude is defined by Keeney as the “alternative-focused thinking.”³⁴

The central point in his Value Focused Thinking (VFT) theory is that alternatives are just means to achieve the more fundamental values and thus, the latter are more important. His theory focus basically in two activities: “first decide what you want and then figure out how to get it.”³⁵

A VFT approach allows the decision maker to think of desirable alternatives as oppose to the alternative-focused thinking, where a predetermined number of alternatives constrains the decision process. Keeney admits that the constrained thinking is easier than constraint-free thinking, because the former limits the range of concerns; nevertheless,

³³ Ibid., 1.

³⁴ Ibid., 6.

³⁵ Ibid., 4.

the payoffs of the latter are usually much greater.³⁶

Values should be defined prior to the alternatives. This method will push the DM to think about what objectives are expected to be achieved in the decision context. Identifying and structuring the objectives requires deep thought and, once this process is completed, the DM will gain insight that will help to achieve the expected goals.

The strategic decision context comprises all the possible alternatives available to the decision maker. Keeney emphasizes that “the strategic objectives have to indicate the essential reasons for being interested in a specific decision situation, as they indicate the reasons for being interested in *any* decision situation.”³⁷

The strategic objectives are the ultimate objectives of the decision maker and all other objectives must be means objectives to achieve it. Moreover, they should provide common guidance to all decisions within the organization.

Keeney explains that once the set of objectives appropriate for the decision situation is defined, the next step is to define the attributes for measuring the degree to which these objectives are met. Next, he continues, there needs to be a general structure to combine the various attributes in some proper manner.³⁸

In summary, VFT begins by identifying the DM’s values in a hierarchy of objectives. Then, the objectives are decomposed until a set of attributes can be specified and measured. Weights are assigned to each objective in order to determine their relative importance and finally all the measures are integrated. The output is the value or utility of

³⁶ Ibid., 7.

³⁷ Ibid., 67.

³⁸ Ibid., 131.

the alternatives under analysis.

3.2 Identifying Objectives

Gregory Parnell developed four structured techniques for qualitative value modeling and named them the gold, platinum, silver, and combined standard, respectively. A short description of each one of them is provided below:³⁹

Gold standard – the gold standard value model depends on information collected from an approved vision, policy, strategy, planning, or doctrine document.

Platinum standard – the platinum value model depends on interviews with decision makers and stakeholders.

Silver standard – if the gold standard documents available aren't adequate, and it is not possible to access senior decision makers and stakeholders, the silver standard model is used as an alternative. It uses data from stakeholders' representatives.

Combined standard – this model is used when different standards are combined. The review of gold standard documents combined with findings from interviews with decision makers and stakeholders is a common example of this technique.

Parnell also proposed the use of affinity diagrams to help organize the ideas collected. ⁴⁰First, several verb-object combinations considered to define the main

³⁹ Gregory S. Parnell, "Value Focused Thinking," in *Methods for Conducting Military Operational Analysis*, ed. Andrew G. Loerch and Larry B. Rainey (Military Operations Research Society, 2007), 626.

⁴⁰ *Ibid.*, 640.

objective need to be identified during the interviews with DMs and the analysis of the gold standard documents.

Next, similar ideas should be aggregated in order to “organize and summarize natural groupings among them to understand the essence of the problem.”⁴¹ Such aggregation should form a “complete, non-redundant, and independent set”⁴², in other words, should be mutually exclusive and collective exhaustive. The final output should be the identification of the fundamental objectives considered to be relevant to the decision context.

It is important to emphasize the difference between fundamental objectives and means objectives. The former represent the essential reasons for interest in the decision situation and they are structured in a fundamental objectives network, while the latter are important because of their implications for some other objective and are structured in a means-ends network.

This concept is explained by Keeney:

in a fundamental objectives hierarchy the lower level objectives under any higher-level objective are the answer to the question “What aspects of the higher-level objective are important?”...In a means-ends objectives network, the lower-level objectives under any higher-level objective are the answer to the question “How can the higher-level objective be better achieved?”⁴³

In a mean-ends network, the lower-level objective is a means to the higher-level objective, showing causal relationship. Also, the means objectives are “not a collective

⁴¹ Michael Brassard and Diane Ritter, *The Memory Jogger 2: Tools for Continuous Improvement and Effective Planning*, 2nd ed. (Goal/QPC, 2010), 12.

⁴² G. S. Parnell et al., “Foundations 2025: A Value Model for Evaluating Future Air and Space Forces,” *Management Science* 44, no. 10 (10, 1998): 1339.

⁴³ Keeney, *Value-Focused Thinking*, 71.

exhaustive representation of the means to the higher-level ends”⁴⁴. In other words, several of the means objectives may be means to many other objectives in the network, resulting in complex interrelationships among them.

On the other hand, in a fundamental objectives hierarchy, the lower-level objective is a part of the higher-level objective, with no causal relationship. Keeney expands this concept explaining that

the higher-level objective is defined by the set of lower-level objectives directly under it in the hierarchy. These lower-level objectives should be mutually exclusive and collectively should provide an exhaustive characterization of the higher-level objectives.⁴⁵

In summary, the use of affinity diagrams provides a systematic method to identify the fundamental objectives of interest. The correct definition of objectives will lead to a better understanding of the values that are really important to the decision context, consequently leading to a better value model.

3.3 Identifying Attributes

An attribute measures the degree to which an objective is achieved and the measurement of objectives “clarifies their meaning, and this may lead to the creation of desirable alternatives.”⁴⁶ Keeney divides the attributes in three types: natural, constructed and proxy.⁴⁷

⁴⁴ Ibid., 78.

⁴⁵ Ibid.

⁴⁶ Ibid., 99.

⁴⁷ Ibid., 101.

The natural attributes (see table 1) usually are the ones that have a common interpretation to everyone and are obviously related to the objectives being measured:

Table 1. Example of a Natural Attribute.

Objective	Attribute
Minimize time	Time measured in minutes

The constructed attributes are used as alternatives when the natural attributes do not exist or cannot be determined. This kind of attributes are developed specifically for a given decision context (see table 2).

Table 2. Example of a Constructed Attribute.⁴⁸

Attribute level	Description of attribute level
0	No loss of productive wetlands or rare species habitat
1	Loss of 320 acres of productive wetlands and no loss of rare species habitat.
2	Loss of 640 acres of productive wetlands and no loss of rare species habitat or loss of 30 acres of rare species habitat and no loss of productive wetlands.
3	No loss of productive wetlands and loss of 50 acres of rare species habitat.
4	Loss of 640 acres of productive wetlands and loss of 40 acres of rare species habitat.
5	Loss of 640 acres of productive wetlands and loss of 50 acres of rare species habitat.

Finally, the proxy attributes are used when it is difficult to identify either a natural attribute or a constructed attribute and it is necessary to use an indirect measure. Keeney defines a proxy attribute as “one that reflects the degree to which an associated objective

⁴⁸ Ibid., 107.

is met but does not directly measure the objective.”⁴⁹

All the three types of attributes described should be measurable, operational and understandable in order to clarify the respective objectives and avoid ambiguity, thus facilitating the next step; the construction of the model’s quantitative part.

Moreover, the set of attributes for each fundamental objective must be defined based on the following desirable properties:⁵⁰

Completeness – the set must cover all the important aspects of the problem.

Operational – it must be used meaningfully in the analysis.

Decomposable – the aspects of the evaluation process can be simplified by breaking down it into parts.

Nonredundant – double counting impacts must be avoided.

Minimal – the problem dimension must be kept as small as possible.

One last aspect to be emphasized is that “a set of attributes is not unique for a specific problem nor is it unique for a specific objectives hierarchy.”⁵¹ The choice of the better set of attributes depends on the uses of the analysis and on the assessments of utilities.

⁴⁹ Ralph L. Keeney and Howard Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs* (John Wiley & Sons Inc, 1976), 55.

⁵⁰ *Ibid.*, 50.

⁵¹ *Ibid.*, 53.

3.4 Value versus Utility

The distinction between value and utility functions is one important aspect to be addressed when working with multiple attributes. The theoretical differences between both concepts must be understood in order to choose the correct approach when trying to build a value model.⁵²

Conventional decision analytic theories and procedures distinguish between riskless and risk events.⁵³ Strictly speaking, value measures should be used when decision making is done under conditions of certainty, in which the events are riskless. On the other hand, in situations where a decision has to be done under uncertainty, a utility function should be built, in order to incorporate the DM's attitudes toward risk.

The elicitation methods used to construct utility functions involve the use of gambles as oppose to the methods used to construct value functions, in which the DM is only required to rank order sure outcomes in a way consistent with his preferences.⁵⁴ Thus, in theory, utility functions are assumed to be different from value functions, because the former incorporate risk attitudes, while value latter does not.⁵⁵

Nevertheless, there is some controversy in the literature about the distinctions of value and utility and some authors argue that there is no distinction between the measures of value and utility.

⁵² The term "value model" is used here for models using utility or value functions.

⁵³ D. von Winterfeldt and W. Edwards, *Decision Analysis and Behavioral Research* (Cambridge University Press, 1986), 211.

⁵⁴ Robert T. Clemen, *Making Hard Decisions: An Introduction to Decision Analysis*, 2nd ed. (South-Western College Pub, 1997), 620.

⁵⁵ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 212.

Winterfeldt and Edwards argue that the distinction between value and utility for theoretical, psychological, and practical reasons are spurious. One of their assertions is that “there are no sure things, and therefore values that are attached to presumably riskless outcomes are in fact attached to gambles.”⁵⁶ According to them the choice between risky and riskless models should be left to the analyst.

On the other hand, Keeney and Raiffa greatly emphasize the theoretical differences between value and utility measures. According to them, the value functions and related elicitation methods should be used when there is a certain known consequence associated to each alternative. The case where the consequence is known only in probabilistic terms should use utility functions.⁵⁷

Nevertheless, more recently, Keeney and Winterfeldt stated that for many decision situations, it is reasonable to assume that the measurable value function and the utility function are identical and this assumption should not be the weak link in any analysis.⁵⁸

In this thesis, the construction of the value model was based on the concepts of utility theory. The decision context of comparing and prioritizing requests of aircraft systems that do not necessarily exist incorporates a certain level of uncertainty about future levels of performance. Thus, the DM’s attitudes toward risk were considered an important aspect to be included in the model.

⁵⁶ Ibid., 213.

⁵⁷ Keeney and Raiffa, *Decisions with Multiple Objectives*, 6.

⁵⁸ Detlof von Winterfeldt and Ralph L. Keeney, “Practical Value Models,” in *Advances in Decision Analysis: From Foundations to Applications*, ed. Ward Edwards and Ralph F. Miles Jr. Jr, 1st ed. (Cambridge University Press, 2007), 237.

3.5 Attitude toward Risk

There are three possible attitudes toward risk that the DM can take: risk-averse, risk-seeking and risk-neutral. To understand these concepts it is important to define certainty equivalent (CE) and risk premium (RP).

First, consider a DM facing a lottery yielding either U\$ 10,000 or U\$ 2,000, with equal probability of 0.5 for both outcomes. Clearly, the expected value (EV) of this lottery is U\$ 6,000. Suppose that the DM is asked to state his preference between receiving U\$6,000 for certain and taking the lottery. If he chooses to receive U\$ 6,000 for certain, it means that he prefers to avoid the risks associated with the lottery, thus showing risk-aversion. The CE of this lottery would be the number such that the DM is indifferent between the lottery and receiving a certain payoff.

In the example above, suppose that the DM is indifferent between receiving U\$ 4,000 (CE) and the lottery. The RP of this lottery is given by the expression $RP(L) = EV(L) - CE(L)$, where L is the associated lottery. This example would yield a RP of U\$ 2,000.

Thus, it is possible to state that, with respect to attitude toward risk, a DM is:⁵⁹

- **Risk-averse** if and only if for any nondegenerate lottery L, $RP(L) > 0$
- **Risk-neutral** if and only if for any nondegenerate lottery L, $RP(L) = 0$
- **Risk-seeking** if and only if for any nondegenerate lottery L, $RP(L) < 0$

⁵⁹ Wayne L. Winston, *Operations Research: Applications and Algorithms*, 4th ed. (Duxbury Press, 2003), 750.

Moreover, the shape of the utility function also shows the DM's attitude toward risk (see fig. 7). Concavity in a utility curve implies that an individual is risk-averse.

On the other hand, a convex utility curve indicates risk-seeking behavior. In the previous example, a risk-seeking DM would choose the lottery instead of the certain amount. In other words, a risk-seeking DM is one who is “willing to gamble.”⁶⁰

Finally, a risk neutral behavior is reflected by a utility function that is simply a straight line.

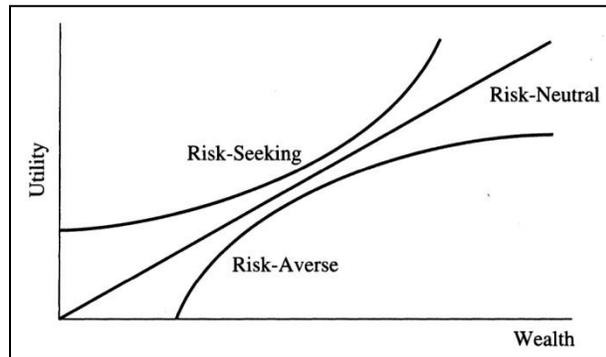


Figure 7. Three Different Shapes for Utility Functions.⁶¹

3.6 Quantitative Value Model

The construction of a value model is characterized by qualitative and quantitative relationships. Once the objectives hierarchy is complete and all the attributes are defined, the measures need to be integrated.

⁶⁰ Keeney and Raiffa, *Decisions with Multiple Objectives*, 158.

⁶¹ Clemen, *Making Hard Decisions*, 532.

The structure to combine the different attributes is built using a value model v (also called objective function) that assigns a number $v(x)$ to each consequence $x=(x_1, x_2, \dots, x_N)$, where x_i is a level of attribute X_i measuring objective O_i , such that the numbers assigned indicate the relative desirability of the consequences and can be used to derive preferences for alternatives.⁶²

As explained earlier, the objective function can be used as a utility function because “most complex decision situations involve significant uncertainties, and therefore attitudes toward risk are important.”⁶³ The ultimate utility function u , related to the overarching objective, is subdivided into parts and later integrated to find the final results.

The multiattribute utility theory (MAUT) addresses the utility measurement in such situations, where single-attribute evaluations are constructed and then the tradeoffs among attributes are quantified as importance weights. Finally, “formal models are applied to reaggregate the single-attribute evaluations.”⁶⁴

One important step during the MAUT model building is to determine the importance weights of each attribute. The swing-weighting technique is one of the most common and “can be used in virtually any weight-assessment situation.”⁶⁵ One important characteristic of this method is that the swing weights are sensitive to the range of values of an attribute. Thus, it is mandatory to emphasize this aspect during the elicitation process, in order to avoid distortions in the results. The use of this technique is also

⁶² Keeney, *Value-Focused Thinking*, 129.

⁶³ *Ibid.*, 132.

⁶⁴ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 259.

⁶⁵ Clemen, *Making Hard Decisions*, 615.

described by Kirkwood.⁶⁶

The aggregation of the single-attribute utility functions will depend on certain independence conditions among the attributes. The interactions among them will define the type of the utility function that will be used, usually the additive or the multiplicative model.

3.7 Independence Conditions

There are four main independence conditions relevant to MAUT: preferential, weak-difference, utility, and additive independence. The first two conditions are related to the use of value functions, with no uncertainty involved. Thus, only utility and additive independence will be addressed in this work, since they are related to situations with uncertainty involved, where utility functions must be defined.

The following definitions and assessment examples were taken from the work of Keeney and Raiffa, where Y and Z are attributes with respective consequences y and z .

“Definition: We shall say that attribute Y is utility independent (UI) of attribute Z when conditional preferences for lotteries on Y given z do not depend on the particular level of z .”⁶⁷

The following questions simulate a hypothetical utility independence assessment with a DM and help to clarify this concept:

⁶⁶ Craig W. Kirkwood, *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets*, 1st ed. (Duxbury Press, 1996), 70.

⁶⁷ Keeney and Raiffa, *Decisions with Multiple Objectives*, 226.

“If z is held fixed through at z^0 , what is your certainty equivalent for a 50-50 gamble yielding values y_1 and y_2 , say? Let us suppose the answer is y^\wedge .”⁶⁸

Next, the following question is asked:

“If z were held fixed at some other fixed value, say z' , would your certainty equivalent shift?”⁶⁹

If the answer is no, then utility independence holds. The inverse procedure must also be done in order to check if Z is UI from Y . If they are, the utility function for Z can be defined without worrying about dependence on y .

All cases are possible: neither holds, one holds without the other, nor both hold. When both attributes are UI, they are Mutually Utility Independent (MUI).

“**Definition:** Attributes Y and Z are additive independent (AI) if the paired comparison of any two lotteries, defined by two joint probability distributions on $Y \times Z$, depends only on their marginal probability distributions.”⁷⁰

An equivalent condition for Y and Z to be additive independent can be represented by the lotteries in figure 8, which must be indifferent to the DM, for all (y, z) given an arbitrarily chosen y' and z' .

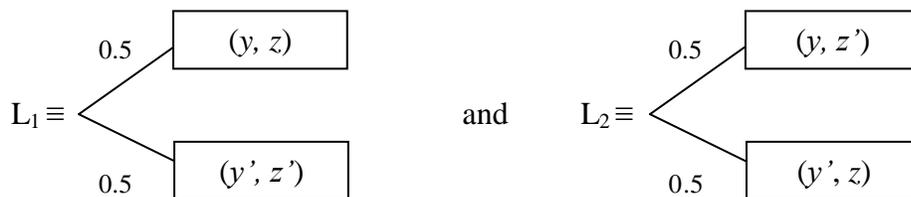


Figure 8. Additive Independence Assessment.⁷¹

⁶⁸ Ibid.

⁶⁹ Ibid.

⁷⁰ Keeney and Raiffa, *Decisions with Multiple Objectives*, 230.

Additive independence is a stronger condition than UI. The intuitive thinking behind AI is that, in assessing uncertain outcomes over both attributes, it is only needed to look at one attribute at a time, regardless of the other attribute's values.

In the case of more than 2 attributes, the procedure is similar. The attributes other than *Y* and *Z* are fixed at some convenient level and the same lottery comparison is made. If the DM remains indifferent between both lotteries, additive independence holds, otherwise, UI needs to be assessed.

Differently from UI, the additive independence is reflexive, thus if the condition holds, it means that both attributes are AI from each other. Also, AI “implies that *Y* and *Z* are MUI, however the converse is not true.”⁷²

The assessment of these independence conditions will define the form of the utility functions comprising the value model. The most common forms are the additive and the multiplicative.

If additive independence holds between the attributes, the additive representation can be used, which is the simplest form. It basically calculates the utility scores for each objective and then add the scores, weighting them according to the relative importance of the various objectives.⁷³ This representation of the utility function does not allow for interactions among the attributes.

⁷¹ Ibid.

⁷² Ibid.

⁷³ Clemen, *Making Hard Decisions*, 599.

The aggregation with an additive model is given by the following equation:⁷⁴

$$u(x_1 \dots x_N) = \sum_{i=1}^N k_i u_i(x_i), \text{ where}$$

u = overall utility function

x_i = measurement (level, degree) of x on attribute i

u_i = single-attribute utility function (attitude toward risk is embodied)

k_i = weight of attribute (indicate value tradeoffs)

If AI does not hold, it is needed to build a utility function that permits interactions among the attributes. In such cases, the multiplicative utility function can be used. In the case of more than 2 attributes, the multiplicative form requires a stronger version of utility independence, in which each subset of attributes must be UI of the remaining attributes. In the case of n attributes, n utility independence assumptions would be required.⁷⁵

This means that it should be possible to partition the attributes in two subsets, and then consider lotteries in one subset, “holding the attributes in the other subset fixed.”⁷⁶ If the preferences for the lotteries remain unchanged, regardless of the level of the remaining attributes, “the multiplicative utility function should provide a good model of the decision maker’s preferences.”⁷⁷

⁷⁴ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 276.

⁷⁵ Keeney and Raiffa, *Decisions with Multiple Objectives*, 292.

⁷⁶ Clemen, *Making Hard Decisions*, 660.

⁷⁷ Ibid.

The multiplicative utility function requires the addition of a single parameter k .

The equation for n different attributes is given by:⁷⁸

$$1 + ku(x_1 \dots x_n) = \prod_{i=1}^n [k k_i u_i(x_i) + 1], \text{ where}$$

u = overall utility function

x_i = measurement (level, degree) of x on attribute i

u_i = single-attribute utility function (attitude toward risk is embodied)

k_i = weight of attribute (indicate value tradeoffs)

k = parameter that defines all interaction terms

According to Keeney and Raiffa, the parameter k “indicates the manner in which the amount of one attribute affects the value of the other attribute.”⁷⁹ According to them, if $k > 0$ then one attribute complements the other, because in this case, it would be important to do well in both attributes in order to increase the utility value. On the other hand, if $k < 0$, the attributes are substitutes of each other, implying that it is important to do well in at least one of the attributes. Finally, if $k = 0$, the model becomes the additive model and there is no interaction among the attributes.⁸⁰

To determine the appropriateness of each one of the independence conditions, a series of paired comparisons must be performed, which will be described later. The

⁷⁸ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 276.

⁷⁹ Keeney and Raiffa, *Decisions with Multiple Objectives*, 241.

⁸⁰ Ibid.

reader should refer to the work of Keeney and Raiffa⁸¹ in order to find an extensive treatment of the proofs and theories behind the subject of this section.

⁸¹ Keeney and Raiffa, *Decisions with Multiple Objectives*.

4. MODEL CONSTRUCTION

4.1 Decision Support

As explained earlier, Brazil is going through a prosperous economic period and the government policies for the Defense area (NSD) are giving strong emphasis on the strengthening and improvement of the operational capabilities of the Armed Forces. The trend is to continue the modernization process of the armament systems.

In the BAF, this policy is reflected mainly by the acquisition of new aircraft systems, which must be carefully selected according to the specific tasks and scenarios expected to be faced in the future. In addition, the costs of aeronautical systems are high and their life cycles usually take from 30 to 40 years. Thus, decisions and choices made today will affect the organization for a long time, which brings more weight to the decision context of this thesis.

The main purpose of this research is to provide the DM with a model composed of both a qualitative and a quantitative component, capable to function as a tool to compare how well each one of the different aircraft systems in consideration contribute to the accomplishment of the BAF's objectives, defined by strategic documents.

Keeney claims that “the motivation for building a value model is the same as for any model; namely, the intent is to have the model lend some insight into a complex situation to complement intuitive thinking.”⁸²

4.2 Definition of Objectives

Jobim points out that “the evaluation of the necessities turns the equipment in a tool to achieve an objective, instead of an end in itself. First the tasks need to be identified and then the means to accomplish them.”⁸³

To construct the model, a top-bottom approach was used, therefore the overarching objective of the model needed to be defined in order to guide the construction of the fundamental objectives hierarchy. Due to the nature of the problem, the research was focused on identifying a clear statement of the objective, related to the operational capability of the BAF.

This work used the combined standard method and this part of the research focused only on strategic and doctrinaire documents related to the Defense area and to the BAF (gold standard documents).

During the research, it was identified that one of the BAF’s strategic objectives is to strengthen and refine its operational capability.⁸⁴ This objective inspired the definition

⁸² Keeney, *Value-Focused Thinking*, 130.

⁸³ Jobim, “A Defesa na Agenda Nacional: O Plano Estratégico de Defesa,” 12.

⁸⁴ Ministry of Defense of Brazil, *National Strategy of Defense*.

of the overarching objective of the model: **maximize the contribution of the aircraft systems to the BAF's operational capability.**

Next, this top-level objective needed to be further specified and clarified in order to break it into logical parts, supposed to “indicate the set of objectives over which attributes should be defined.”⁸⁵

This step required a clear definition of the meaning of *operational capability* in order to guide the research efforts. Although a clear definition of the term was not found in any official document, the following concepts were used to derive it, as well as the opinion of senior DMs:

Operational readiness - The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed. May be used in a general sense or to express a level or degree of readiness.⁸⁶

Operational efficiency – Ability of an operational organization to accomplish, appropriately and with economy of means, all the combat missions, provided in its doctrinal basis.⁸⁷

Operational capability (DM) – Ability to perform the tasks for which the organization is designed.

Thus, for the purpose of this work, the operational capability of the BAF was defined as:

⁸⁵ Keeney, *Value-Focused Thinking*, 69.

⁸⁶ The U.S. Department of Defense, *The Dictionary of Military Terms*, Original. (Skyhorse Publishing, 2009), 345.

⁸⁷ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas* (Brasília, Brasil, 2007), 87.

the ability to perform the missions or functions for which the BAF is designed, according to its doctrinal basis.

This definition was used to derive the lower level objectives, which are supposed to answer the following question: “what aspects of the higher level objective are important?”⁸⁸

The next step of the research used the affinity diagram methodology in order to answer this question. Since the scope of the decision context was limited to analyze the contribution of aircraft systems to the BAF’s operational capability, the research in the gold standard documents as well as the elicitations focused only on aspects related to the aerial component.

For example, the tasks related to the maintenance of a runway strip were not considered, even though they contribute to the BAF’s operational capability. Figure 9 illustrates this approach, where a strategic objective needs to be specified in order to limit the decision context and define the overall fundamental objective.

⁸⁸ Keeney, *Value-Focused Thinking*, 71.

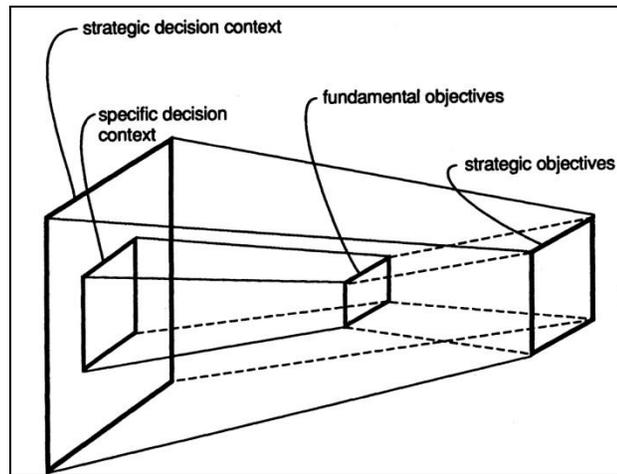


Figure 9. Decision Frame with Fundamental Objectives.⁸⁹

All the tasks collected during the research were later combined into logical groups. The result was a set of four mutually exclusive, collective exhaustive groups, which had names assigned to them according to the nature of their tasks.

Table 3 shows the source of each one of the tasks collected and figures 10 and 11 show the four major groups initially identified by the first affinity exercise. The letters D (DCA 1-1), N (NSD) and R (Research) relate each task to their source.

⁸⁹ Ibid., 84.

Table 3. Tasks Listed by Source.

DCA 1-1	NSD	RESEARCH AND ELICITATION
Airlift cargo	Attack precisely	Attack submerge targets
Airlift personnel	Autonomous navigation	Attack targets in surface
Attack targets	Control airspace	Communicate securely
Deploy troops	Control jurisdictional waters	Control airspace
Destroy enemy	Control territory	Defend air force assets
Escort friendly force	Ensure local air superiority	Destroy target
Extract information	Exercise surveillance of the air	Detect naval assets in sea level
Integrate communications	Exercise surveillance of the jurisdictional waters	Detect submerge naval assets
Integrate equipment	Exercise surveillance of the territory	Identify targets
Intercept targets	Maintain readiness	Integrate communications
Maximize flexibility	Maximize C2 capacity	Integrate data
Maximize mobility	Maximize intelligence capacity	Integrate equipment
Maximize penetration	Maximize interoperability	Intercept target
Maximize range	Maximize mobility	Maintain air superiority
Maximize speed	Maximize presence	Maximize auto defense
Minimize decision loop time	Maximize rescue capability	Maximize C2 capability
Neutralize enemy	Maximize search capability	Maximize data link capability
Observe	Monitor airspace	Maximize detection capacity
Patrol area of interest	Monitor jurisdictional waters	Maximize equipment availability
Perform Aerial Refuel	Monitor territory	Maximize Intelligence capability
Perform AWACS	Perform vigilance of air	Maximize mobility
Perform basic training	Perform vigilance of land	Maximize presence
Perform close air support (CAS)	Perform vigilance of sea	Operate in bare bases
Perform flight inspection	Project power	Operate in hostile electromagnetic environment
Perform Intelligence Activities	Respond promptly	Perform CSAR operations
Perform Medical Evacuation	Transport troops	Use airborne sensors in subsurface
Perform reconnaissance	Use intelligence aircrafts	Use airborne sensors in the air
Recover personnel		Use airborne sensors in the surface
Rescue		Use short runways
Respond promptly		
Resupply		
Search		
Secure the use of EW		
Suppress enemy defense		

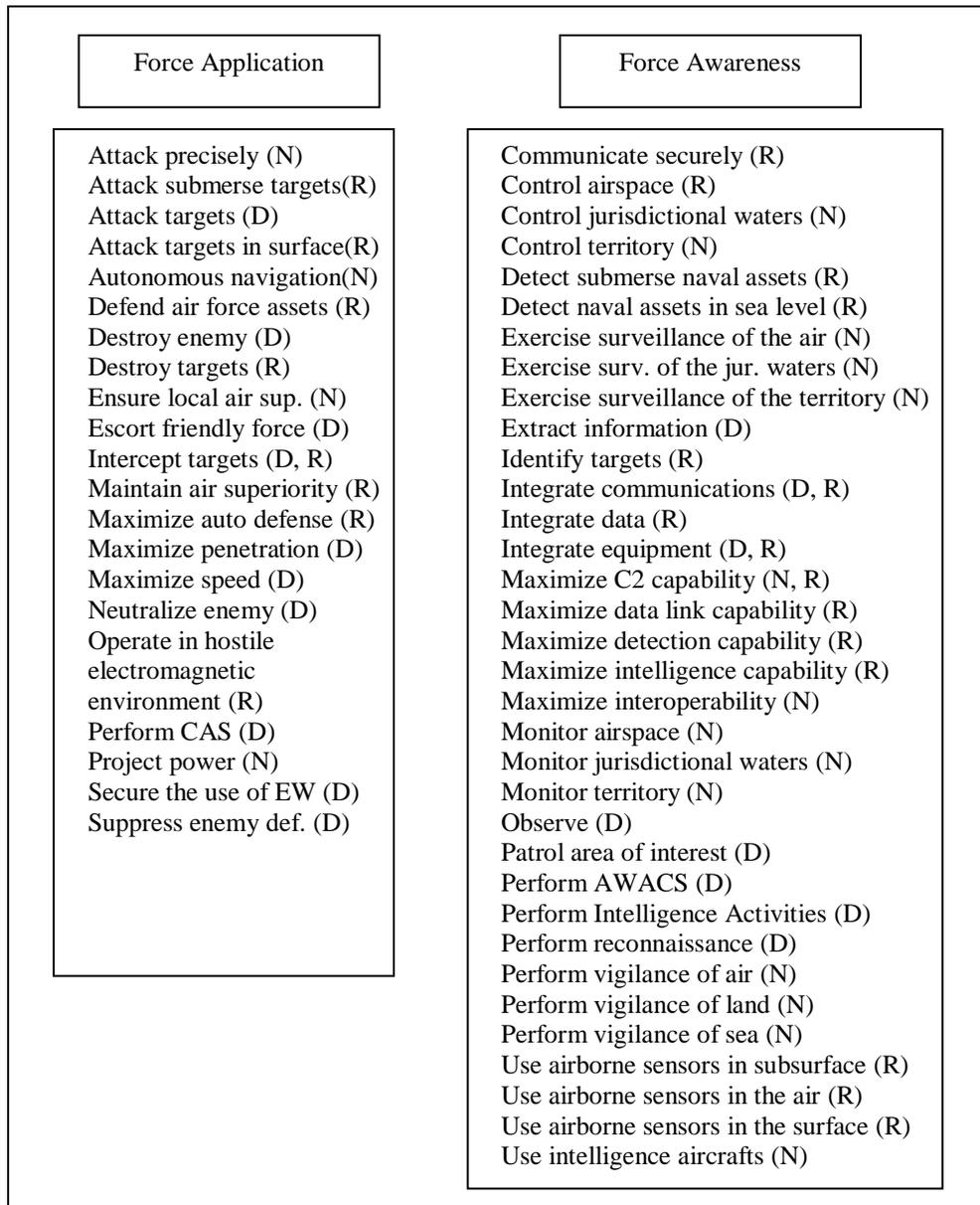


Figure 10. First Affinity Diagram Exercise – Part 1.

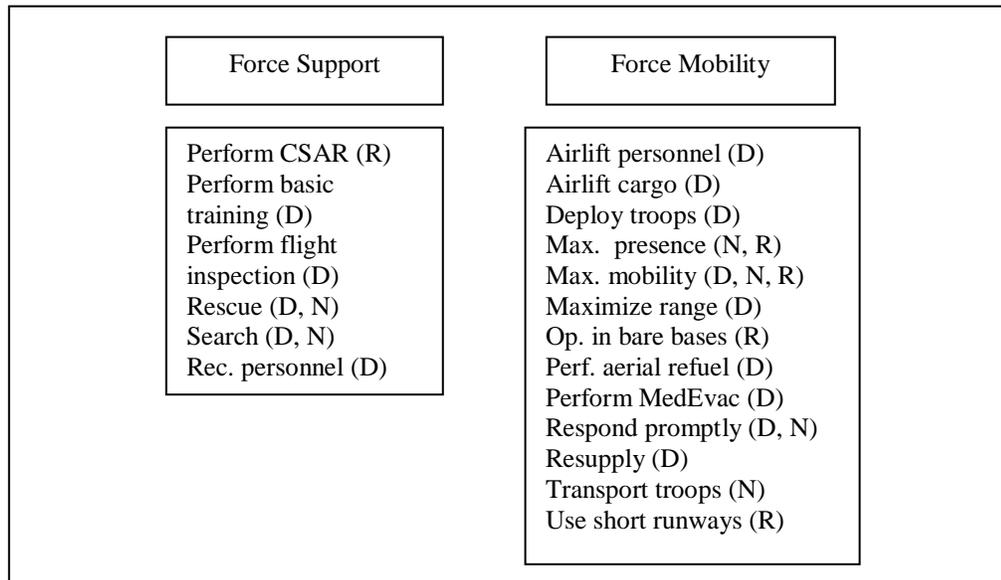


Figure 11. First Affinity Diagram Exercise – Part 2.

4.3 The Model

The high level objectives were defined according to the ideas identified in the affinity diagrams and were meant to specify the overarching objective of the model. Therefore, the overall utility function was defined as having four major components, each one of them concerning one important area thought to contribute to the BAF's operational capability.

These four high level objectives were identified as:

1. Maximize the contribution to the Force Application capability.
2. Maximize the contribution to the Force Awareness capability.
3. Maximize the contribution to the Force Mobility capability.
4. Maximize the contribution to the Force Support capability.

The following definitions were adopted in order to clarify the meaning of each objective and guide the construction of the remaining tiers of the hierarchy. They are based on the ideas in the affinity diagrams upon which the objectives were defined.

Force Application: ability to destroy, neutralize and affect targets including forces, people, and equipment as well as the ability to survive in a hostile environment.

Force Awareness: ability to maintain an accurate perception of the factors and conditions affecting the environment by detecting and processing relevant information to create a composite picture of the current situation and act on this picture to make a decision or to perform further exploration.⁹⁰

Force Mobility: ability to move personnel, materiel and forces by air and operate with the same efficiency from any airfield.⁹¹ This includes both airlift and air refueling.

Force Support: ability to perform missions that provide support to personnel as well as to the aeronautical infra structure. Includes rescue missions and basic flight training.

The second affinity diagram exercise specified the four high level objectives until a complete set of objectives was defined (see fig. 12 to 15).

⁹⁰ D. Curtis Schleher, *Electronic Warfare in the Information Age* (Artech House Publishers, 1999), 31.

⁹¹ Comando da Aeronáutica, *DCA 1-1 Doutrina Básica da Força Aérea Brasileira* (Brasília, Brasil: Comando da Aeronáutica, 2005), 21.

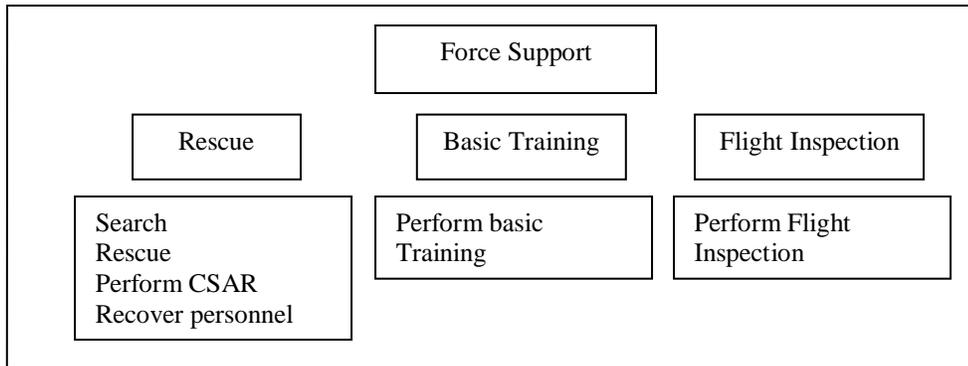


Figure 12. Second Affinity Diagram Exercise – Force Support.

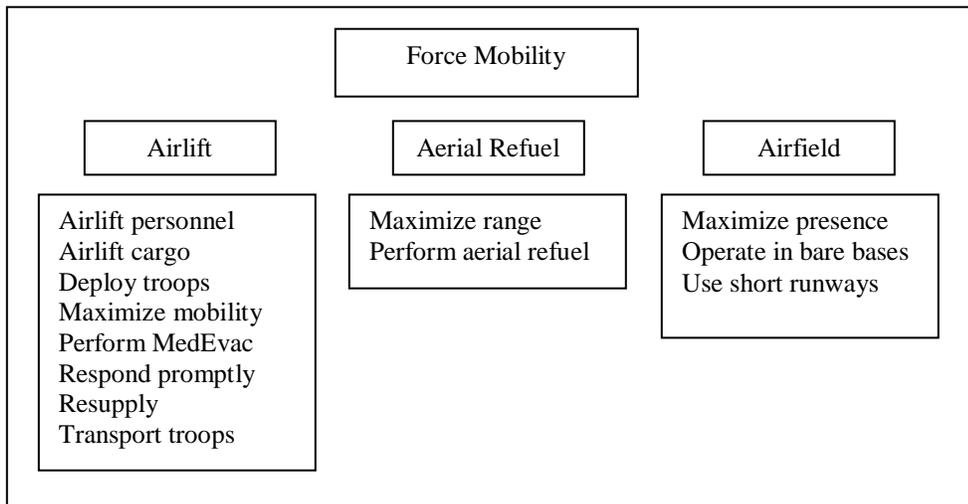


Figure 13. Second Affinity Diagram Exercise – Force Mobility.

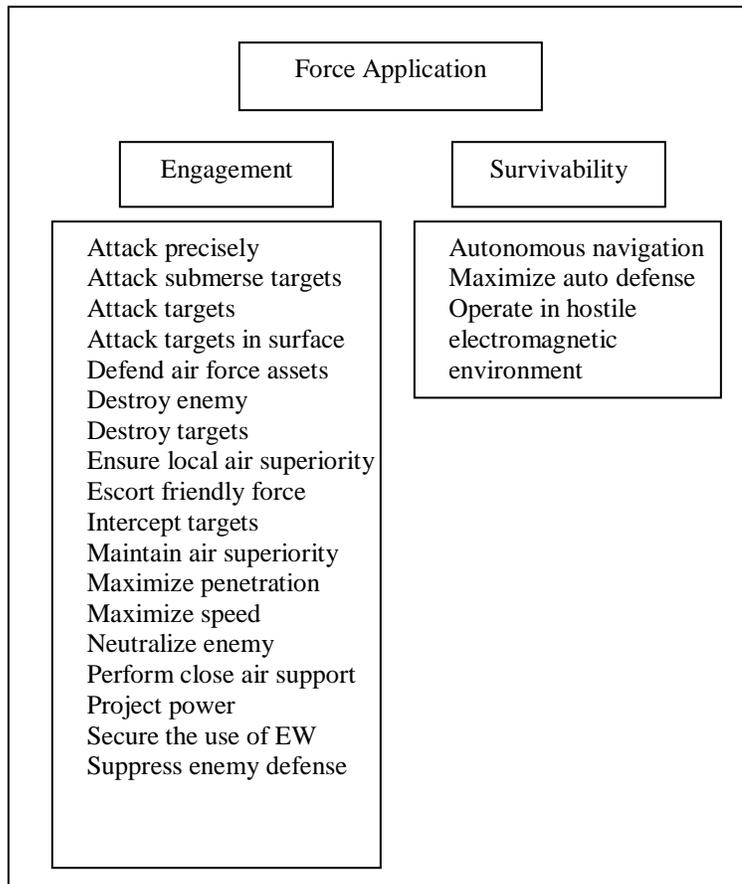


Figure 14. Second Affinity Diagram Exercise – Force Application.

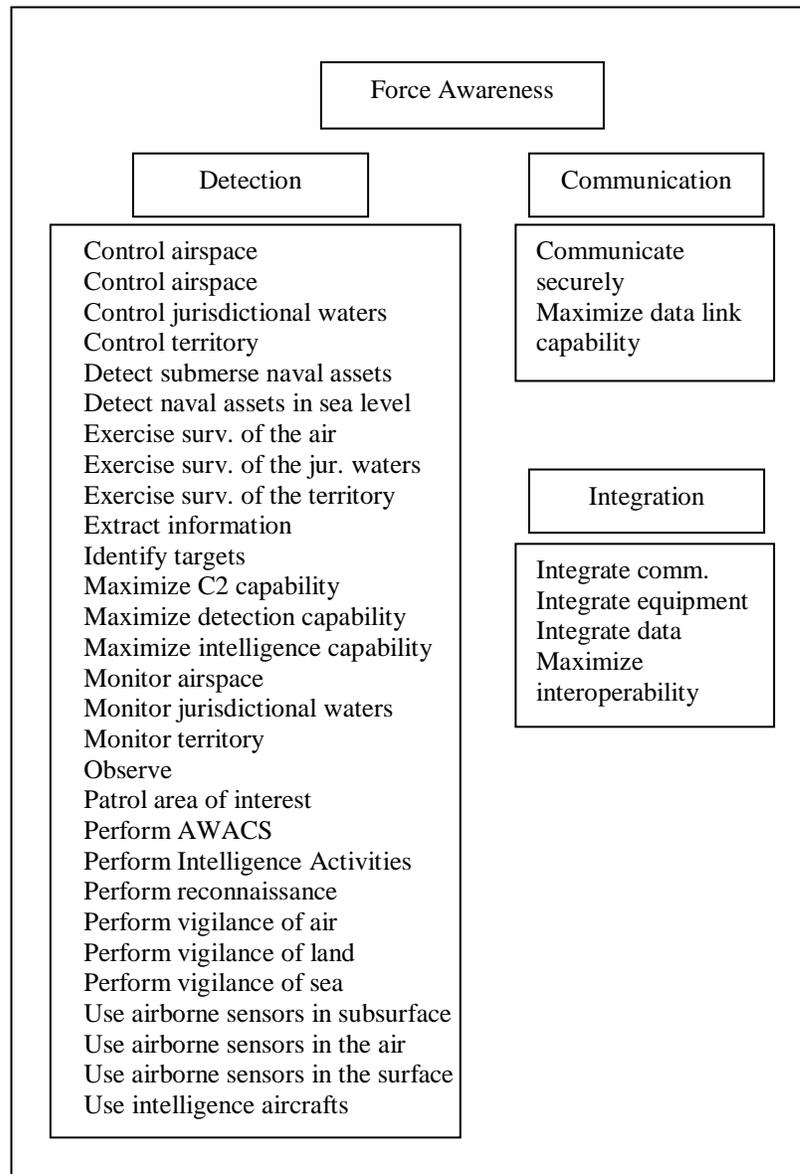


Figure 15. Second Affinity Diagram Exercise – Force Awareness.

Some objectives were considered as fundamentally different, depending on the medium in which they take place. For example, to engage a target in the air is completely

different from engaging a target in the surface or in the subsurface. The same rationale applies when trying to detect a target.⁹²

Therefore, some activities were considered as being different capabilities according to the medium in which they are performed. This distinction generated a further specification of the respective fundamental objectives (see fig. 16 to 20).⁹³ It is important to note that the medium distinction intends to distinguish where the target is located and not where the aircraft engaging or detecting is located.

Also, the objective 2.3 Communication was further specified in Data and Voice, which are considered different means of communication and require different capabilities and equipments. A complete specification of the objectives is listed in the Appendix 1.

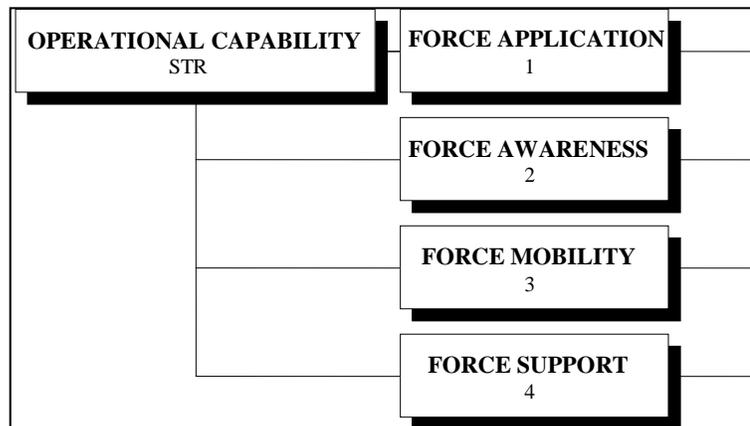


Figure 16. Fundamental Objectives Hierarchy - Top Level.

⁹² Parnell et al., “Foundations 2025,” 1341.

⁹³ From Logical Decision for Windows (LDW).

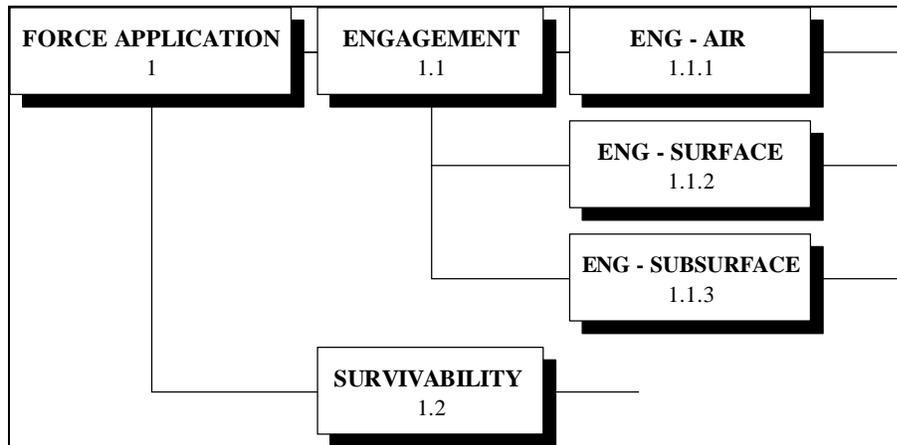


Figure 17. Fundamental Objectives Hierarchy – Force Application.

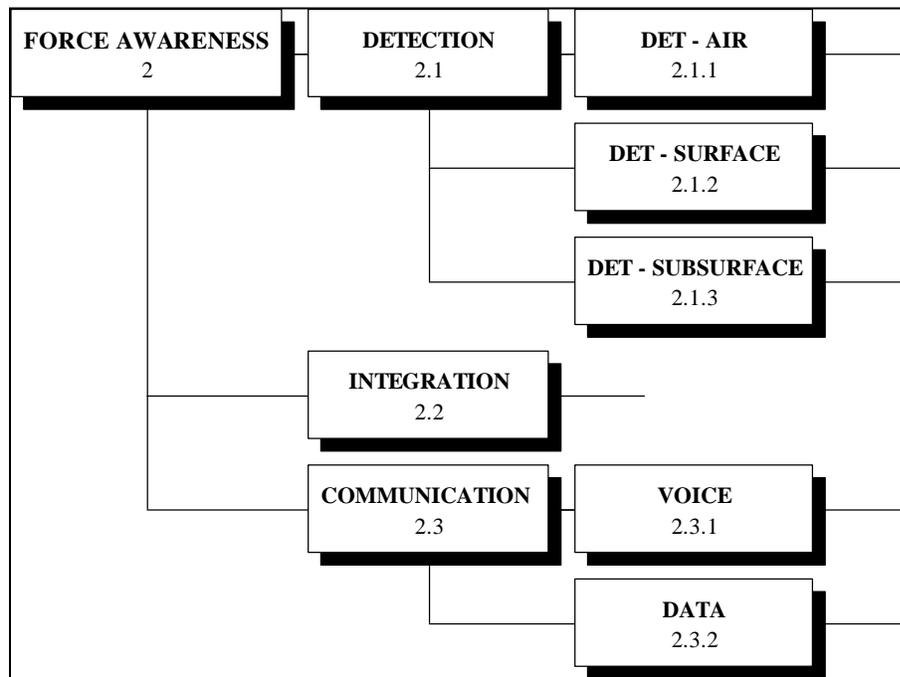


Figure 18. Fundamental Objectives Hierarchy – Force Awareness.

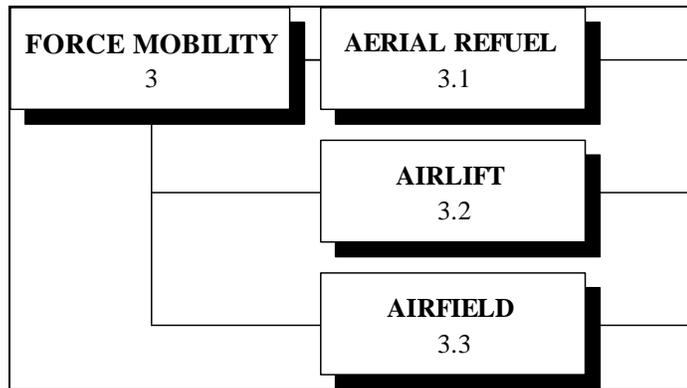


Figure 19. Fundamental Objectives Hierarchy – Force Mobility.



Figure 20. Fundamental Objectives Hierarchy – Force Support.

The proliferation of the hierarchy in the lateral direction, as well as the vertical must be avoided. Thus, after the hierarchy was completed, the test of importance was conducted in order to check if any of the objectives could be discarded “without leading the DM astray.”⁹⁴

Such test consisted in asking the DM whether he felt the best course of action could be altered if a specific objective was excluded. An affirmative response implied

⁹⁴ Keeney and Raiffa, *Decisions with Multiple Objectives*, 43.

that the objective should be kept in the hierarchy. A negative response was taken as a reason for exclusion.⁹⁵

One important aspect is that the objectives hierarchy for a particular problem is not unique. Keeney and Raiffa argue that “whether one arrangement is better than another is mainly a matter of the particular points the decision maker and the analyst wish to make.”⁹⁶

4.3.1 Attributes

Though the hierarchy described in the previous section represented an important achievement in the development of the qualitative part of the model, meaningful attributes to the lower level objectives still needed to be defined. This step was accomplished, based on personal expertise, research, and elicitations with experts. The goal was to identify the set composed of the most important attributes for each fundamental objective at the lower level of the hierarchy.

Since the process of identifying attributes is “basically creative in nature”⁹⁷, several attributes were generated for each objective using a brainstorming type of approach. Then, the list was refined taking the attributes desired properties in consideration. For example, the first assessment of the objective **1.1.1(maximize the**

⁹⁵ Ibid.

⁹⁶ Ibid., 47.

⁹⁷ Ibid., 64.

capability to engage targets in the air) generated nine different attributes that were later reduced to only three.

The attribute *Multirole* was initially generated with the intent to measure the adaptability to different types of missions. It was judged to be redundant with the attribute *Scope*, which measures the capability to perform missions in different weather conditions. The analysis showed that the *Multirole* capability was already being addressed by the model as a whole and thus, *Scope* would be more important to measure for that particular objective.

Another important aspect, during the attributes definition was to choose a metric for each one of them. Using the attribute *A1.1Combat Radius* as an example, the metric chosen was Nautical miles, which is a natural scale of distance commonly used in aviation.

Next, a range (best and worst levels) needed to be defined. Winterfeldt and Edwards recommend that the end points of the scale should not only consider the available alternatives, but also any possible future alternatives. This approach was considered to be most appropriate to use in this work and thus, the acceptable ranges were defined, based on the “objects that one would be willing to consider.”⁹⁸

Continuing with the previous example, the range of *A1.1Combat Radius* was defined based on research to identify aircraft with different levels of this attribute. The best performance levels were used as a guide to define the top of the range. The bottom

⁹⁸ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 230.

was defined as zero, a value that would be suitable to any alternative without the capability to engage targets in the air.

Figures 21 to 24 show the whole structure of the value model with its objectives and attributes, divided according to each high level fundamental objective. A complete explanation of all the attributes can be found in Appendix 2 and will not be repeated here.

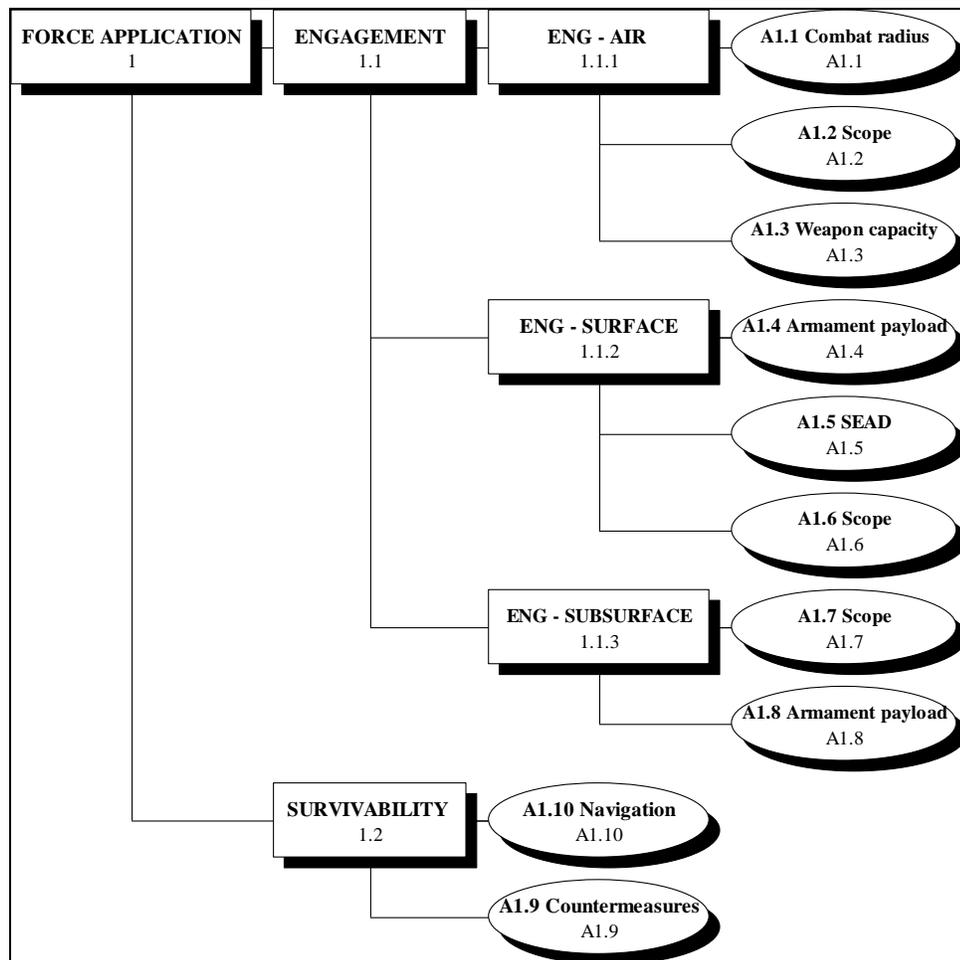


Figure 21. Force Application Objectives Hierarchy and Attributes.

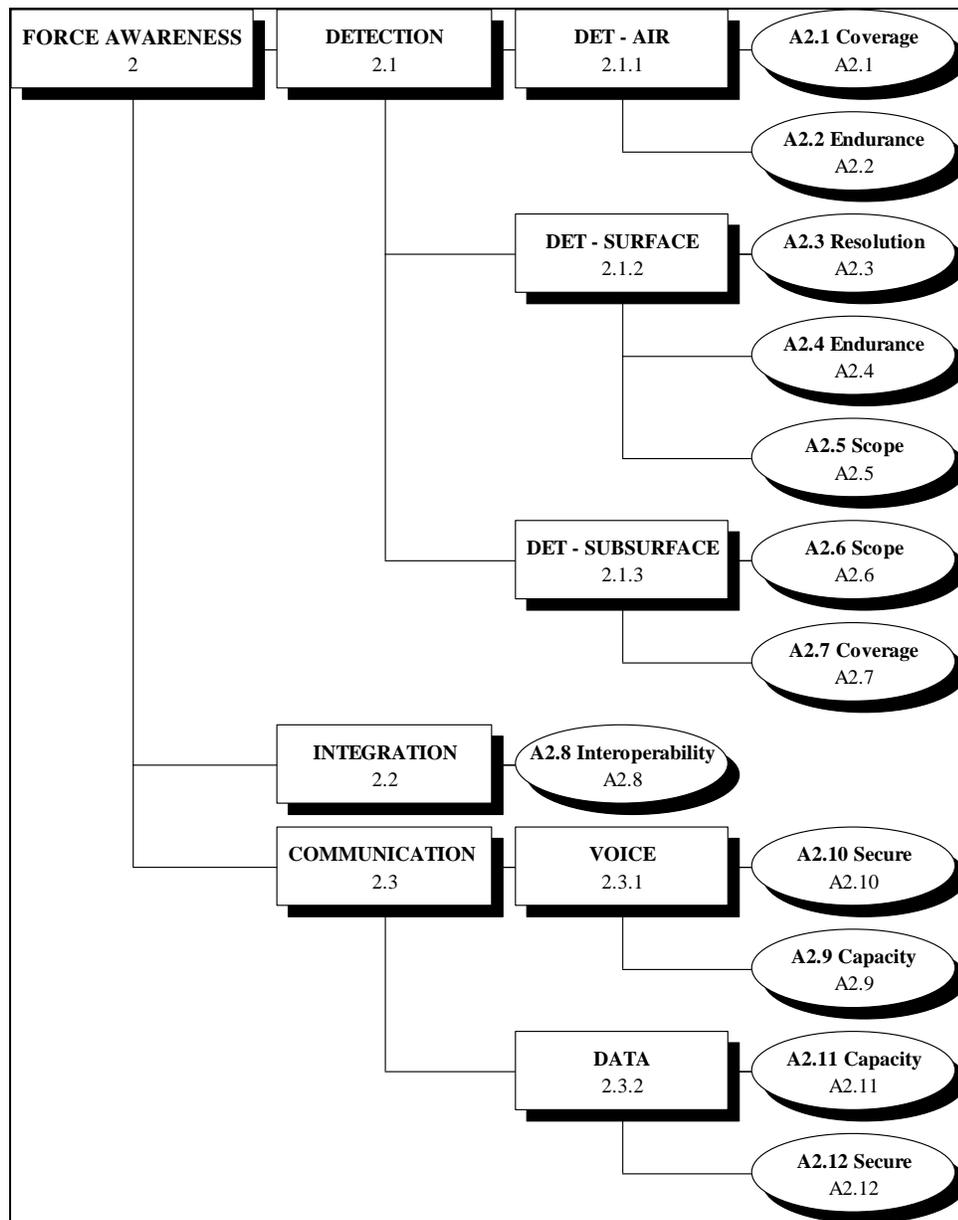


Figure 22. Force Awareness Objectives Hierarchy and Atributes.

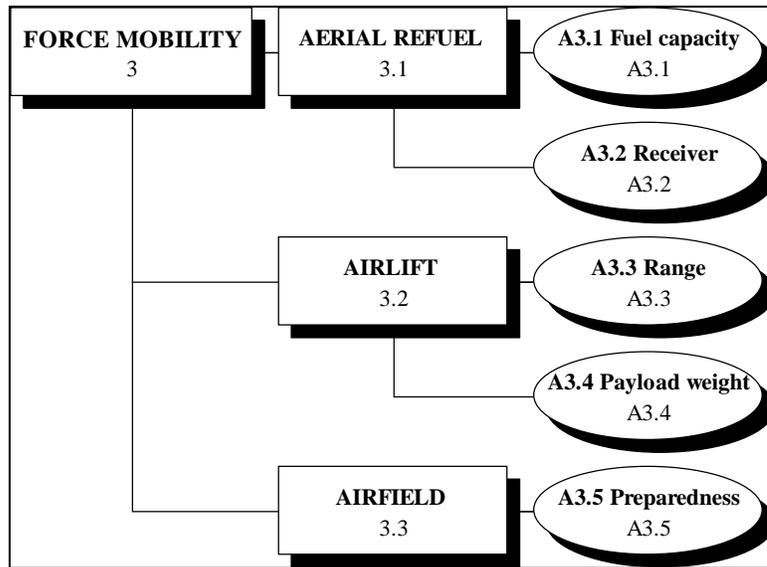


Figure 23. Force Mobility Objectives Hierarchy and Attributes.

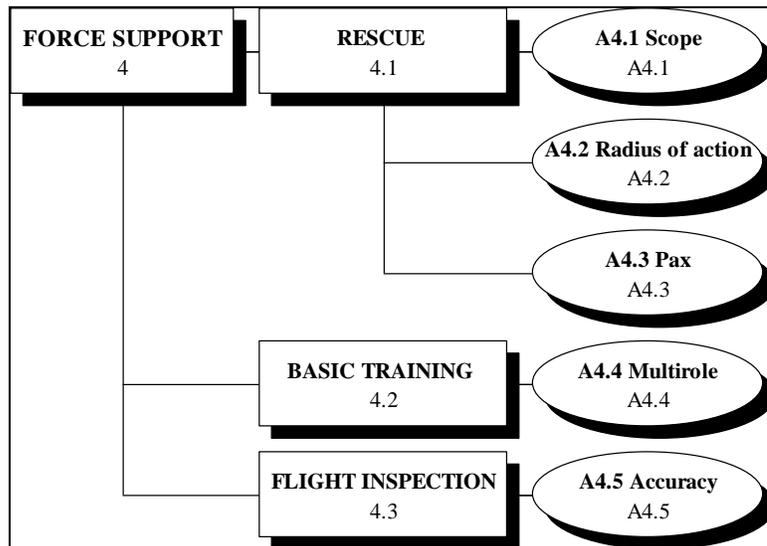


Figure 24. Force Support Objectives Hierarchy and Attributes.

4.3.2 Assumptions

As described before, the value model was built based on the identification of objectives using affinity diagrams. This methodology identified ideas that were mutually exclusive and collective exhaustive, considering the decision context of this research.

In other words, mutual exclusivity means that the objectives stemming from the same parent should not be redundant, while collective exhaustive means that the objectives expressed at each level of the hierarchy must completely define its parent.

The goal was to identify fundamental objectives as oppose to means objectives. As explained before, the theory behind the fundamental objectives is that the lower-level objectives are part of the higher-level objectives, with no causal relationships. “Fundamental objectives hierarchies have a clear and simple order. Each lower-level objective pertains only to the upper level objective directly above it.”⁹⁹ This structure led to the assumption of an additive value model for the fundamental objectives hierarchy.

Clemen and Reilly argue that the additive utility function is very useful when used in value models with many attributes:

any approach that helps to understand tradeoffs among objectives is welcome and the additive utility function, despite its limitations, is exceptionally useful in the process of understanding preferences and resolving a difficult decision, especially in complicated situations with many attributes.¹⁰⁰

⁹⁹ Keeney, *Value-Focused Thinking*, 78.

¹⁰⁰ Clemen, *Making Hard Decisions*, 621.

Keeney and Winterfeldt point out that “not always it is necessary or useful to construct a ‘state – of – the art’ value model, completely justified on theoretical grounds.”¹⁰¹ They claim that

Approximations may do well both in modeling and assessment. The choice of value models and assessment procedures is a function of the characteristic of the decision being faced, the characteristics of the decision maker or makers, the time available for the process, and the skills of the analyst that is facilitating the process.¹⁰²

The methodology used to construct the hierarchy followed all the steps to ensure that the objectives generated were fundamental objectives and not means objectives, thus the additive utility function was considered to be a reasonable assumption.

This approach made possible the use a simpler method to assess the independence conditions. The process was done by verifying the independence assumptions among the attributes stemming from each fundamental objective.

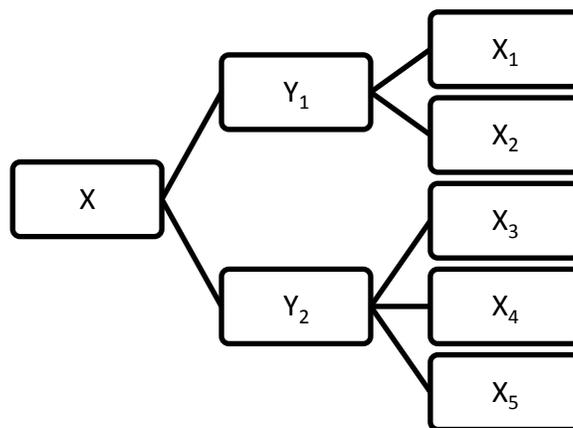


Figure 25. A Hierarchy of Objectives for a Hypothetical Problem.¹⁰³

¹⁰¹ Winterfeldt and Keeney, “Practical Value Models,” 233.

¹⁰² Ibid.

¹⁰³ Keeney and Raiffa, *Decisions with Multiple Objectives*, 332.

Using the objectives hierarchy in figure 25 as an example, Keeney and Raiffa say that once the subset of attributes Y_1 is determined to be utility independent of Y_2 , it is possible to speak of preferences and utility functions over Y_1 without considering the levels of the attributes within Y_2 , which can be specified at some convenient level.¹⁰⁴

Hence, the verification of independence assumptions was done within each subset of attributes stemming from the fundamental objective they were supposed to measure. The results showed that some attributes interacted, thus the multiplicative utility function was used to integrate them.

4.3.3 Assessment Procedure

Due to restrictions of time and access to senior DMs, the complete elicitation process was actually done just in part of the model. The remainder of the model was assessed using information collected through research and personal experience. This should not be considered a major limitation, since the main concern is to correctly apply the proposed methodology. Moreover, the data used to build the model can be updated at any time.

The following steps were followed during the elicitation with the DM:¹⁰⁵

1. Introduction of terminology and ideas.
2. Identification of relevant independence conditions.

¹⁰⁴ Ibid., 332-333.

¹⁰⁵ Ibid., 261.

3. Assessment of the conditional utility functions.
4. Assessment of the scaling constants.
5. Consistency check.

Before the assessment began it was made very clear to the DM that the preferences of interest to the model are his. It was explained that there are no correct preferences and that the preferences should represent his subject feelings.

Also, since one of the purposes of the utility analysis is to make the DM think with care about his preferences, it was emphasized that changes along the process were completely normal and necessary for a correct analysis.

As described earlier, the ranges of the attributes were defined based on research and expert assessment. Thus, it was also emphasized that the preferences assessed should only consider the consequences within that limited space, which is represented by (y, z) with $y^0 \leq y \leq y^*$ and $z^0 \leq z \leq z^*$ (see fig. 26).¹⁰⁶

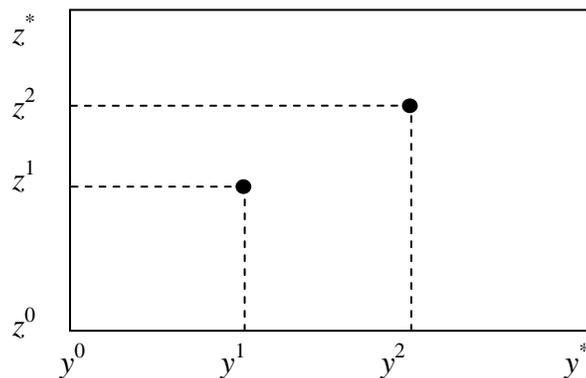


Figure 26. A Two-Attribute Consequence Space.

¹⁰⁶ Ibid., 262.

The next step was to verify the additive independence assumptions. It was done through assessment of the attributes under each fundamental objective in order to define the form of the utility function (see section 3.7). The assessment procedure was conducted following the methodology proposed by Keeney and Raiffa.¹⁰⁷

Since the additive independence implies utility independence, the assessment started verifying the former. If additive independence did not hold, then utility independence was assessed.

As an example, the procedure used to assess the independence conditions between the attributes **A3.3 Range** (y) and **A3.4 Payload Weight** (z) will be described. The attributes Y and Z are additive independent if and only if the lotteries in figure 27 are indifferent for all amounts of y, z given a specific y', z' .

In this example: $y = 5, y' = 0, z = 250, z' = 0$

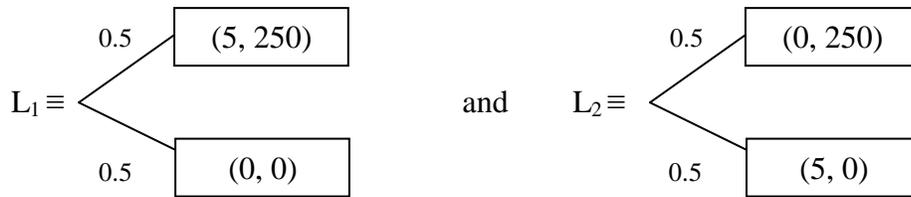


Figure 27. Additive Independence Assessment.

Practically speaking, for any of the pairs taken from figure 26, the DM should be indifferent between lotteries L_1 and L_2 for additive independence to hold. In this specific

¹⁰⁷ Keeney and Raiffa, *Decisions with Multiple Objectives*.

example, additive independence did not hold because the DM preferred L_2 . For him it would be undesirable to run the risk to have both attributes at such a low level as proposed in L_1 . He felt it was more comfortable to have at least one of the attributes at a high level. As explained in section 3.7, this is a case where the attributes complement each other and the utility function must be multiplicative.¹⁰⁸

If additive independence held, step three of the assessment procedure could have begun. Since it did not hold, it was necessary to verify utility independence. The following questions, adapted from Keeney and Raiffa (226), were made to the DM:

Analyst: Consider a 50-50 lottery between 5 (y_1) and 0 (y_2) for a fixed level of $z = 100$ (z_1). Now think hard about what amount of y you would want for certain, always keeping z_1 fixed, so that you are indifferent between the certainty amount and the 50-50 lottery (this question elicited the CE, which will be used later).

DM: Ok

Analyst: Now, when you were thinking about your break-even y , was it important to you to keep in mind the level of z ? Suppose we let $z = 50$ (z_2) instead of 100 (z_1), would it have made any difference?

DM: No, it would not.

This answer suggested utility independence between the two attributes. Since the property is not reflexive, the same assessment was made to check if Z was utility independent of Y , and thus, mutually utility independent (MUI). In a similar manner, Z

¹⁰⁸ Ibid., 291.

was found to be utility independent of Y . This result suggested that a **multiplicative** utility function could be used in this part of the model.¹⁰⁹

When the number of attributes was $n > 2$, the independence assumptions were checked in a similar way, according to the explanation in section 3.7. When additive independence did not hold, n utility independence assumptions were verified to make sure that the multiplicative form could be used.

Continuing with our example, the next step was to assess the single utility functions of each attribute. The method used involved the use of 50-50 lotteries, in order to determine the CE for that particular lottery.

The first step was to determine the CE $x_{.5}$ for the lottery (x_1, x_0) , where x_1 has utility 1 (best level of the attribute) and conversely, x_0 has utility 0 (worst level of the attribute):

$$u(x_{.5}) = 0.5 u(x_1) + 0.5 u(x_0)$$

Next, the CE for $(x_1, x_{.5})$ and $(x_{.5}, x_0)$ were assessed in a similar fashion, yielding:

$$u(x_{.75}) = 0.5 u(x_1) + 0.5 u(x_{.5})$$

$$u(x_{.25}) = 0.5 u(x_{.5}) + 0.5 u(x_0)$$

¹⁰⁹ Ibid., 289.

Still using the attribute **A3.3 Range** as an example, it was clear that the DM's preferences increase in x , meaning that more range is better, thus the following points in the utility function could be derived:

$$u(x_0) = u(300) = 0$$

$$u(x_{.25}) = u(900) = 0.25$$

$$u(x_{.5}) = u(1800) = 0.5$$

$$u(x_{.75}) = u(2700) = 0.75$$

$$u(x_1) = u(4000) = 1$$

A consistency check was performed by assessing the CE for $(x_{.25}, x_{.75})$. The result should be equal to $u(x_{.5}) = u(1800) = 0.5$. In this example the DM was indifferent between the lottery and $x_{.5}$, thus consistent with his preferences.

The assessment procedure yielded a risk averse utility function, meaning that the CEs are less than the expected consequences of their respective lotteries, which means that the DM always prefers the expected consequences to run the risks involved with a lottery.

Since the overall assessment involved the definition of five points, and no serious inconsistencies were identified in the DM's preferences, a three points curve was used to define the utility function -- the least preferred level of the sub-range, the most preferred level of the sub-range and the mid-preference level of the sub range (see fig. 28).

An exponential SUF formula was used to fit a smooth curve to the points using the software LDW. The general formula used was:¹¹⁰

$$U(x) = a + (be^{(-cX)}),$$

where a , b , and c are computed scaling constants and e is the mathematical constant 2.718...

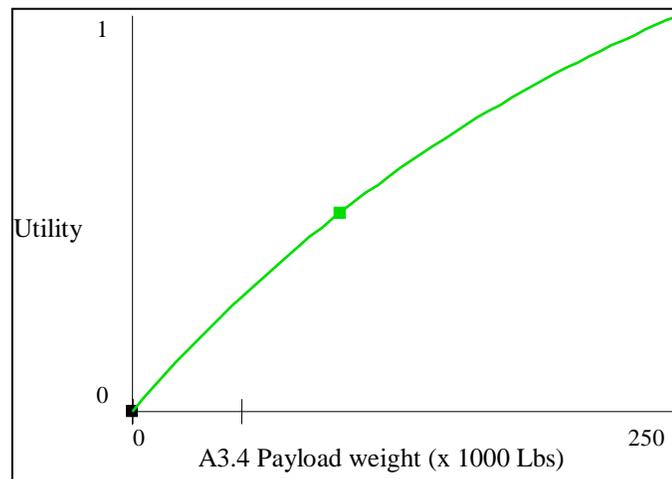


Figure 28. Utility Function for the Attribute A3.4 – Range.

A similar procedure was used to define the utilities for the constructed attributes, which are defined over a discrete scale. The variable probability method presents the DM

¹¹⁰ Gary R. Smith, *Logical Decisions - User's Manual* (Fairfax, VA: Little Booklets & Manuals, 2008), 9-19.

with the option to choose a lottery or a sure thing.¹¹¹ The attribute **A2.3 Resolution** will be used as an example (see fig. 29).

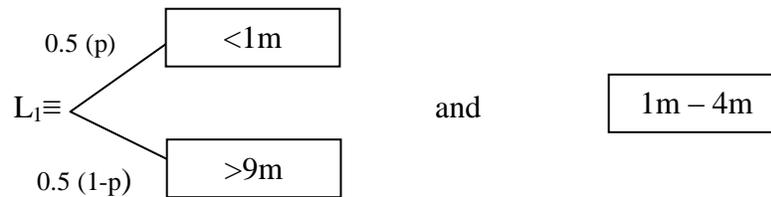


Figure 29. Utility Assessment.

In this gamble the DM is either offered the best level of resolution or the worst level of resolution, both with equal probability of 0.5. The sure thing in this example is the second best level of resolution (1m-4m). The DM is then asked to set the probabilities such that he would be indifferent between the gamble and the sure thing.

In this particular example, the DM felt that the resolution range of 1 to 4 meters was pretty good and he decided to choose it, instead of accepting the gamble. This decision implied that his indifference probability lied between 0.5 and 0.99. After some more thought, he decided that he would be indifferent between the gamble and the sure offer if p was set to 0.80.

The same process was repeated for the remaining levels of this attribute and the utilities were defined according to figure 30. All the utility functions used in the value model can be found in Appendix 3.

¹¹¹ Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 241-243.

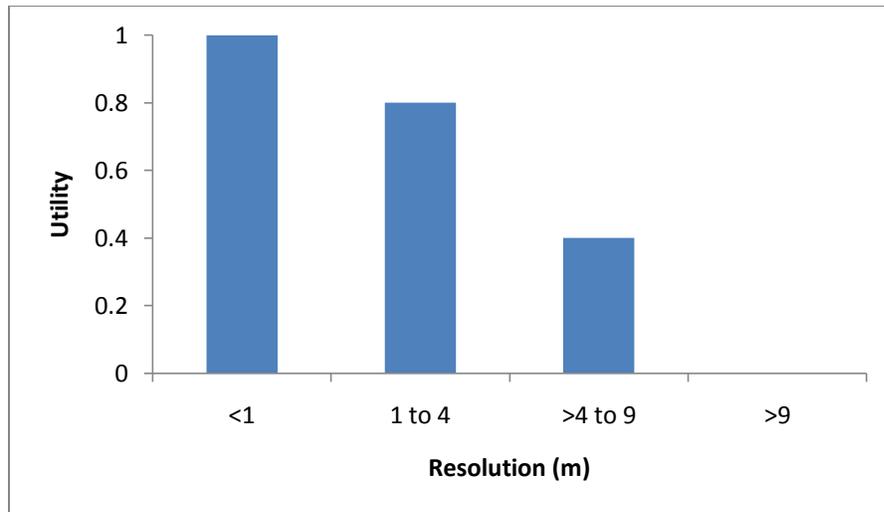


Figure 30. Utility for the Attribute A2.4 – Resolution.

4.3.4 Assessing weights

The swing weighting technique was used to assess the weights of each one of the attributes and objectives of the model. This method requires a thought experiment in which the decision maker compares individual attributes directly by imagining hypothetical outcomes.¹¹²

The following example describes the assessment procedure used to define the weights for the attributes under the fundamental objective **2.1.2 (maximize the capability to detect targets in the surface)**. The first step was to set all the attributes at their worst level. Then the DM was presented with the hypothetical situation in which he was allowed to improve just one member from its least preferred to its most preferred

¹¹² Clemen, *Making Hard Decisions*, 615.

level. The DM decided to improve the attribute **A2.3 Resolution**, which was then assigned a swing weight of 100.

Then, the DM was asked to identify the member he would next most like to improve, and assign it a swing weight reflecting the estimate relative importance of improving this attribute compared with improving his first choice. The DM chose to improve the attribute **A2.5 Scope** and felt that it was as important as the attribute **A2.3 Resolution**. The last attribute of this assessment was **A2.4 Endurance**, which was assigned a swing weight of 75 percent.

Finally, the weights were calculated by determining the normalized ratings, so that the weights sum to 1. Figure 31 illustrates the procedure, performed with the help of LDW.

	Least Preferred Level	Most Preferred Level	Swing Weight (100 = most imp.)
A2.3 Resolution (Meters)	>9	<1	0.364
A2.5 Scope	VMC/day	AWX/day/night	0.364
A2.4 Endurance (Hours)	0	24	0.273

Figure 31. Swing Weights for Objective 2.1.2.

It is important to emphasize that the range of values over which the attributes are defined have great importance when using swing weights. For example, if the attribute

A2.4 Endurance ranged from 0 to 5, the increase in utility from swinging from the worst to the best level would be smaller, probably resulting in a small weight for this attribute.¹¹³ Therefore, the DM was reminded that his judgment should always consider the ranges of each attribute being assessed.

To assess the weights of the fundamental objectives, a similar procedure was used, but the ranges were always between 0 and 1, since they are measured by their respective utility functions.

When the multiplicative utility function was applicable, it was needed to define the parameter k , which represents the interaction among all attributes that are part of that particular utility function.

This step was accomplished using the software LDW, which provides a tool to calculate the value of k . This feature consists of a comparison between lotteries¹¹⁴ called probability method (see fig. 32).

```

Please enter P so that A and B are equally preferred:

Alternative A

  50 percent chance of
    Power = 175 and Fuel Economy = 16
and 50 percent chance of
    Power = 109 and Fuel Economy = 23

Alternative B

P = 50 percent chance of
    Power = 175 and Fuel Economy = 23
and 100 - P percent chance of
    Power = 109 and Fuel Economy = 16

```

Figure 32. LDW Probability Method Example.¹¹⁵

¹¹³ Keeney and Raiffa, *Decisions with Multiple Objectives*, 272-273.

¹¹⁴ *Ibid.*, 240.

The lotteries presented to the DM were similar to the ones used to verify additive independence (see section 3.7). Continuing with the example of the previous section, in alternative A the DM would get the most preferred level on either **A3.4 Payload Weight** or **A3.3 Range**. Alternative B is the "all or nothing" alternative. The DM would get the most preferred level on both measures with probability P or the least preferred level on both measures with probability (1-P).¹¹⁶

In this particular example, the DM chose Alternative B. Then, he was asked to establish the probabilities which would make him indifferent between the alternatives. He decided that P=35%. This value was used by LDW to calculate the parameter k of the multiplicative utility function. When $n > 2$, the attributes chosen to compose the lotteries were the ones with the highest weights.¹¹⁷

A complete description of the procedure to derive the weight parameters for an additive as well as for a multiplicative utility function can be found in the work of Keeney and Raiffa.¹¹⁸

¹¹⁵ Smith, *Logical Decisions - User's Manual*, 5-17.

¹¹⁶ Ibid.

¹¹⁷ Elicited from Gary Smith, developer of LDW.

¹¹⁸ Keeney and Raiffa, *Decisions with Multiple Objectives*.

5. VALUE MODEL RESULTS

5.1 Populating the Model

In order to demonstrate the use of the model, a hypothetical scenario was built, in which the decision maker has to define the priorities among a set of OCRs. The OCRs chosen for this particular scenario are related to aircraft systems with fundamentally different purposes and characteristics (e.g. fighters and helicopters), so that the flexibility and scope of the model could be demonstrated.

It is important to emphasize that, when applicable, the value output of the system requested by an OCR was compared with the value output of the system it was supposed to replace. In this case, the value of interest for the decision context is the marginal contribution to the BAF's operational capability provided by that specific aircraft system (i.e. the difference between utilities).

On the other hand, the aircraft systems supposed to provide a completely new capability to the BAF or to replace a system in the retirement phase of its life cycle were not compared with any other alternative. Therefore, when this situation applied, the utility yielded by the model was directly used in the ranking of alternatives.

An OCR is not supposed to request specific aircraft systems, but only needed capabilities, thus the equipments used in this example are fictional. Nevertheless, data

from real aircraft, available in open sources¹¹⁹, was used to populate the model in order to give more credibility to the results.

Table 4 shows the hypothetical aircraft systems used in this example (see Appendix 5 for a detailed description of their characteristics):

Table 4. Aircraft Systems.

Requested systems	Current systems
Fighter (FTR)	Retirement Phase
Cargo (CGO)	Retirement Phase
Unmanned Aerial Vehicle (UAV)	Non existent
Anti-submarine Warfare(ASW)	Non existent
Helicopter A (HLA)	Helicopter B (HLB)

In this hypothetical decision context, the aircraft systems called Fighter (FTR) and Cargo (CGO) are supposed to replace systems that are in the retirement phase of their life cycle. Therefore, the related OCRs are requesting systems to replace capabilities that will be lost very soon. As explained earlier, in this case the result yielded by the model will be used in the ranking of alternatives.

Similar rationale is applied to OCRs requesting aircraft systems that will bring new capabilities to the BAF. This is the case of the aircraft systems identified as Anti-submarine Warfare (ASW) and Unmanned Aerial Vehicle (UAV).

The aircraft system Helicopter A (HLA) fits in the case where the marginal improvement needs to be determined. It simulates the situation where an OCR requests a new aircraft system due to a good market opportunity. In this example, HLA is supposed

¹¹⁹ Paul Jackson, Kenneth Munson, and Lindsay Peacock, *Jane's All the World's Aircraft 2008-2009* (Jane's Information Group, 2008).

to replace Helicopter B (HLB), which is a system currently in the operational phase of its life cycle, with potentially 10 more years before the retirement phase begins. If HLA is procured, HLB will be sold to another country.

The data listed in Appendix 5 was used to populate each attribute of the model, when applicable. For example, FTR has no rescue capability, thus the attribute **A4.2 Radius of Action** was not applicable to this system. On the other hand, FTR is requested to have an A/A radar with detection capability of approximately 60 Nm, which is considered a surveillance capability, thus, attribute **A2.1 Coverage** is applicable.

In summary, if the aircraft system under analysis has the capabilities required to accomplish a certain fundamental objective, the respective attributes were populated, if not, the attributes were left at their minimum level, yielding a utility of zero in that particular measure.

5.2 Ranking the Alternatives

Once all the data was inserted in the LDW software, the results produced by the model could be assessed. Figure 33 shows the ranking order between all the alternatives under analysis.

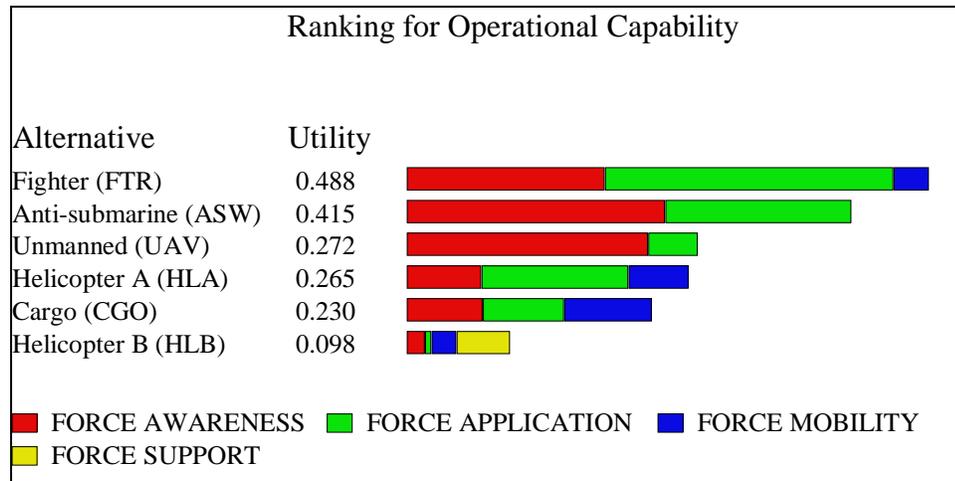


Figure 33. Utilities – Operational Capability.

FTR was ranked as the best alternative. According to the model, it brings the largest contribution to the BAF’s operational capability, followed by ASW, UAV, HLA and CGO. Nevertheless, HLA needs to be analyzed in terms of its marginal contribution for the reasons previously stated.

Figure 34 shows a comparison between HLA and HLB. The total difference between utilities is 0.167, which is smaller than HLA’s original utility of 0.265. This result puts HLA in the last position of the alternatives’ rank, showing how important it is to consider the systems already in use when the situation is applicable. If this aspect was not taken into consideration, the rank among alternatives would certainly be distorted.

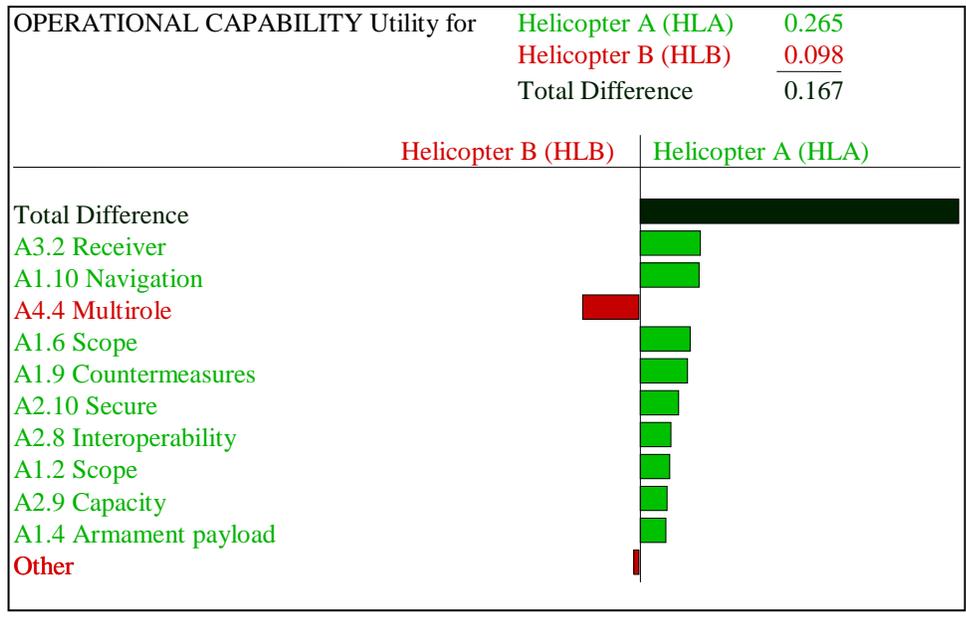


Figure 34. Comparison between Helicopter A (HLA) and Helicopter B (HLB).

Figures 35 to 39 show the results of the remaining alternatives, with their utilities divided by the four high level fundamental objectives. For example, FTR obtained its highest utility under the fundamental objective Force Application and the lowest under the fundamental objective Force Support. The width of each bar is proportional to the weight of the respective objective.

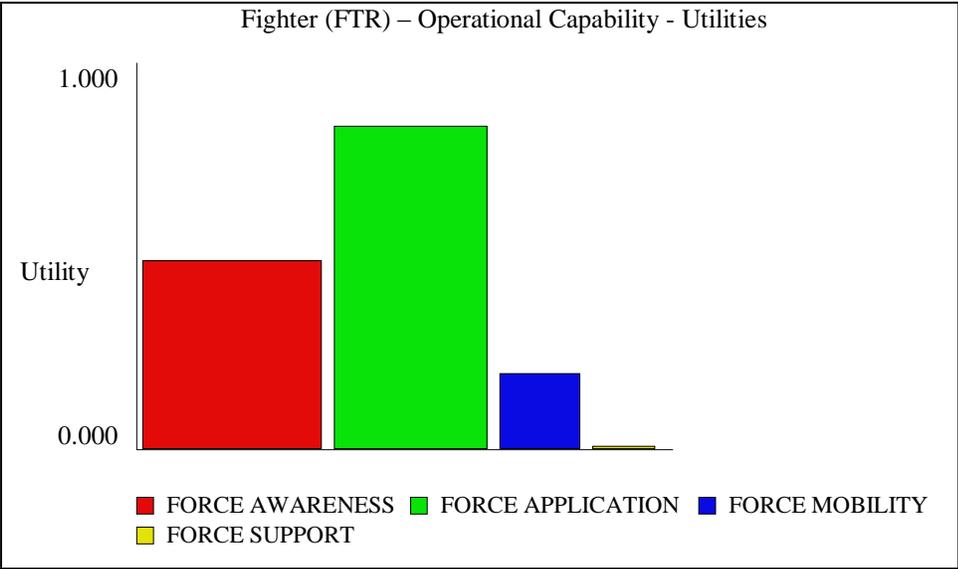


Figure 35. Utilities for Fighter (FTR).

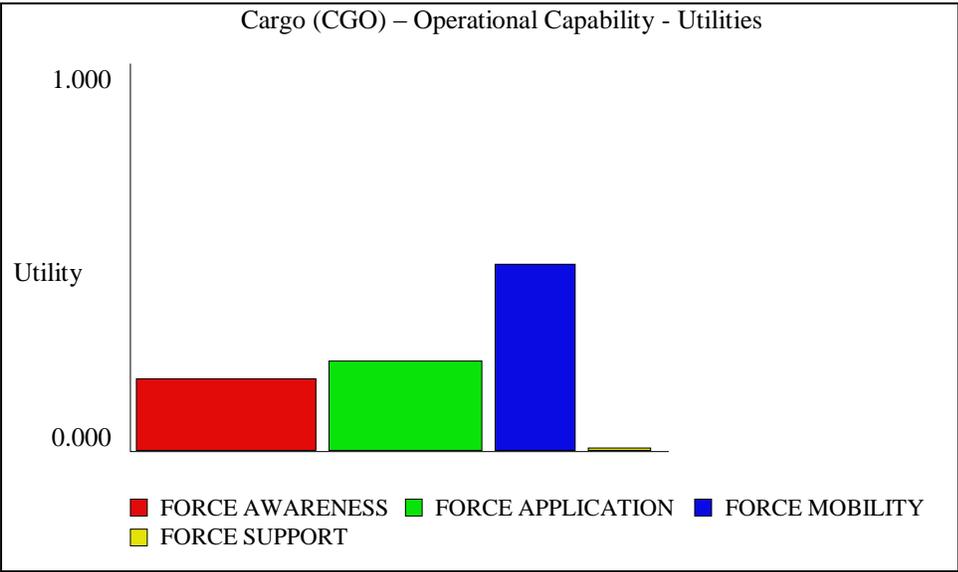


Figure 36. Utilities for Cargo (CGO).

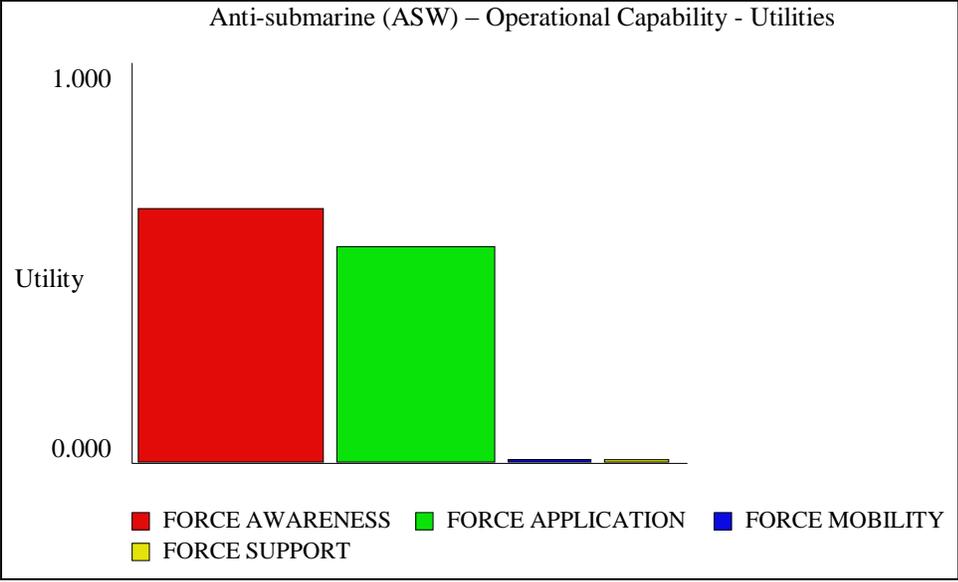


Figure 37. Utilities for Anti-submarine Warfare (ASW).

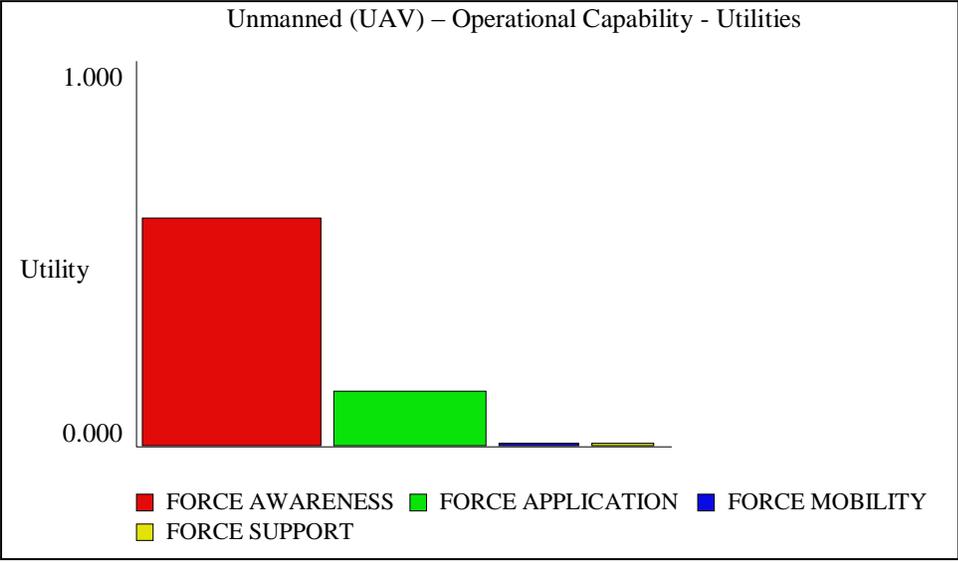


Figure 38. Utilities for Unmanned Aerial Vehicle (UAV).

So, what would be the final rank when considering all the alternatives at hand?

Figure 39 shows the results, now considering HLA's marginal contribution.

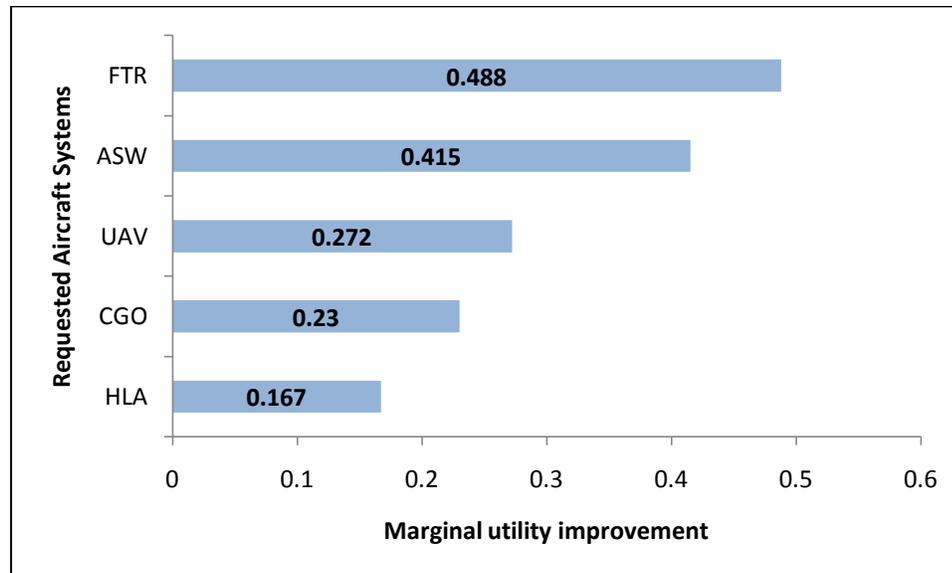


Figure 39. Final Rank of Alternatives.

The final ranking of alternatives will probably generate questions by the DM about the methods used and the reasons for that particular result. For example, if the DM is not comfortable with the fact that the HLA is the last ranked, it can be explained that HLB is currently in use and will be fully operational for years to come, thus the comparison among HLA and HLB yielded a lower utility for HLA.

This type of questions will stimulate a better understanding of important aspects of the decision context and provide the DM with valuable insight, which will complement

the information already provided by the ranking of alternatives, thus justifying the use of decision analysis processes

6. SENSITIVITY ANALYSIS

6.1 Varying Weights

In order to check the robustness of the alternative rankings, a sensitivity analysis was performed by varying the weights. The weights of the higher levels of the objective hierarchy are of particular importance because “many of the weights at lower levels involve technical factors that limit the ability of non-experts to make the required judgments.”¹²⁰ Also, the high level weights represent policy judgments, and it is likely that they could be very different from decision maker to decision maker.¹²¹

Moreover, Winterfeldt and Edwards state that “it is unlikely that the weight judgments at lower levels of the value tree deserve to be included in the sensitivity analysis. Important sensitivities to weights arise at higher levels of those trees.”¹²²

Thus, the first part of the sensitivity analysis was focused on the variation of the weights of the highest level fundamental objectives: Force Application, Force Awareness, Force Mobility and Force Support.

¹²⁰ John C. Butler et al., “The Adoption of Multiattribute Utility Theory for the Evaluation of Plutonium Disposition Options in the United States and Russia,” in *Advances in Decision Analysis: From Foundations to Applications*, ed. Ward Edwards, Ralph F. Miles Jr. Jr, and Detlof von Winterfeldt, 1st ed. (New York, NY: Cambridge University Press, 2007), 499.

¹²¹ Ibid.

¹²² Winterfeldt and Edwards, *Decision Analysis and Behavioral Research*, 414.

This type of analysis looks for points where two or more options are equated in overall utility, the so called switchover points. These points are important because if the results are “remote from switchover points, the analyst can be confident of his conclusions.”¹²³ If not, any small variation on the weights can change the ranking of the alternatives.

The first graph (see fig. 40) shows the effects of varying the weight on the Force Application objective. The line representing this objective’s weight is next to a switchover point between UAV and HLA, which means that small variations in weight could change the ranking order between them. Since the utility value used to rank HLA is based on the comparison with HLB, the sole interpretation of the graph is not enough because the value of interest in this case is the marginal contribution provided by HLA. There is also a switchover point between HLA and CGO and the same rationale applies.

In order to check if any change in the rank of the alternatives would really happen, a table was built with variations of +/- 10% in the Force Application’s weight. The results show that, although the HLA’s utility increases, the ranking of the alternatives remains unchanged.

¹²³ Ibid., 400.

Table 5. Variation of Weight on Force Application.

ACFT	Force Ap. (32.07%)	ACFT	Force Ap. (42.07%)	ACFT	Force Ap. (22.07%)
FTR	0.488	FTR	0.549	FTR	0.447
ASW	0.415	ASW	0.44	ASW	0.402
UAV	0.272	UAV	0.262	UAV	0.296
CGO	0.23	CGO	0.243	CGO	0.244
HLA	0.167	HLA	0.21	HLA	0.136

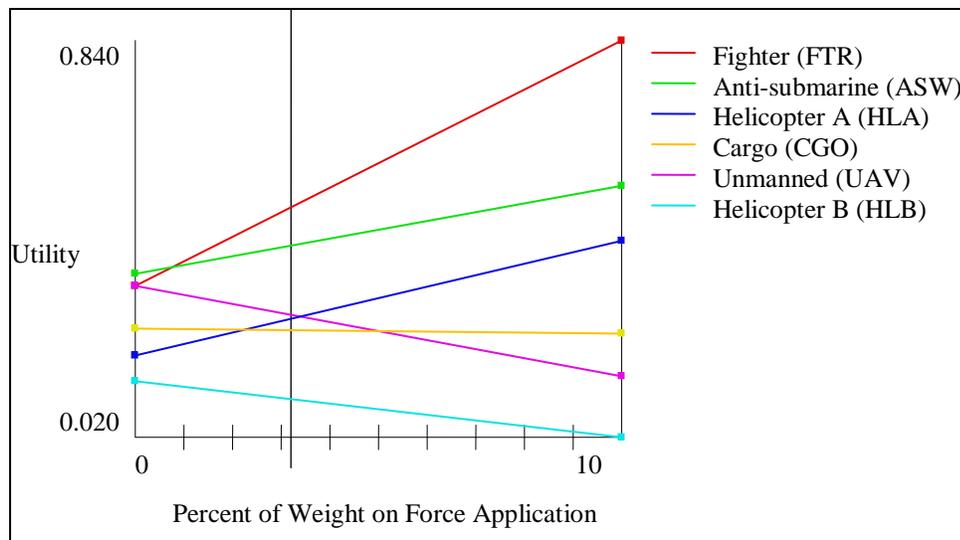


Figure 40. Weight Variation on Force Application.

Similarly to the previous figure, the weight line on Force Awareness is right over the switchover point between UAV and HLA (see fig. 41). But this time, an increase in weight will increase the UAV's utility and decrease the HLA's utility. The inverse occurs if the weight is decreased. Also, there is a switchover point between UAV and CGO relatively close to the weight line.

The great variations in the utility of the UAV and the ASW are an expected effect, since these aircraft systems are directly related to ISR missions, which contribute directly to the force awareness. Table 6 shows that no variation occurs in the ranking of the alternatives when the weight is increased. On the other hand, a decrease of weight by 10% on Force Awareness is enough to invert the ranking between CGO and than UAV.

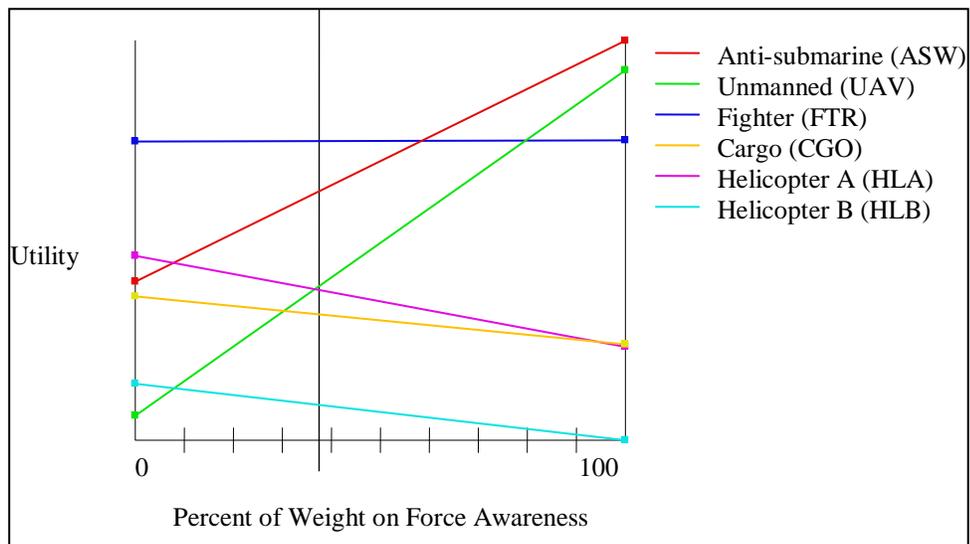


Figure 41. Weight Variation on Force Awareness.

Table 6. Variation of Weight on Force Awareness.

ACFT	Force Aw. (37.73%)	ACFT	Force Aw. (47.73%)	ACFT	Force Aw. (27.73%)
FTR	0.488	FTR	0.5	FTR	0.496
ASW	0.415	ASW	0.457	ASW	0.384
UAV	0.272	UAV	0.331	CGO	0.248
CGO	0.23	CGO	0.239	UAV	0.227
HLA	0.167	HLA	0.169	HLA	0.178

An increase in the weight on Force Mobility yields an increase in the utility of HLA and a decrease in the utility of UAV. This is a result of the HLA's capability to operate in unprepared runways. A decrease in weight would produce inverse effects. Figure 42 shows that the weight line is over the switchover point between these two alternatives. As in the previous case, there is also a switchover point between UAV and CGO relatively close to the weight line.

The results show that an increase of 10% in the weight on Force Mobility will change the ranking order between UAV and CGO. This is an intuitive result, since CGO's main purpose is to provide mobility to the force. The ranking order of the other alternatives remains unchanged.

Table 7. Variation of Weight on Force Mobility.

ACFT	Force Mob. (16.98%)	ACFT	Force Mob. (26.98%)	ACFT	Force Mob. (6.98%)
FTR	0.488	FTR	0.462	FTR	0.534
ASW	0.415	ASW	0.37	ASW	0.471
UAV	0.272	CGO	0.275	UAV	0.313
CGO	0.23	UAV	0.245	CGO	0.212
HLA	0.167	HLA	0.177	HLA	0.17

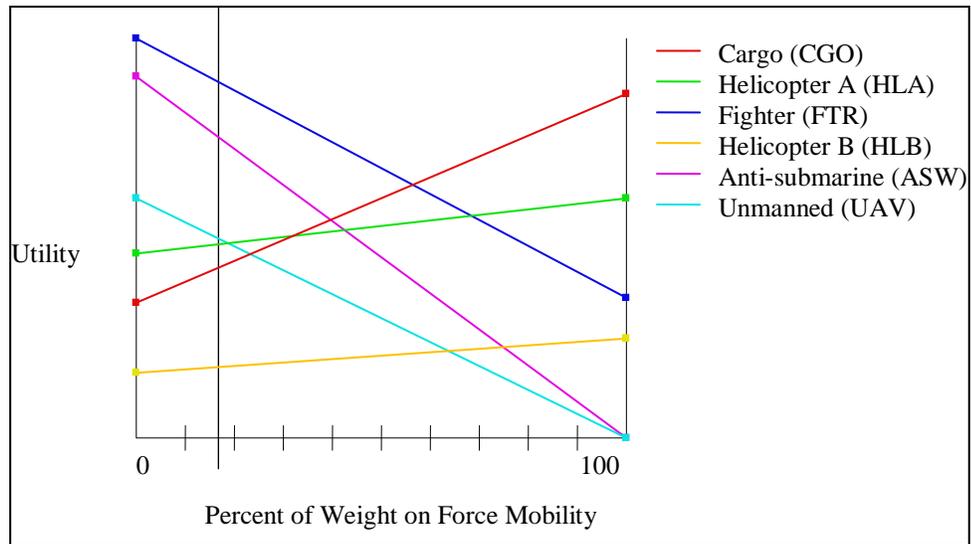


Figure 42. Weight Variation on Force Mobility.

Finally, small variations in the weight of Force Support do not show any significant change in the results of the sensitivity analysis. The utilities of HLA and UAV vary exactly the same with the variations of weight on Force Support. The variations in the marginal contribution yielded by HLA are caused by the variations in the utility of HLB, which has some of its main capabilities linked to the Force Support fundamental objective (see fig. 43).

Table 8. Variation of Weight on Force Support.

ACFT	Force Sup. (14.79%)	ACFT	Force Sup. (24.79%)	ACFT	Force Sup. (4.79%)
FTR	0.488	FTR	0.432	FTR	0.546
ASW	0.415	ASW	0.364	ASW	0.461
UAV	0.272	UAV	0.242	UAV	0.306
CGO	0.23	CGO	0.211	CGO	0.267
HLA	0.167	HLA	0.098	HLA	0.227

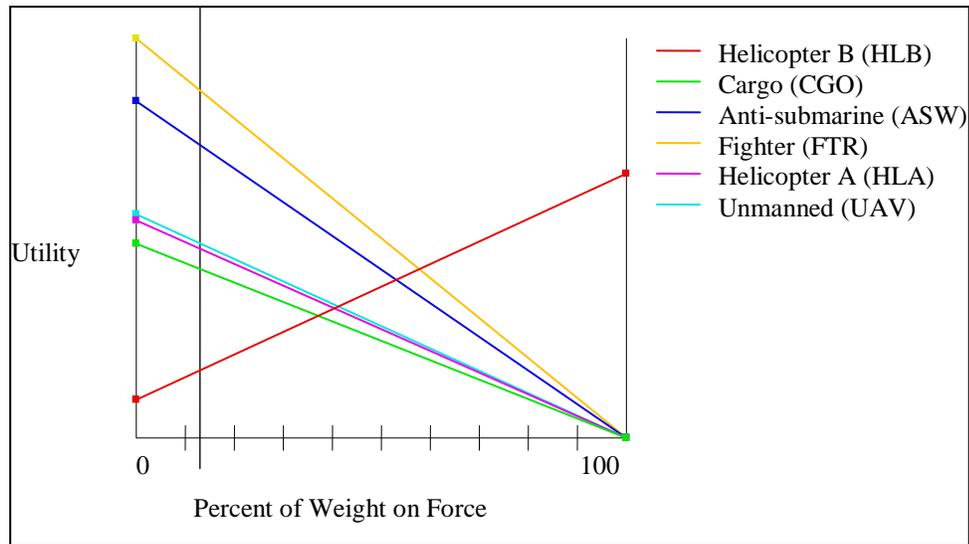


Figure 43. Weight Variation on Force Support.

This first part of the analysis showed that the results are robust for most of the alternatives. The exception is related to the UAV and CGO aircraft systems, which showed some sensitivity to variations in the weights of Force Awareness and Force Mobility.

6.2 Hypothetical Scenarios

The second part of the sensitivity analysis proposes two simple hypothetical scenarios to check if significant changes occur in the ranking of the alternatives. The hypothetical DM was asked to change the weights of the fundamental objectives, according to his assessment of the scenario in hand. A short description of the proposed scenarios can be found in Appendix 6.

As before, the weights variations were done only on the fundamental objectives of the hierarchy, but now the lower level objectives were also changed according to the scenario. The results showed that there was no significant change in the ranking order of the alternatives (see fig. 44).

In the Amazon scenario, the main changes in weights occurred in the objectives related to the subsurface environment, which were decreased. As expected, the ASW alternative had a significant decrease in its utility, due to its very specific anti-submarine warfare capabilities. Even then, it remained the second ranked alternative, due to its other capabilities still applied to the Amazon scenario, showing great flexibility.

On the other hand, in the South Atlantic (SA) scenario, the weights related to the subsurface environment were increased. The ASW alternative increased its utility while the other aircraft systems decreased. Even then, ASW remained as the second best alternative among all the options.

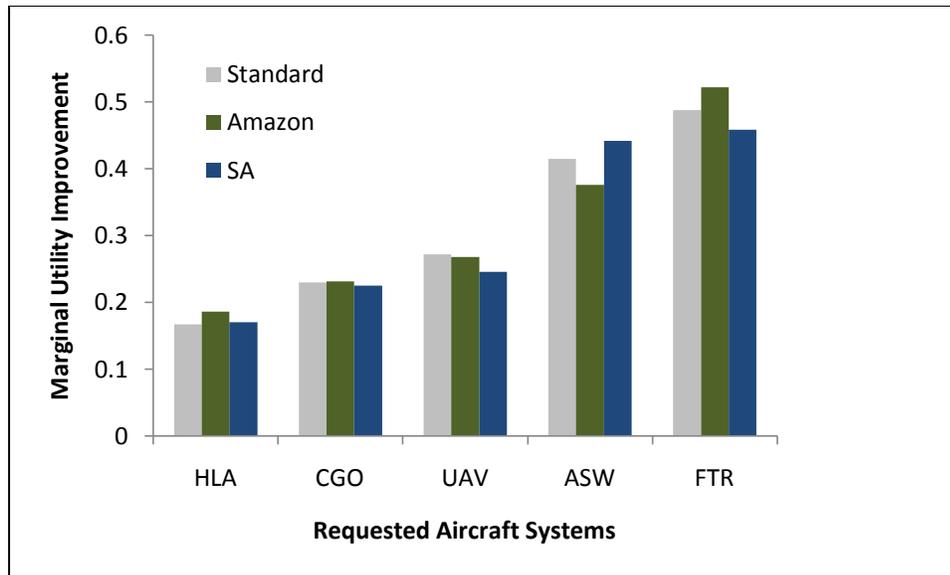


Figure 44. Utility Variation According to Scenario.

Table 9. Utility According to Scenario.

Aircraft	Standard	Amazon	SA
FTR	0.488	0.522	0.458
ASW	0.415	0.376	0.442
UAV	0.272	0.268	0.246
CGO	0.23	0.231	0.225
HLA	0.167	0.186	0.17

This second part of the sensitivity analysis showed that the different scenarios did not cause changes in the ranking order, although the utilities of the alternatives varied significantly.

In conclusion, the robustness of the model could be verified through several variations in the most important weights of the hierarchy. Two different approaches were

used to check the effects of these variations. The most sensitive alternatives are UAV and CGO, when considering variations of weight on Force Awareness and Force Mobility.

Further analysis, considering budgetary and political aspects is recommended in order to identify other important aspects that could be also used to support the decision making process.

7. COST EFFECTIVENESS ANALYSIS

The sensitivity analysis revealed interesting aspects of the model and the systems under consideration, providing important insights about the contributions of each aircraft system. The cost effectiveness analysis can be used to provide more valuable information to support the DM. The only costs considered for this analysis were the estimated acquisition costs of one unit of the requested system. This is one limitation of the methodology, since no life-cycle costs are available at this phase of the process, which could provide more insights to the DM and a more detailed analysis.

The approach consists of a graph where all the alternatives' utilities are compared against their cost. The objective is to present the results in a clear, concise and easy to understand way.¹²⁴

In this example, the area of the graph is divided in four parts, where it is possible to classify the alternatives in terms of their cost effectiveness:

1. Low Cost / High Utility
2. High Cost / High Utility
3. High Cost / Low Utility
4. Low Cost / Low Utility

¹²⁴ David A. Fulk, Theodore P. Lewis, and Gloria Castro, "Analysis Support for Acquisition: Part I: Analysis of Alternatives," in *Methods for Conducting Military Operational Analysis*, ed. Andrew G. Loerch and Larry B. Rainey (Military Operations Research Society, 2007), 171.

The actual thresholds can be defined by the DM in order to establish the minimum acceptable level of utility and the maximum acceptable cost. In this example, the best region of the graph for an alternative to be is region 1 and the worst is region 4 (see fig. 45).

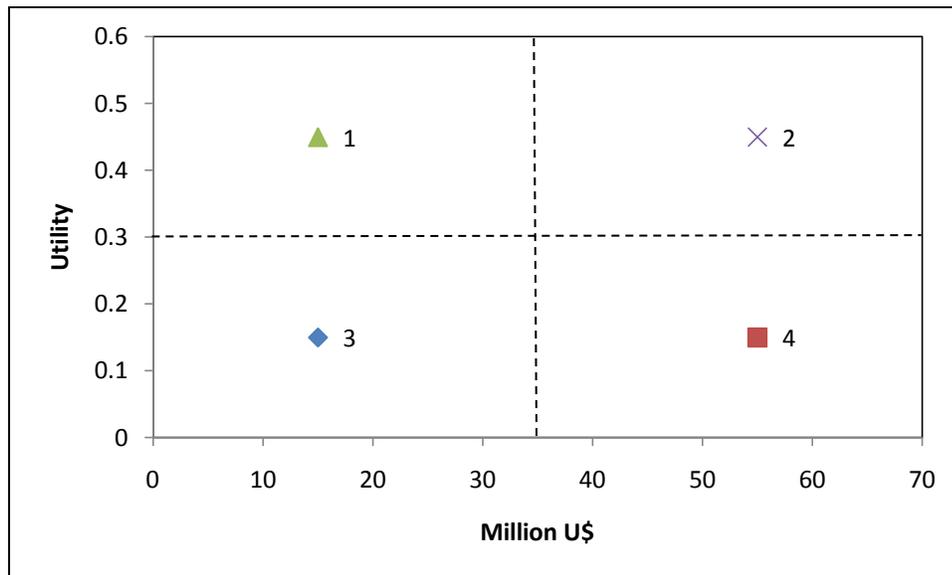


Figure 45. Cost Effectiveness Regions.

In the hypothetical scenario, the alternative ASW is in the borderline between region 1 and 2, thus it may or not meet the cost requirements if estimates vary enough. The FTR alternative is the most expensive, but it also brings the largest contribution to the BAF's operational capability. On the other hand, CGO is below the utility threshold and is the second most expensive alternative, thus it should be one of the less preferred by the DM. Finally, HLA and UAV are the only alternatives within region 1, but small

variations in the UAV's utility can shift it to region 2. They have the lowest costs, but also the lowest utilities (see fig. 46).

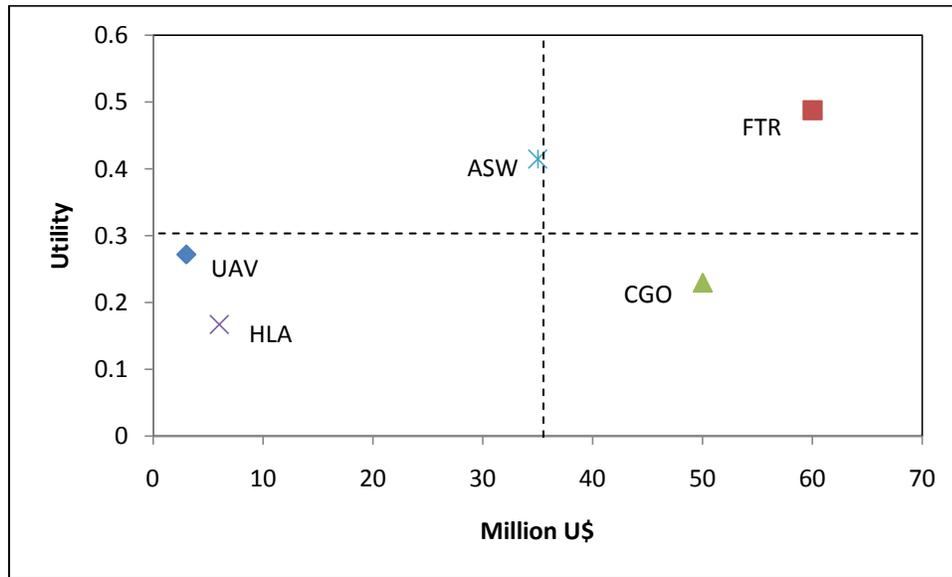


Figure 46. Alternatives – Cost Effectiveness.

This type of analysis will complement the results yielded by the model and will help the DM to gain insights in order to address the important trade-offs needed to establish priorities among the alternatives.

The utilities and ranking of alternatives yielded by the model must not be considered as the only indicators to support the decision. The sensitivity and the cost effectiveness analysis must be integrated into the set of information available to the DM so that he can make an informed decision based on accurate data, which is the real benefit provided by decision analysis.

8. CONCLUSION

Brazil is a huge country with vast natural reserves, mainly located in the Amazon region and the South Atlantic. In the past decade its economic growth has motivated an increase in the Defense expenditure and the publication of the NSD, focused on the modernization and development of the Brazilian Armed Forces.

The acquisition and development of modern defense systems are being fostered by government policies in order to replace obsolete equipments and improve the BAF's operational capability.

In this scenario it is mandatory to identify the required capabilities needed to accomplish the strategic objectives of the organization. The correct choice of the aircraft systems that will be in use by the BAF in the next decades needs to be a careful and detailed process to assure the best use of the available resources.

The AFCS is a key organization in this process, represented by the OPS, which analyses the OCRs and is responsible for the important task of determining priorities among them and deciding the systems that will continue their life cycle.

The model proposed in this thesis has the purpose to provide the BAF with a qualitative and quantitative analysis of this decision problem, in order to help DMs to rank alternatives and define priorities among them.

The research and the development of the model were based on strategic policies and doctrinaire documents so as to build a fundamental objectives hierarchy intended to guide the accomplishment of the most important strategic goals of the BAF.

The attributes were defined by elicitation and research in order to identify the most important aspects needed to measure the achievement of each objective. The final qualitative model should be a simple, but yet complete depiction of the decision problem.

The definition of the quantitative model was done using elicitations and expert judgments to check independence conditions, utilities and weights. The final model used MAUT to aggregate all the measures using additive and multiplicative utility functions.

A hypothetical decision situation was built in order to demonstrate the use of the model and check its robustness through a sensitivity analysis. The alternatives were ranked according to their contribution to the operational capability of the BAF. The variations on the fundamental objectives weights did not cause significant variations in the rank of the alternatives, thus proving the robustness of the model.

At last, a cost effectiveness analysis was conducted, providing important insights to the DM, which could even change the alternatives rank, according to budget and political inputs.

The aim of this work is to improve the current methodology used to analyze and prioritize OCRs related to aircraft systems, by guiding the process using a systematic method based on strategic policies, in order to avoid the misuse of resources and provide guidance for the acquisition process.

Finally, this research intends to foster the expansion of the systematic decision analysis processes to as many areas of the BAF as possible, through examples of use in limited decision contexts and later in increasingly more complex scenarios.

APPENDIX 1

FUNDAMENTAL OBJECTIVES

Maximize the contribution of the aircraft systems to the Brazilian Air Force operational capability.

1. Maximize the Force Application capability

Force Application: ability to destroy, neutralize and affect targets including forces, people, and equipment as well as the ability to survive in a hostile environment.

1.1 Maximize the capability to engage targets

Engagement – Encounter which involves hostile action by at least one participant.¹²⁵

1.1.1 In the air

Air - Air near Earth's surface usually taken to be (% by volume): nitrogen 78.08; oxygen 20.95; argon 0.93; other gases (in descending order of concentration, carbon dioxide, neon, helium, methane, krypton, hydrogen, xenon and ozone) 0.04.¹²⁶

1.1.2 In the surface

Surface – 6.Generalized term for Earth's surface, hence surface target = one on land or water.¹²⁷

1.1.3 In the subsurface

Subsurface – Below, under, beneath the surface.

¹²⁵ Bill Gunston, *The Cambridge Aerospace Dictionary*, 2nd ed. (Cambridge University Press, 2009), 212.

¹²⁶ *Ibid.*, 27.

¹²⁷ *Ibid.*, 612.

1.2 Maximize the survivability capability

Survivability – Capability of a system to withstand a manmade hostile environment without suffering an abortive impairment of its ability to perform its designated mission.¹²⁸

2. Maximize the Force Awareness capability

Force Awareness: ability to maintain an accurate perception of the factors and conditions affecting the environment by detecting and processing relevant information to create a composite picture of the current situation and act on this picture to make a decision or to perform further exploration.¹²⁹

2.1 Maximize the capability to detect targets

Detection – Act or effect of perceiving or making contact (visual, electromagnetic, acoustic, among others) with a given target.¹³⁰ Includes ISR activities.

2.1.1 In the air (see 1.1.1)

2.1.2 In the surface (see 1.1.2)

2.1.3 In the subsurface (see 1.1.3)

2.2 Maximize the integration capability

Integration – 1. Action of connecting a set of subsystems in a logical whole, so that the interactions between them are more important than their own subsystems, or that the interactions between them could generate a synergistic effect.¹³¹

2.3 Maximize the communication capability

Communication – To use any means or method to convey information of any kind from one person or place to another¹³² such that military components can be linked in the battlefield.

¹²⁸ Ibid., 614.

¹²⁹ Schleher, *Electronic Warfare in the Information Age*, 31.

¹³⁰ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 82.

¹³¹ Ibid., 138.

¹³² The U.S. Department of Defense, *The Dictionary of Military Terms*, 92.

2.3.1 Using voice

Voice – Sound produced by the human vocal organs.

2.3.2 Using data

Data – Representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means. Any representations such as characters or analog quantities to which meaning is or might be assigned.¹³³

3 Maximize the Force Mobility capability

Force Mobility: ability to move personnel, materiel and forces by air and operate with the same efficiency from any airfield. This includes both airlift and air refueling.

3.1 Maximize the aerial refuel capability

Air refueling – The refueling of an aircraft in flight by another aircraft.¹³⁴

3.2 Maximize the airlift capability

Airlift - Operations to transport and deliver forces and materiel through the air in support of strategic, operational, or tactical objectives.¹³⁵

3.3 Maximize the capability to operate in unprepared airfields

Airfield - An area prepared for the accommodation (including any buildings, installations, and equipment), landing, and takeoff of aircraft.¹³⁶

Unprepared airfield - Usual meaning is without permanent paved runway.¹³⁷

¹³³ Ibid., 124.

¹³⁴ Ibid., 19.

¹³⁵ US Air Force, *AFDD 1-2 Air Force Glossary* (US Air Force, 2007), 42, <http://www.e-publishing.af.mil/>.

¹³⁶ The U.S. Department of Defense, *The Dictionary of Military Terms*, 15.

¹³⁷ Gunston, *The Cambridge Aerospace Dictionary*, 676.

4 Maximize the Force Support capability

Force Support: ability to perform missions that provide support to BAF's personnel as well as to the aeronautical infra structure.

4.1 Maximize the capability to rescue personnel

Rescue - Air mission designed to rescue crew and passengers of aircraft shot down or crashed as well as ships or persons in distress. In war time is called CSAR.¹³⁸

4.2 Maximize the capability to provide basic training

Basic Training – Air mission carried out in order to provide a degree of proficiency to pilots undergoing basic flight training.¹³⁹

4.3 Maximize the capability to perform flight inspection

Flight Inspection – Air mission carried out by specially equipped aircraft, in order to verify the accuracy of nav aids.¹⁴⁰

¹³⁸ Comando da Aeronáutica, *DCA 1-1 Doutrina Básica da Força Aérea Brasileira*, 41.

¹³⁹ *Ibid.*, 50.

¹⁴⁰ Gunston, *The Cambridge Aerospace Dictionary*, 241.

APPENDIX 2

ATTRIBUTES

A1.1 Combat Radius

Maximum distance aircraft can travel away from its base along given course with normal combat load and return without refueling, allowing for all safety and operating factors.¹⁴¹

A1.2 Scope

Scope of operation in terms of environment (weather conditions, daytime and nighttime).

AWX/day/night – ACFT capable to execute the task in any weather conditions, during the day or during the night.

AWX/day – ACFT capable to execute the task in any weather condition during the day. At night, needs VMC.

VMC/day/night – ACFT capable to execute the task only in VMC, during the day or during the night.

VMC/day – ACFT capable to execute the task only in VMC during the day.

A1.3 Weapon Capacity

Maximum number of A/A armament that can be carried in a typical A/A configuration (includes cannon when applicable).

A1.4 Armament Payload

Maximum A/G armament payload that can be carried in a typical A/G configuration.

A1.5 SEAD

Type of equipments used for Suppression of enemy air defense.

Destructive – e.g. use of a HARM. Possibly lethal consequences.¹⁴²

Nondestructive – e.g. use of active jamming to disrupt enemy radars or weapons.

Nonlethal.¹⁴³

None – no capability.

¹⁴¹ Ibid., 492.

¹⁴² Schleher, *Electronic Warfare in the Information Age*, 133-134.

¹⁴³ Ibid.

A1.6 Scope

See A1.2

A1.7 Scope

See A1.2

A1.8 Armament Payload

Maximum A/S armament payload that can be carried in a typical A/S configuration.

A1.9 Countermeasures

EW equipment used for self-defense against hostile sensors such as radar, IR, visual, TV or noise.¹⁴⁴

Complete – RWR, MAWS, Chaff, Flares, SPJ.

Good – RWR, Chaff, Flares, MAWS or SPJ.

Standard – RWR, Chaff, Flares.

Minimum – Chaff and/or Flares.

None – no capability.

A1.10 Navigation

Capability to navigate autonomously using INS.

A2.1 Coverage

Maximum distance covered by A/A sensor (Nm).

A2.2 Endurance

Maximum time aircraft can continue flying under given conditions without refueling (Hours).¹⁴⁵

A2.3 Resolution

Measure of ability of optical system, radar, video/TV or other EO system, photographic film or other scene-reproducing method to reveal two closely spaced objects as separate

¹⁴⁴ Gunston, *The Cambridge Aerospace Dictionary*, 152.

¹⁴⁵ *Ibid.*, 211.

bodies; normally defined in terms of angle at receiver subtended by two objects which can just be distinguished as separate.¹⁴⁶

A2.4 Endurance

See A2.2

A2.5 Scope

See A1.2

A2.6 Scope

See A1.2

A2.7 Coverage

Maximum distance covered by A/S sensor.

A2.8 Interoperability

Capacity of systems to exchange information or services or accept them from other systems and also to use these services or information without compromising its functionality.¹⁴⁷

Data, voice and secure – Datalink, voice communications and communications security equipment are interoperable.

Data or voice, secure – Datalink or voice communications are interoperable, as well as communications security equipment.

Data and voice – Datalink and voice communications are interoperable.

Data or voice – Datalink or voice communications are interoperable.

None – no interoperability.

A 2.9 Capacity

Different types of voice communication capabilities supported by the ACFT.

A2.10 Secure

Communications security capabilities supported by the ACFT (voice).

¹⁴⁶ Ibid., 509.

¹⁴⁷ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 140.

A 2.11 Capacity

Amount of data that can be transmitted or received by data link equipment (Mbts).

A2.12 Secure

Communications security capabilities supported by the ACFT (data).

A3.1 Fuel Capacity

Maximum fuel a tanker ACFT is capable to transport, that is available to refuel receiver ACFTs.

A3.2 Receiver

Capability to be refueled in the air.

A3.3 Range

Distance aircraft can travel, under given conditions, without refueling in flight (Nm x 1000).

A3.4 Payload Weight

The sum of the weight of passengers and cargo that an aircraft can carry (Lbs).

A3.5 Preparedness

Level of preparedness of the runway (pavement type) that the ACFT is capable to operate safely.

Unprepared – An unsurfaced natural ground area suitable for operation with little or no preparation.

Semi-prepared – Unpaved semi-prepared compacted surface (gravel, dirt).

Prepared – Paved runway (asphalt or concrete).

A4.1 Scope

See A1.2

A4.2 Radius of Action

See A1.1

A4.3 Pax

Maximum number of litters that can be carried in one sortie (rescued passengers).

A4.4 Multirole

Percentage of missions of a specific basic instruction program that can be executed by the aircraft.

A4.5 Accurate

Percentage of flight inspection missions that can be executed respecting accuracy standards described in the FAA 8200-1C.¹⁴⁸

¹⁴⁸ The Federal Aviation Administration, *8200.1-C United States Standard Flight Inspection Manual* (The Federal Aviation Administration, 2009).

APPENDIX 3

UTILITY FUNCTIONS

1 Maximize the contribution to the Force Application capability.

1.1 Maximize the capability to engage targets.

1.1.1 In the air.

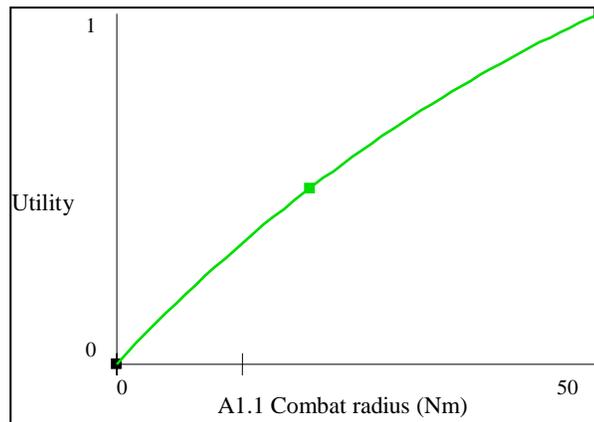


Figure A3.1- A1.1 Combat radius

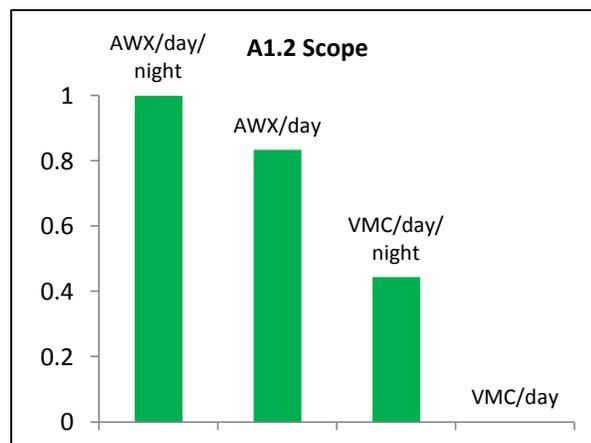


Figure A3.2 - A1.2 Scope

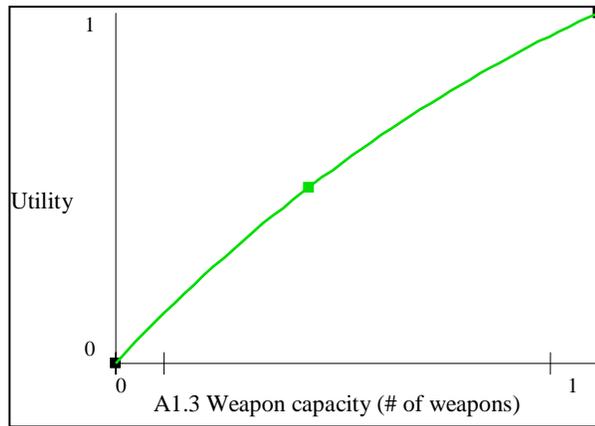


Figure A3.3 - A1.3 Weapon capacity

1.1.2 In the surface

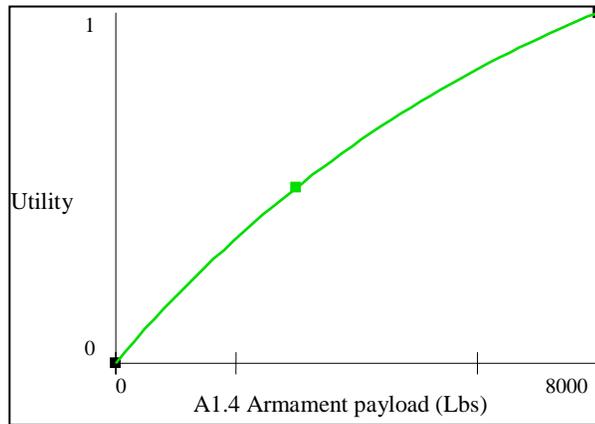


Figure A3.4 - A1.4 Armament payload

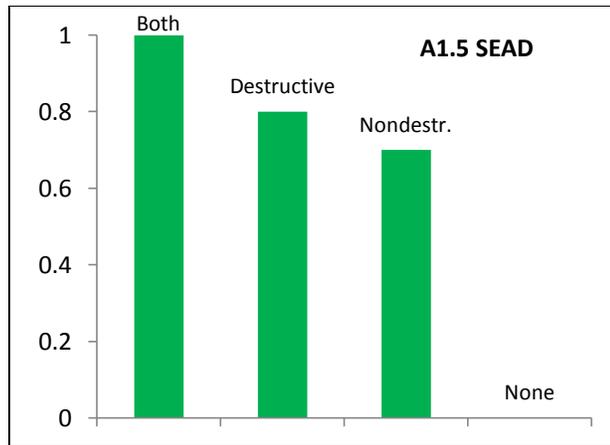


Figure A3.5 - A1.5 SEAD

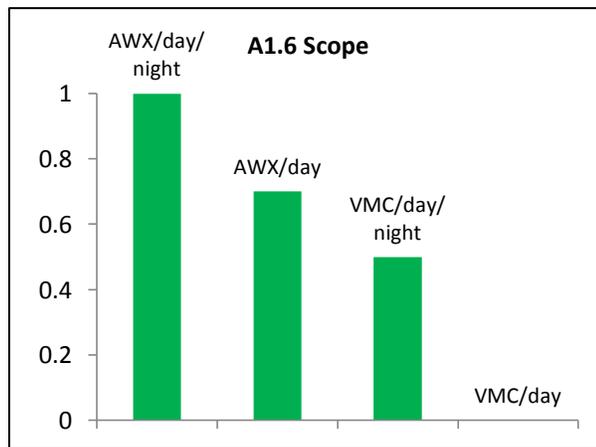


Figure A3.6 - A1.6 Scope

1.1.3 In the subsurface

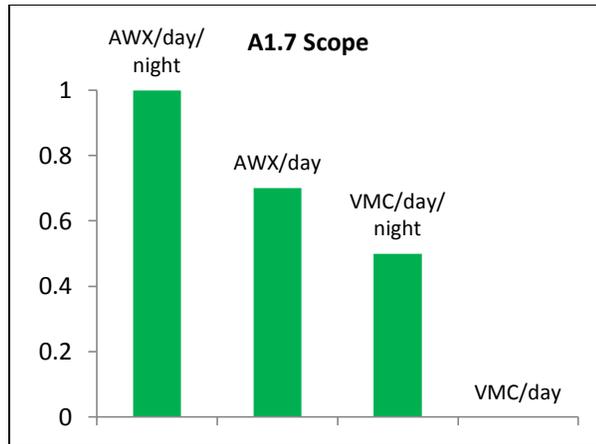


Figure A3.7 - A1.7 Scope

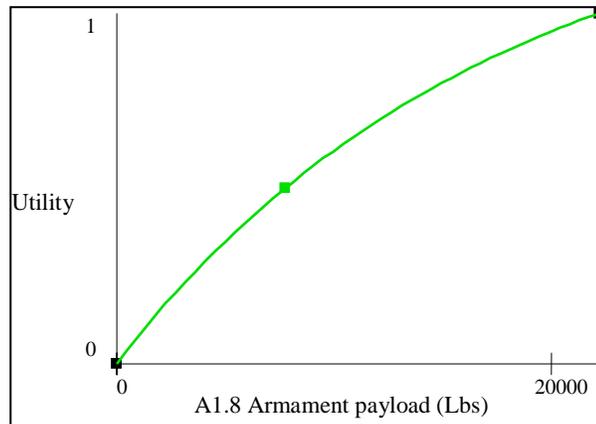


Figure A3.8 - A1.8 Armament payload

1.2 Maximize the survivability capability

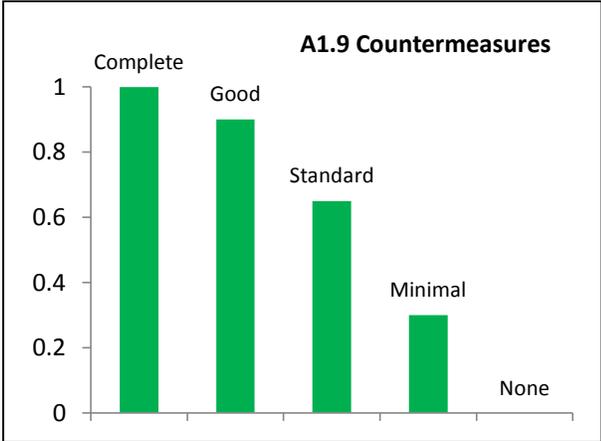


Figure A3.9 - A1.9 Countermeasures

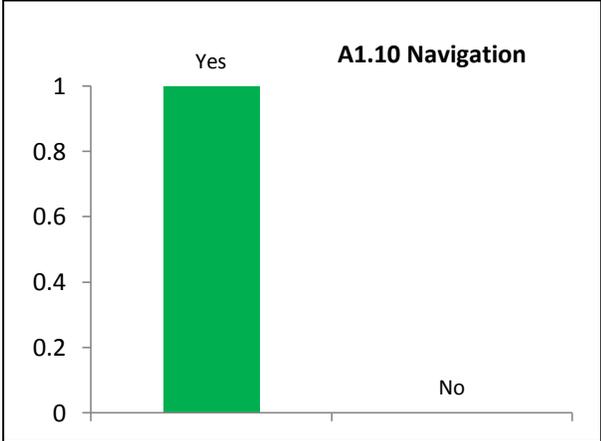


Figure A3.10 - A1.10 Navigation

2 Maximize the Force Awareness capability.

2.1 Maximize the capability to detect targets.

2.1.1 In the air.

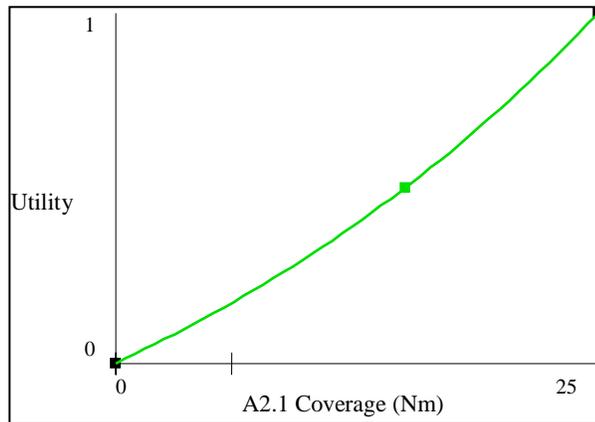


Figure A3.11- A2.1Coverage



Figure A3.12 - A2.2 Endurance

2.1.2 In the surface.

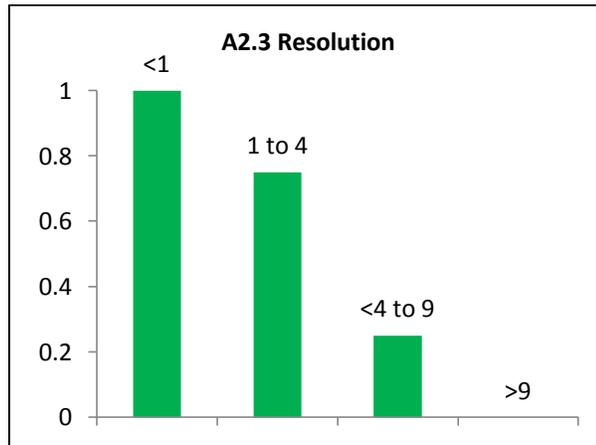


Figure A3.13 - A2.3 Resolution¹⁴⁹

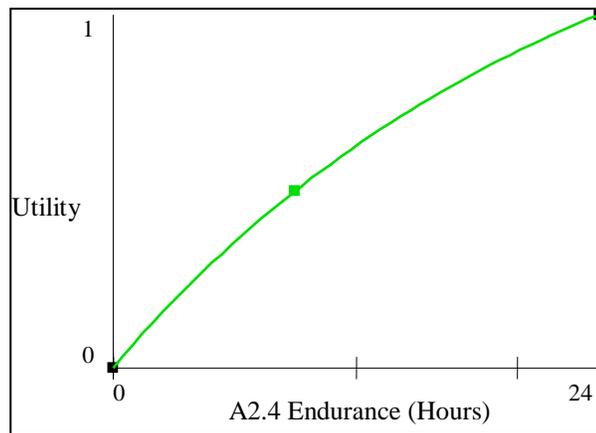


Figure A3.14 - A2.4 Endurance

¹⁴⁹ "IMINT - NIIRS National Image Interpretability Rating Scales," <http://www.fas.org/irp/imint/niirs.htm>.

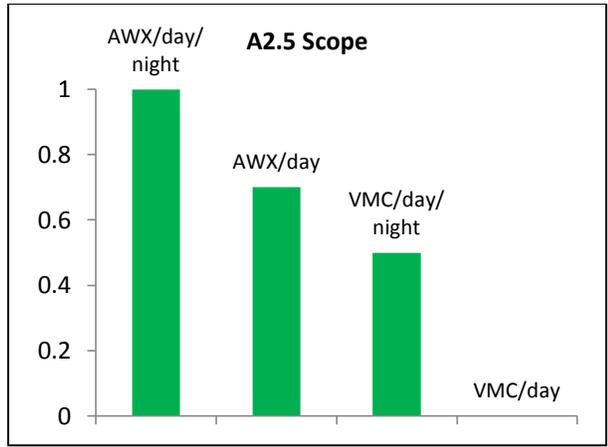


Figure A3.15 - A2.5 Scope

2.1.3 In the subsurface.

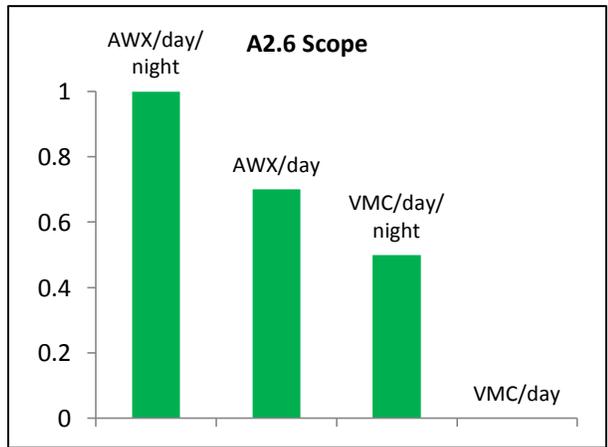


Figure A3.16 - A2.6 Scope

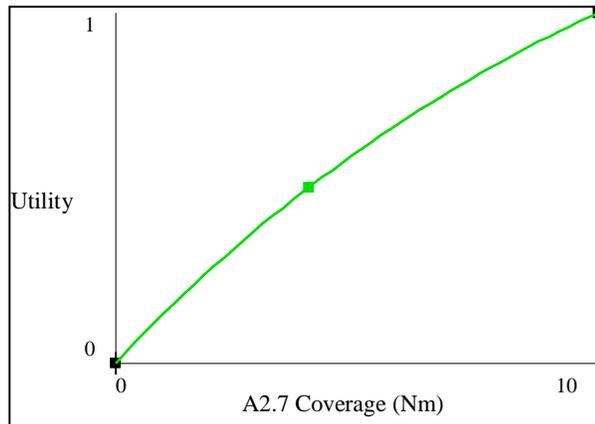


Figure A3.17 - A2.7 Coverage

2.2 Maximize the integration capability

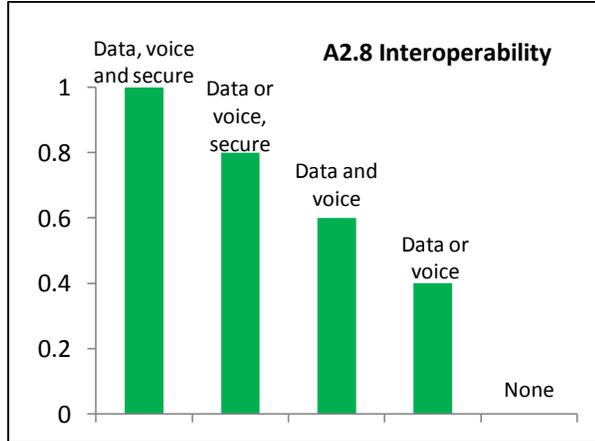


Figure A3.18 - A2.8 Interoperability

2.3 Maximize the communication capability

2.3.1 Using voice

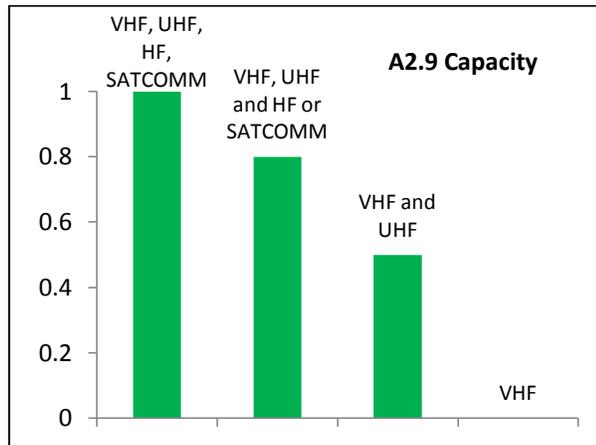


Figure A3.19 - A2.9 Capacity.

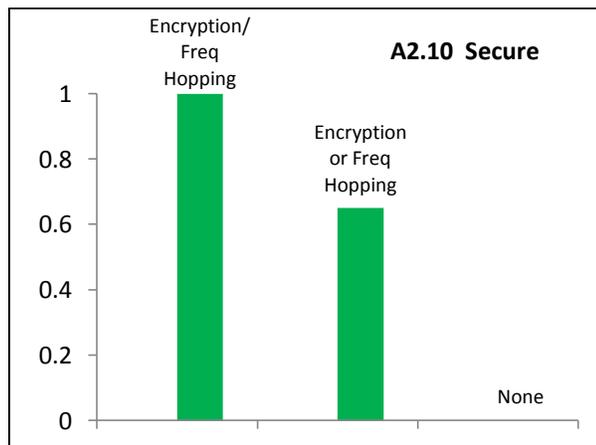


Figure A3.20 - A2.10 Secure.

2.3.2 Using data

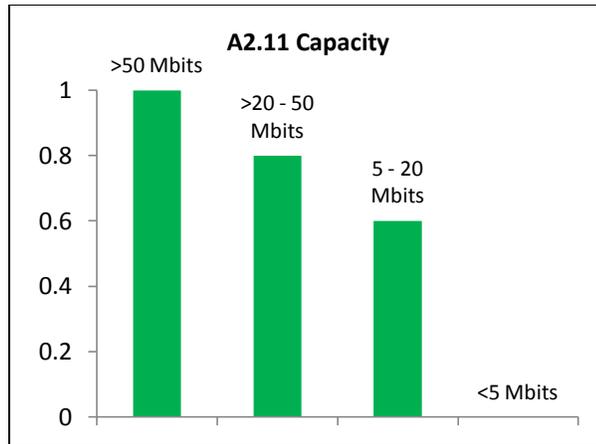


Figure A3.21 - A2.11 Capacity

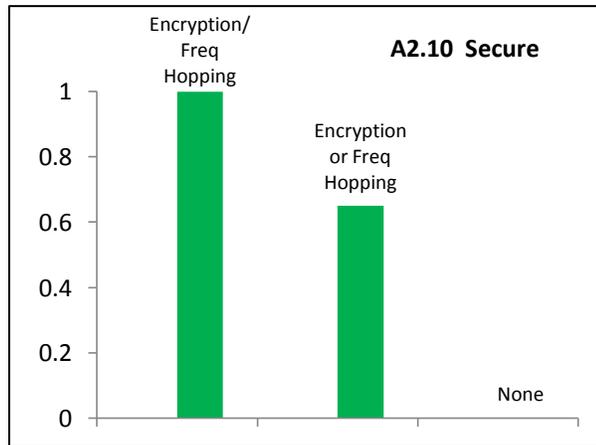


Figure A3.22 - A2.12 Secure.

3 Maximize the Force Mobility capability.

3.1 Maximize the aerial refuel capability.

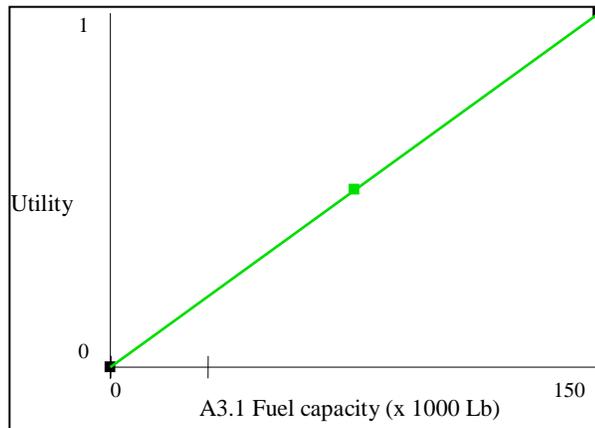


Figure A3.23 - A3.1 Fuel capacity.

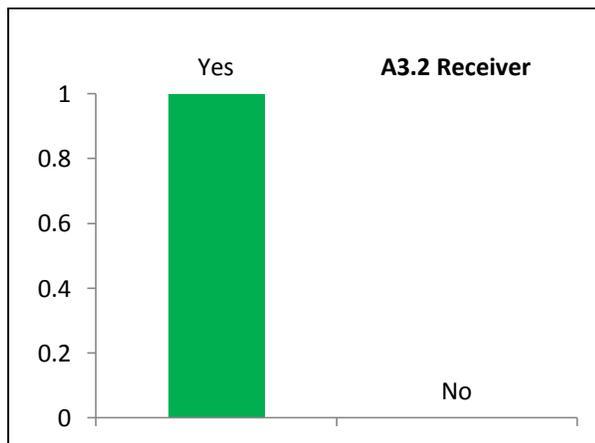


Figure A3.24 - A3.2 Receiver.

3.2 Maximize the airlift capability

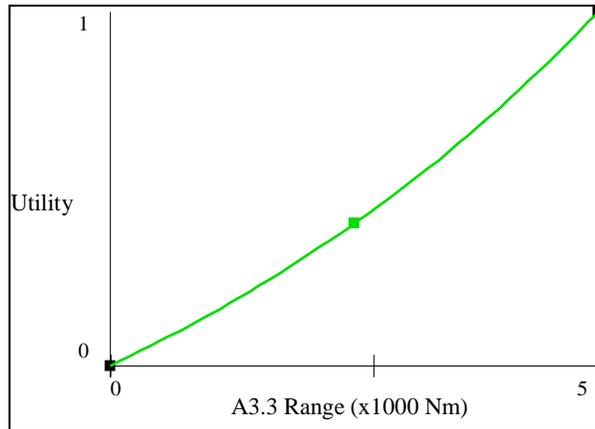


Figure A3.25 - A3.3 Range.

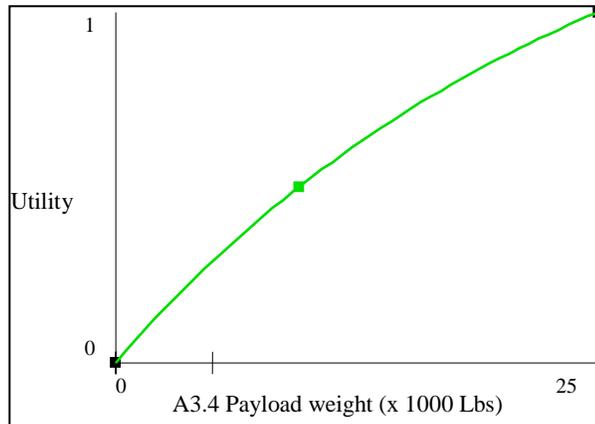


Figure A3.26 - A3.4 Payload weight.

3.3 Maximize the capability to operate in unprepared airfields.

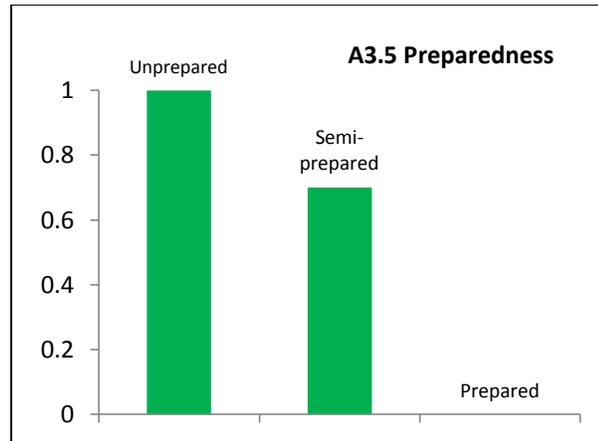


Figure A3.27 - A3.5 Preparedness.

4 Maximize the Force Support capability.

4.1 Maximize the capability to rescue personnel.

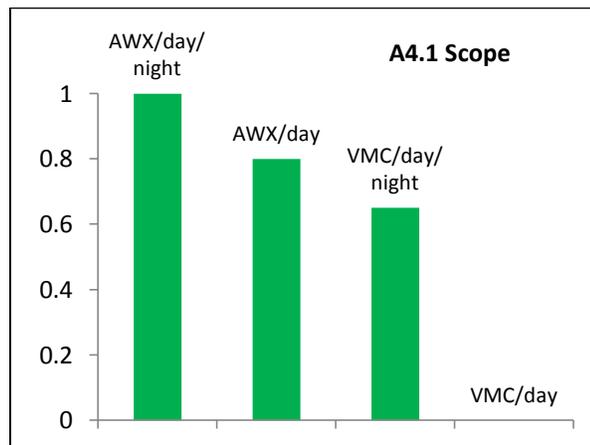


Figure A3.28 - A4.1 Scope.

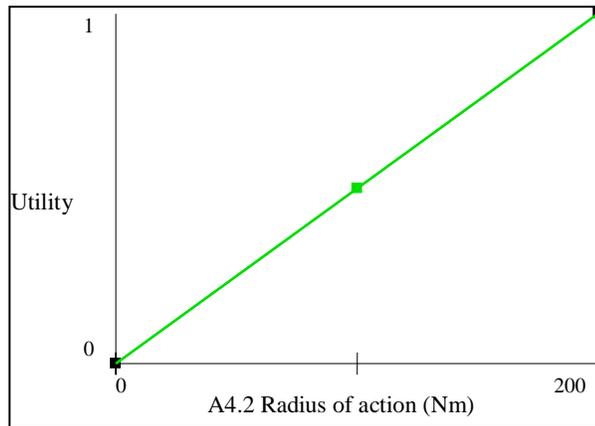


Figure A3.29 - A4.2 Radius of action.

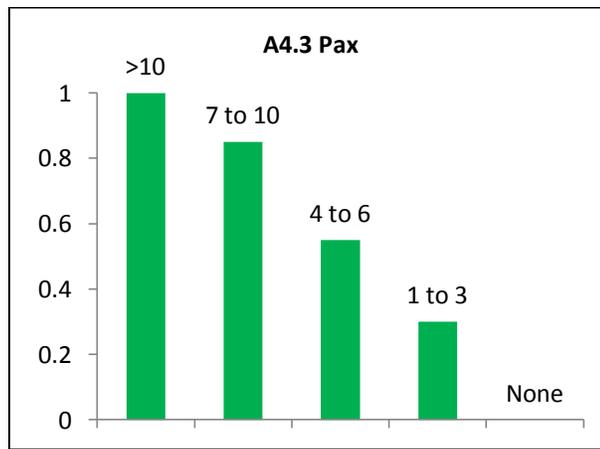


Figure A3.30 - A4.3 Pax.

4.2 Maximize the capability to provide basic training.

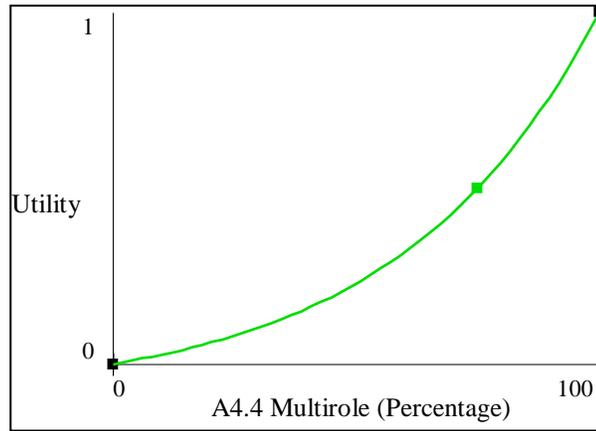


Figure A3.31 - A4.4 Multirole.

4.3 Maximize the capability to perform flight inspection.

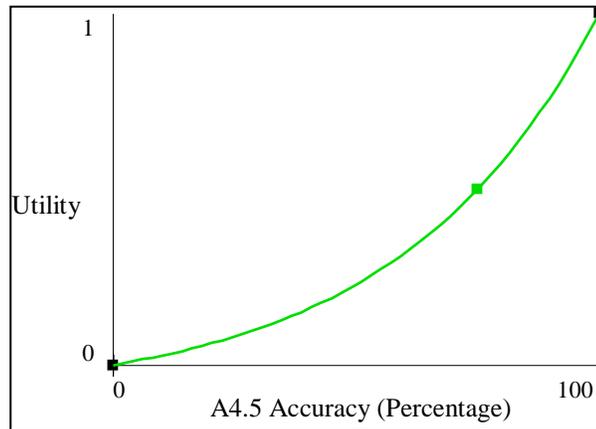


Figure A3.32 - A4.5 Accuracy.

APPENDIX 4

WEIGHTS

Standard World

Table A4-1. System Scoring – Force Application.

1 Force Application 0.3208	1.1 Engagement 0.7692	1.1.1 Air 0.4545	A1.1 Combat Radius	0.2763
			A1.2 Scope	0.3316
		A.1.3 Weapon capacity	0.3664	
		K	0.0744	
	1.1.2 Surface 0.4091	A1.4 Arm. payload	0.3784	
		A1.5 SEAD	0.2270	
		A1.6 Scope	0.3216	
		K	0.2537	
	1.1.3 Subsurface 0.1364	A1.7 Scope	0.4444	
		A1.8 Arm. payload	0.3556	
		K	1.2656	
	1.2 Survivability 0.2308	A1.9 Countermeasures		0.4444
		A1.10 Navigation		0.3556
K		1.2656		

Table A4-2. System Scoring – Force Awareness.

2 Force Awareness 0.3774	2.1 Detection 0.5882	2.1.1 Air 0.4348	A2.1 Coverage	0.4324
			A2.2 Endurance	0.3676
		K	1.2582	
	2.1.2 Surface 0.3913	A2.4 Resolution	0.3500	
		A2.5 Endurance	0.2625	
		A2.6 Scope	0.3500	
	2.1.3 Subsurface 0.1739	A2.7 Scope	0.3556	
		A2.8 Coverage	0.4444	
	2.2 Integration 0.1176		A2.9 Interoperable	1.0000
	2.3 Communication 0.2941	2.3.1 Voice 0.4737	A2.10 Capacity	0.4000
			A2.11 Secure	0.4000
		K	1.2901	
		A2.12 Capacity	0.4000	
		A2.13 Secure	0.4000	
		K	1.2901	

Table A4-3. System Scoring – Force Mobility.

3 Force Mobility 0.1698	3.1 Aerial Refuel 0.3953	A3.1 Fuel capacity	0.5000
		A3.2 Receiver	0.5000
		K	0.0000
	3.2 Airlift 0.4651	A3.3 Range	0.4211
		A3.4 Payload weight	0.3789
		K	1.2534
3.3 Airfield 0.1395	A3.5 Preparedness	1.0000	

Table A4-4. System Scoring – Force Support.

4 Force Support 0.1321	4.1 Rescue 0.6667	A4.1 Scope	0.4118
		A4.2 Radius of Action	0.2882
		A4.3 Pax	0.2471
		K	0.1783
	4.2 Basic Training 0.2333	A4.4 Multirole	1.0000
4.3 Flight Inspection 0.1000	A4.5 Accurate	1.0000	

Amazon Scenario

Table A4-5. System Scoring – Force Application (Amazon).

1 Force Application 0.3448	1.1 Engagement 0.7692	1.1.1 Air 0.5000	A1.1 Combat Radius	0.2763
			A1.2 Scope	0.3316
			A.1.3 Weapon capacity	0.3664
		K	0.0744	
	1.1.2 Surface 0.4500	A1.4 Arm. payload	0.3784	
		A1.5 SEAD	0.2270	
		A1.6 Scope	0.3216	
		K	0.2537	
	1.1.3 Subsurface 0.0500	A1.7 Scope	0.4444	
		A1.8 Arm. payload	0.3556	
K		1.2656		
1.2 Survivability 0.2308	A1.9 Countermeasures	0.4444		
	A1.10 Navigation	0.3556		
	K	1.2656		

Table A4-6. System Scoring – Force Awareness (Amazon).

2 Force Awareness 0.3448	2.1 Detection 0.5882	2.1.1 Air 0.500	A2.1 Coverage	0.4324
			A2.2 Endurance	0.3676
			K	1.2582
		2.1.2 Surface 0.4500	A2.3 Resolution	0.3500
			A2.4 Endurance	0.2625
			A2.5 Scope	0.3500
		2.1.3 Subsurface 0.0500	A2.6 Scope A2.7 Coverage K	0.3556
				0.4444
				1.2656
	2.2 Integration 0.1176		A2.8 Interoperable	1.0000
	2.3 Communication 0.2941	2.3.1 Voice 0.4737	A2.9 Capacity	0.4706
			A2.10 Secure	0.3294
2.3.2 Data 0.5263		A2.11 Capacity A2.12 Secure K	1.2901	
			0.4706	
		0.3294		
		1.2901		

Table A4-7. System Scoring – Force Mobility (Amazon).

3 Force Mobility 0.1724	3.1 Aerial Refuel 0.3953	A3.1 Fuel capacity	0.5000
		A3.2 Receiver	0.5000
		K	0.0000
	3.2 Airlift 0.4651	A3.3 Range	0.4211
		A3.4 Payload weight	0.3789
		K	1.2534
	3.3 Airfield 0.1395	A3.5 Preparedness	1.0000

Table A4-8. System Scoring – Force Support (Amazon).

4 Force Support 0.1379	4.1 Rescue 0.7692	A4.1 Scope	0.4118
		A4.2 Radius of Action	0.2882
		A4.3 Pax	0.2471
		K	0.1783
	4.2 Basic Training 0.1538	A4.4 Multirole	1.0000
	4.3 Flight Inspection 0.0769	A4.5 Accurate	1.0000

South Atlantic Scenario

Table A4-9. System Scoring – Force Application (SA).

1 Force Application 0.3448	1.1 Engagement 0.7692	1.1.1 Air 0.3846	A1.1 Combat Radius	0.2763	
			A1.2 Scope	0.3316	
			A1.3 Weapon capacity K	0.3664 0.0744	
		1.1.2 Surface 0.3462	A1.5 Arm. payload	0.3784	
			A1.6 Electronic attack	0.2270	
			A1.7 Scope	0.3216	
			K	0.2537	
		1.1.3 Subsurface 0.2692	A1.8 Scope	0.4444	
			A1.9 Arm. payload	0.3556	
	K		1.2656		
	1.2 Survivability 0.2308			A1.10 Countermeasures	0.4444
				A1.11 Navigation	0.3556
K				1.2656	

Table A4-10. System Scoring – Force Awareness (SA).

2 Force Awareness 0.3448	2.1 Detection 0.5882	2.1.1 Air 0.3846	A2.1 Coverage	0.4324		
			A2.2 Endurance	0.3676		
			K	1.2587		
		2.1.2 Surface 0.3462	A2.3 Resolution	0.3500		
			A2.4 Endurance	0.2625		
			A2.5 Scope	0.3500		
			K	0.1209		
		2.1.3 Subsurface 0.2692	A2.6 Scope	0.3556		
			A2.7 Coverage	0.4444		
	K		1.2656			
	2.2 Integration 0.1176			A2.8 Interoperable	1.0000	
	2.3 Communication 0.2941	2.3.1 Voice 0.4737			A2.9 Capacity	0.4706
					A2.10 Secure	0.3294
		2.3.2 Data 0.5263			K	1.2901
					A2.11 Capacity	0.4706
A2.12 Secure					0.3294	
				1.2901		

Table A4-11. System Scoring – Force Mobility (SA).

3 Force Mobility 0.1724	3.1 Aerial Refuel 0.4359	A3.1 Fuel capacity	0.5000
		A3.2 Receiver	0.5000
		K	0.0000
	3.2 Airlift 0.5128	A3.3 Range	0.4211
		A3.4 Payload weight	0.3789
		K	1.2534
3.3 Airlift 0.0513	A3.5 Preparedness	1.0000	

Table A4-12. System Scoring – Force Support (SA).

4 Force Support 0.1379	4.1 Rescue 0.7692	A4.1 Scope	0.4118
		A4.2 Radius of Action	0.2882
		A4.3 Pax	0.2471
		K	0.1783
	4.2 Basic Training 0.1538	A4.4 Multirole	1.0000
	4.3 Flight Inspection 0.0769	A4.5 Accurate	1.0000

APPENDIX 5

AIRCRAFT DESCRIPTION

All the data was collected from open sources¹⁵⁰ and describes hypothetical aircraft systems, created in order to simulate the decision context of this thesis.

Fighter (FTR)

- 4th generation light fighter jet.
- Combat radius of approximately 900 Nm in typical A/A configuration (4 IR missiles, 4 BVR missiles and 1 full 30mm cannon).
- Combat radius of approximately 600 Nm in typical A/G configuration (8000 lbs of bombs under the wings).
- NVG capability.
- AWX A/G attack capability
- AWX A/A interceptor
- INS capability
- Chaffs, Flares, RWR, MAWS
- A/G radar mode capable to detect moving targets on the ground and on the sea (range 60 Nm) in all weather conditions
- A/A radar (range 60 Nm with resolution of approximately 5m)
- Endurance for CAP mission around 3 hours
- Can perform maritime surveillance using A/G radar
- Encrypted data link (>35Mbps) and voice communication (2 VHF and 2 UHF), and fully interoperable systems
- Capable to be air refueled
- Estimated unit acquisition cost – U\$ 60 million.

¹⁵⁰ Jackson, Munson, and Peacock, *Jane's All the World's Aircraft 2008-2009*.

CARGO (CGO)

- Medium lift transport aircraft
- Capable to be configured as a tanker (maximum of 30000 lbs of available fuel to receiver aircraft)
- Capable to be air refueled
- Chaff, flares, MAWS
- NVG capability
- INS capability
- Encrypted data link (>15Mbps) and voice communication (2 VHF, 2 UHF and 1 HF) and fully interoperable systems
- Capable to operate in semi-prepared runways (SPR)
- Maximum range of approximately 2700 Nm
- Maximum payload weight of 50000 lbs
- Estimated unit acquisition cost – U\$ 50 million

HELICOPTER A (HLA)

- Combat helicopter intended for close support of ground troops and attack of ground armored targets
- Capable to be air refueled
- Chaff, flares, RWR
- NVG capability
- INS capability
- Encrypted data link (>15Mbps) and voice communication (2 VHF and 2 UHF) and fully interoperable systems
- Maximum combat radius of 130 Nm (A/G and A/A)
- 30mm cannon capable to engage targets in the ground and in the air
- Maximum external armament payload of 2000 lbs
- AWX A/G capability
- Estimated unit acquisition cost – U\$ 6 million

HELICOPTER B (HLB)

- Light attack helicopter with SAR capability
- Flight characteristics suitable to be used in basic formation of helicopter pilots
- No data link and encrypted communication (only 2 VHF)
- No AWX and NVG capability
- Maximum combat radius of 100 Nm (A/G)
- Maximum external armament payload of 2000 lbs
- No auto-defense systems
- Capable to transport 2 litters in SAR configuration

ANTI SUBMARINE WARFARE (ASW)

- Long range anti submarine warfare patrol aircraft
- Submarine detection sensors such as directional frequency and ranging (DIFAR) sonobuoys and magnetic anomaly detection (MAD) equipment
- Anti surface torpedoes, missiles and mines
- Chaff, flares, RWR
- High endurance (approximately 12 hours)
- INS capability
- Encrypted data link (>15Mbps) and voice communication (2 VHF, 2 UHF and SATCOMM) and fully interoperable systems
- Maximum combat radius of 1300 Nm for all missions
- Maximum armament payload for anti ship mission - 6000 lbs
- Maximum armament payload for anti submarine mission -18000 lbs
- AWX A/G detection and engagement capability
- Range of detection sensors 100 Nm (surface and under surface)
- Estimated unit acquisition cost – US\$ 36 million

UNMANNED AERIAL VEHICLE (UAV)

- Medium size UAV designed to supply real time intelligence data to ground stations
- Endurance of approximately 20 hours
- Encrypted data link (>35Mbps) and voice communication (1 VHF, 1 UHF and SATCOM) and fully interoperable systems
- Maximum combat radius of 100 Nm
- No auto-defense systems
- INS capability
- High resolution imagery sensors (<1m) capable to operate at night/AWX
- Estimated unit acquisition cost – U\$ 3 million

APPENDIX 6

HYPOTHETICAL SCENARIOS

Amazon scenario:

Large land border area, with several different countries.

Low demographic density.

Limited infra-structure.

Dense rainforest.

Limited airfields in the region.

Short and unprepared runways.

Large distances between Air Bases.

Unstable weather.

High political instability in neighboring countries raises the level of attention of

Brazilian forces in order to secure the borders and the airspace.

South Atlantic scenario:

National offshore oil rig protection, distant from the coastline.

Specialized sensor desired for overwater and underwater surveillance.

Large jurisdictional waters area to be protected.

Unstable weather.

Several large and prepared runways available in the coastline.

High demographic density.

Discovery of new oil and natural gas reserves increases the strategic importance of the area.

APPENDIX 7

SYSTEM SCORING

1. Force Application

Table A7-1. System Scoring – Force Application 1

ACFT	A1.1	A1.2	A1.3	A1.4	A1.5
CGO	0	VMC/day	0	0	None
ASW	0	VMC/day	0	6000	None
FTR	900	AWX/day/night	9	8000	None
HLA	130	VMC/day/night	1	2000	None
UAV	0	VMC/day	0	0	None
HLB	0	VMC/day	0	0	None

Table A7-2. System Scoring – Force Application 2

ACFT	A1.6	A1.7	A1.8	A1.9	A1.10
CGO	VMC/day	VMC/day	0	Good	Autonomous
ASW	AWX/day/night	AWX/day/night	18000	Complete	Autonomous
FTR	AWX/day/night	VMC/day	0	Complete	Autonomous
HLA	AWX/day/night	VMC/day	0	Standard	Autonomous
UAV	VMC/day	VMC/day	0	Minimal	Autonomous
HLB	VMC/day	VMC/day	0	None	Not autonomous

2. Force Awareness

Table A7-3. System Scoring – Force Awareness 1

ACFT	A2.1	A2.2	A2.3	A2.4	A2.5	A2.6	A2.7
CGO	0	0	>9	0	VMC/day	VMC/day	0
ASW	0	0	1 - 4	12	AWX/day/night	AWX/day/night	100
FTR	60	3	> 4 - 9	0	AWX/day/night	VMC/day	0
HLA	0	0	>9	0	VMC/day	VMC/day	0
UAV	0	0	<1	20	AWX/day/night	VMC/day	0
HLB	0	0	>9	0	VMC/day	VMC/day	0

Table A7-4. System Scoring – Force Awareness 2

ACFT	A2.8	A2.9
CGO	Data or voice, secure	VHF, UHF and HF or SATCOM
ASW	Data, voice and secure	VHF, UHF and HF or SATCOM
FTR	Data, voice and secure	VHF and UHF
HLA	Data or voice, secure	VHF and UHF
UAV	Data, voice and secure	VHF, UHF and HF or SATCOM
HLB	Data or voice	VHF

Table A7-5. System Scoring – Force Awareness 3

ACFT	A2.10	A2.11	A2.12
CGO	None	5 - 20	None
ASW	Encryption/Freq Hopping	5 - 20	Encryption/Freq Hopping
FTR	Encryption/Freq Hopping	>20 - 50	Encryption/Freq Hopping
HLA	Encryption/Freq Hopping	<5	None
UAV	Encryption/Freq Hopping	>20 - 50	Encryption/Freq Hopping
HLB	None	<5	None

3. Force Mobility

Table A7-6. System Scoring – Force Mobility

ACFT	A3.1	A3.2	A3.3	A3.4	A3.5
CGO	30	Yes	2.7	50	Semi-prepared
ASW	0	No	0	0	Prepared
FTR	0	Yes	0	0	Prepared
HLA	0	Yes	0	0	Unprepared
UAV	0	No	0	0	Prepared
HLB	0	No	0	0	Unprepared

4. Force Support

Table A7-7. System Scoring – Force Support

ACFT	A4.1	A4.2	A4.3	A4.4	A4.5
CGO	VMC/day	0	None	0	0
ASW	VMC/day	0	None	0	0
FTR	VMC/day	0	None	0	0
HLA	VMC/day	0	None	0	0
UAV	VMC/day	0	None	0	0
HLB	VMC/day	100	1 to 3	100	0

APPENDIX 8

GLOSSARY

anti-submarine warfare - operations conducted against submarines¹⁵¹

cargo aircraft – aircraft equipped to transport personnel and material.¹⁵²

communications security - The protection resulting from all measures designed to deny unauthorized persons information of value that might be derived from the possession and study of telecommunications, or to mislead unauthorized persons in their interpretation of the results of such possession and study.¹⁵³

communications security equipment — Equipment designed to provide security to telecommunications by converting information to a form unintelligible to an unauthorized interceptor and by reconvertng such information to its original form for authorized recipients, as well as equipment designed specifically to aid in (or as an essential element of) the conversion process.¹⁵⁴

datalink – 1. Any highway or channel along which messages are sent in digital form.
2. Communications channel or circuit used to transmit data from sensor to computer, readout device or storage.¹⁵⁵

electronic countermeasures – Subdivision of EW; actions to reduce or exploit effectiveness of enemy electromagnetic radiation.¹⁵⁶

electronic warfare – military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. Electronic warfare consists of three divisions: electronic attack, electronic protection, and electronic warfare support.¹⁵⁷

¹⁵¹ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 123.

¹⁵² Ibid.

¹⁵³ The U.S. Department of Defense, *The Dictionary of Military Terms*, 92.

¹⁵⁴ Ibid., 93.

¹⁵⁵ Gunston, *The Cambridge Aerospace Dictionary*, 166.

¹⁵⁶ Ibid., 207.

¹⁵⁷ The U.S. Department of Defense, *The Dictionary of Military Terms*, 157.

encrypted data – Data, that before transmitted or received by a communication line, are encoded or decoded, respectively by specific equipment.¹⁵⁸

encrypted voice – see **encrypted data**.

fighter aircraft – Aircraft equipped for combat aircraft in the air and destroy attack surface targets.¹⁵⁹

frequency hopping – Unpredictable continual and rapid changes of frequency of radar or other military electronics to defeat hostile ECM.¹⁶⁰

Inertial Navigation System – A self-contained navigation system using inertial detectors, which automatically provides vehicle position, heading, and velocity. Also called INS.¹⁶¹

intelligence, surveillance, and reconnaissance — An activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations.¹⁶²

maritime patrol aircraft – Aircraft for the systematic investigation or non-maritime area of interest in order to detect, locate, identify, track, neutralize or destroy targets at sea.¹⁶³

NAVAID. Any facility used in, available for use in, or designated for use in aid of air navigation, including landing areas, lights, any apparatus or equipment for disseminating weather information, for signaling, for radio direction finding, or for radio or other electronic communication, and any other structure or mechanism having a similar purpose for guiding or controlling flight in the air or the landing or takeoff of aircraft.¹⁶⁴

reconnaissance – a mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or adversary, or to secure data concerning the meteorological, hydrographic, or geographic characteristics of a particular area.¹⁶⁵

¹⁵⁸ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 72.

¹⁵⁹ *Ibid.*, 22.

¹⁶⁰ Gunston, *The Cambridge Aerospace Dictionary*, 253.

¹⁶¹ The U.S. Department of Defense, *The Dictionary of Military Terms*, 227.

¹⁶² *Ibid.*, 237.

¹⁶³ *Ibid.*, 22.

¹⁶⁴ The Federal Aviation Administration, *8200.1-C United States Standard Flight Inspection Manual*, A1-20.

¹⁶⁵ The U.S. Department of Defense, *The Dictionary of Military Terms*, 393.

reconnaissance aircraft – aircraft equipped to carry out the aerial reconnaissance.¹⁶⁶

SEAD – is that activity which neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means.¹⁶⁷

search and rescue aircraft – aircraft designed to locate, provide relief and rescue aircraft crews and passengers killed or injured, and also ship passengers who are in emergency situation or danger.¹⁶⁸

semi-prepared runway – is an unpaved runway that has been prepared to safely support required aircraft maneuvers.

surveillance – Systematic observation of aerospace, surface or subsurface objects by any kind(s) of sensor.¹⁶⁹

¹⁶⁶ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 22.

¹⁶⁷ US Air Force, *AFDD 2-5.1 Electronic Warfare* (US Air Force, 1999), 8, <http://www.e-publishing.af.mil/>.

¹⁶⁸ Ministério da Defesa, *MD 35-G01 Glossário das Forças Armadas*, 22.

¹⁶⁹ Gunston, *The Cambridge Aerospace Dictionary*, 613.

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