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Systems Decision Process - A Systematic Approach to Support Decisions on Defense Acquisitions in the Development of Complex Weapon Systems

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Capability development is a complex process involving interactions between industrial suppliers of goods and services with multiple government agencies often trying to balance competing objectives. The big dilemma is: how do governments acquire equipment, goods and services needed for their armed forces at a reasonable price, appropriate quality, and with a reasonable time frame? In this context, the development of new weapons systems is a challenging process, which entails increasingly long development periods, the use of cutting-edge technologies in an environment of high uncertainty, requiring, for that reason, a decision-making support process that adjusts to these specific requirements. Nowadays, decision-making is based on models used in certain decision-making instances, not considering the nature of the development programs above. Using a systems decision process (SDP) would allow a systemic and iterative, collaborative process and a value-based decision process that could be applied throughout the whole life cycle of this new weapons system.
Keywords: defense acquisition, weapons development, value-focused thinking, decision making, systems decision process, Systems Engineering.

Rendszerdöntési folyamat – Az összetett fegyverrendszerek fejlesztésének rendszerszintű megközelítése a védelmi beszerzéssel kapcsolatos döntés támogatása során

A képességfejlesztés összetett folyamat, amely magában foglalja az ipari termékek és szolgáltatások beszállítói és a kormányhivatalok közötti interakciókat, amelyek során gyakran egymással versengő célkitűzések kiegyenlítésére van szükség. Felmerül a kérdés ezzel kapcsolatban, hogy az egyes országok kormányai hogyan vásárolják meg a fegyveres erők számára szükséges felszereléseket, eszközöket és szolgáltatásokat elfogadható áron, megfelelő minőségben és adott határidőn belül? Ehhez kapcsolódóan kiemelt fontosságú az új fegyverrendszerek fejlesztése, amely rendkívül összetett folyamat. A fejlesztésre fordított idő egyre inkább megnövekedik, viszont a legmodernebb technológia alkalmazását igényli, amely nagyfokú bizonytalansággal terhelt környezetben valósul meg. Épp ezért olyan döntéstámogatási folyamatra van szükség, amely alkalmazkodik ezekhez a különleges követelményekhez. A jelenleg használatos döntéshozatali modellek nem veszik figyelembe a fejlesztési programok sajátosságait a döntéshozatal során. A rendszerdöntési folyamat (SDP) alkalmazása lehetővé tenné a rendszerszintű, interaktív, együttműködésen alapú, valamint értékalapú döntéshozatali folyamatot, amely az új fegyverrendszer teljes életciklusa során alkalmazhatóvá válna, már a kezdetektől figyelembe véve a tervezési követelményeket, korlátozásokat és a szükséges kompromisszumokat.

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Kulcsszavak: Védelmi beszerzés, fegyverfejlesztés, értékközpontú gondolkodás, rendszerdöntési folyamat, rendszerfejlesztés

Introduction

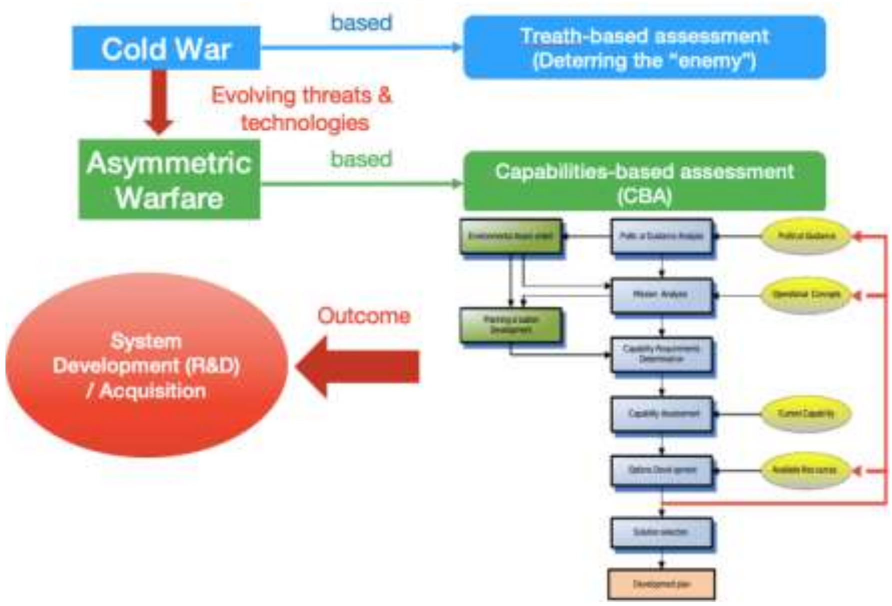
The development of new weapons systems is a highly complex process, which usually involves making decisions associated with balancing the acquisition of new military equipment at a "reasonable" price, with appropriate quality, and the foregoing within a rational time frame. The development of these new weapons systems at the top level of the US Department of Defense (DoD) is managed and executed through a complex defense procurement system, in which decisions are made in a high-risk, high-responsibility environment, and high uncertainty with very dynamic operating environments[2]. Defense capability-planning and defense acquisition programs are part of the capability building process. Both require methods and models to assess alternatives as part of the decision support analysis, which is why the use of Multi-Objective Decision Analysis (MODA) methods is one of the most prevalent among defense organizations In this context, a multi-disciplinary engineering approach called Systems Engineering, born in academia and the defense industry during the Second World War, emerges as an approach whose primary objective is to define customer requirements together with the necessary functions at an early stage of the development of complex systems. This approach considers the whole problem with a holistic vision that includes operations, costs and programming, performance, training and support, testing, manufacturing and disposal activities. However, to be successful, it requires a good decision-making process and a formal decision management process. The purpose of this decision management process, according to ISO/IEC 15288:2015, is to: *"(...) provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for a decision at any point in the life cycle and select the most beneficial course of action"*.[3] The increased use of a MODA with a Value-Focused Thinking (VFT) approach in defense programs makes one think about its applicability in the decision-making process throughout the life cycle of capability development. In this sense, the SDP is a methodology developed in the Department of Systems Engineering of the United States Military Academy at West Point. Delivering a solid and systematic framework it also integrates a VFT approach that, given its flexibility and dynamism, allows its integration into the capacity development process at an early stage, providing a proven systemic structure for decision-making and favouring the generation of alternatives.

Capability assessment, defense acquisition system and decision support analysis

During the cold war, the US and several NATO member states used a threat-based approach to plan future requirements for the military capabilities of their armed forces. At that time, the threat

2 Guajardo 2020,121.
3 ISO/IEC 15288:2015, 36.

environment was well-circumscribed and focused on curbing the Soviet threat in Europe. Thus, a threat-based approach seems to have been the best tool for developing future military capabilities (capability building). With the fall of the Soviet Union and the end of the Cold War in 1990, the existence of the Soviet Union as a threat disappeared and migrated to one with a non-existent central enemy and a considerable increase in an ambiguous threat composed of multiple threats, both conventional and unconventional. States were no longer seen as threats, the potential adversaries adopting other forms such as insurgents, terrorists, and religious extremist groups. Many countries had to reassess their strategies to develop their forces.[4]



1. Figure

Defense planning strategy evolution since the Cold War

(*Source*: author based on Kovač, Mitar et al. 2013, 552.)

In this context, one of the most widely used approaches in defense capacity development planning emerges as a response, which is capacity-based planning (CBP), the latter being the ultimate objective of providing the capacities to defense in order to fulfill the mission and defense tasks in terms of national protection and the collective interests of states and the Alliance[5]. This development of capacities involves a functional analysis, analysis of functional requirements and an analysis of solutions designed to: define the mission, identify the required capabilities, determine the

4 Hébert 2017, 4.

5 Kovač, Mitar et al. 2013, 551.

attributes/standards of the capabilities, identify the gap, evaluate the operational risk associated with gaps, prioritize gaps, identify, and evaluate potential non-material solutions, as well as provide recommendations to address gaps.[6] The evaluation of potential solutions considers evaluating different alternatives during their life cycle, taking into account different development/acquisition, operation and maintenance costs and the withdrawal of the abovementioned capabilities, expecting to have the least costly solution-efficiency in the shortest time at the end of this evaluation, in addition, when all the above meet the initially defined requirements (military capabilities). As highlighted,[7] this type of planning prepares defense organizations for the future, except in terms of particular weapons systems or levels of an endowment. Instead, this type of planning identifies the tasks and capabilities required to achieve them.

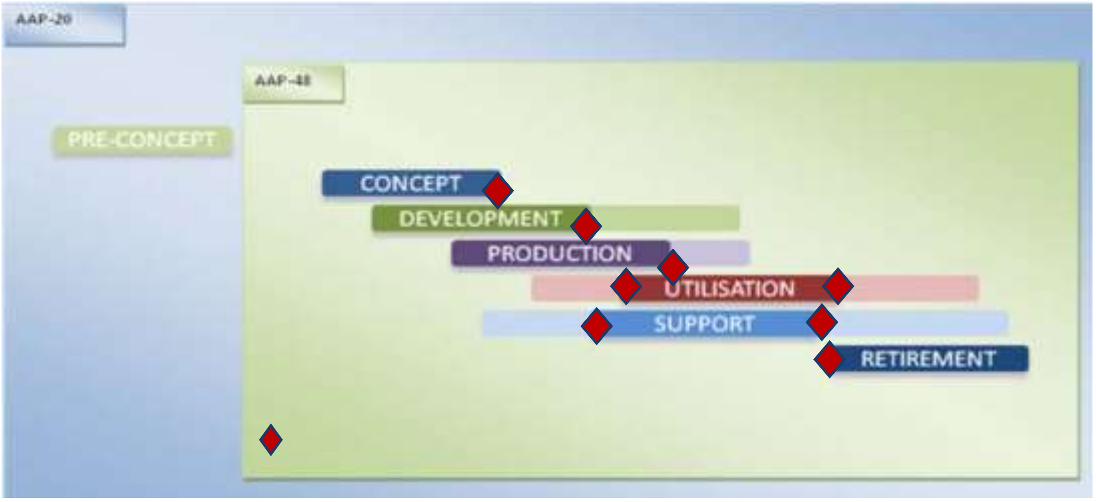
Defense planning requires the use of analytical models and methodologies, for which varied models and methods allow an efficient choice of potential solutions. Authors, such as Hillestad & David,[8] Mezey,[9] Kovač et al[10] and Nesterenko et al,[11] who, in general, propose models and the use of softwares as decision support tools, based on multi-objective problems to be applied as a strategy that seeks for an efficient allocation of resources. For instance, Hillestad & David and Kovač et al. present a decision support software called Dynarank used in defense planning, as well as for or the evaluation of public policy alternatives with high employability. On the other hand, Mezey and Nesterenko et al. propose both qualitative, quantitative, and combined models for the definition of military capabilities, including models such as the Self-service Technology and Quality Function Deployment (SST/QFD), and analytic hierarchy process (AHP).

In defense procurement, once the decision to acquire/develop a new weapons system is made at the political-strategic level, this new requirement enters the defense procurement system (DAS) as a development program, which the Ministry/Department of Defense generally administers.

A widely used approach to support defense decision making is life cycle cost analysis (LCC). This tool has been in use since the late 1960s, mainly by the US arms industry, and has spread to both defense organizations around the world and private industry. This analysis contributes to the decision-making process, being a fundamental tool for decision-makers to evaluate alternatives, regardless of the phase of the program in which they are. The possible alternatives or choices could include the evaluation of future expenses, comparison among solution alternatives, administration of the current budget, acquisition alternatives and evaluation of cost reduction opportunities; this LCC analysis represents an estimate of the defense programs being of uncertain and risky nature, encompassing the

6 Small, Colin. 2016, 3.
7 Faber, Peter. 2003, 2.
8 Hillestad, Richard et al. 1998.
9 Mezey, Gyula. 2008.
10 Kovač, Mitar et al. 2013.
11 Nesterenko, Oleksandr et al. 2020.

entire life cycle of the development program, which includes, among others, development, production, operation and support (including both sustainment and disposal).



2. Figure

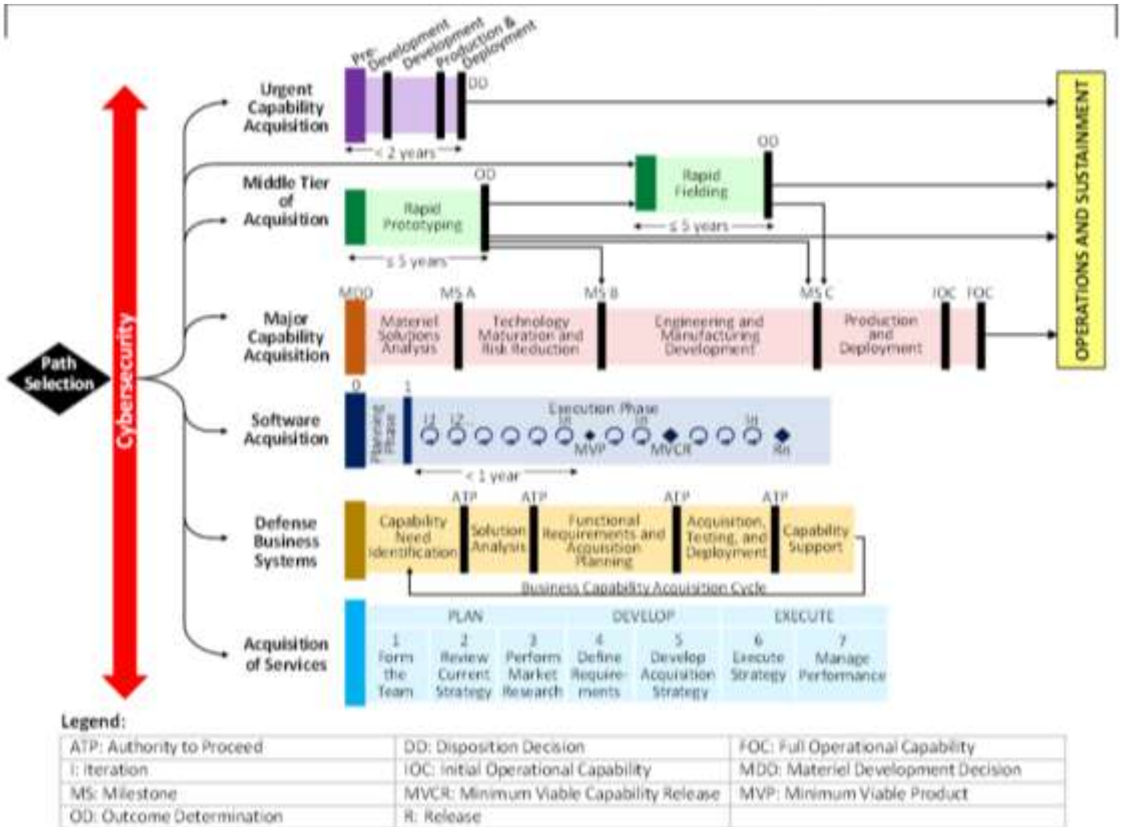
NATO Programme Life Cycle

(*Source*: APP-48. 2015, 1–3.)

The life cycle classification varies from country to country. In addition to depending on the nature of the defense programs and their level of uncertainty (risk), these can be classified into different categories, and according to these, adopt the subsequent acquisition strategy. For example, in terms of acquisition strategies, the Spanish Ministry of Defense classifies defense programs into development programs, acquisition programs, research and development (R&D) programs, modernization programs, and maintenance programs.[12] The U.S. Department of Defense, for its part, defines in its DODI 5000.02 the procurement strategy to be adopted by program managers, depending on the nature and risk of the capacity to be acquired, adapting the stages of the life cycle of the capacity to develop depending on the procurement strategy used.[13]

12 MDE

13 DODI 5000.02, 9.



3. Figure
US DoD Adaptive Acquisition Framework
(*Source*: DODI 5000.02, 9.)

The different paths/strategies can be described as follows:

- *Urgent Capability Acquisition:* The primary purpose of this acquisition strategy is to complete urgent existing / or emerging or rapid reaction operational needs in less than two years (DoDD 5000.71 and DoDI 5000.81).
- *Middle Tier of Acquisition:* The primary purpose of this acquisition strategy is to rapidly develop deployable prototypes within an acquisition program to demonstrate new capabilities and rapidly deployable field production quantities of systems with proven technologies that require minimal development. (DoDI 5000.80).
- *Major Capability Acquisition:* The primary purpose of this acquisition strategy is to acquire and modernize unique military programs that provide durable capability.
- *Software Acquisition:* The primary purpose of this acquisition strategy is to facilitate rapid and iterative delivery of software capability (e.g., software-intensive systems and software-intensive components or subsystems) to the user.

- *Defense Business Systems (DBS) Acquisition:* The primary purpose of this acquisition strategy is to acquire information systems that support the commercial operations of the US Department of Defense, applying both to the commercial defense capabilities and its commercial systems of support, as well as in non-development acquisition programs that make intensive use of software and are not commercial systems (DoDI 5000.75).

Within this defense procurement process defined by the U.S. Department of Defense, one of the most critical elements to consider is the process of analysis of alternatives (AoA),[14,15] which is an analytical comparison between the cost of the life cycle, the operational effectiveness and the suitability of alternatives that satisfy the required military capabilities and is typically carried out in order to:

- identify and evaluate the risks, uncertainty and relative advantages/disadvantages of the alternatives being considered.
- demonstrate the sensitivity of each alternative evaluated to possible changes to which it could be faced.
- help "decision-makers" evaluate if the proposed alternatives comply or not, with sufficient economic/operational merits to be considered a valid option.

Within this particular process, one of the most critical steps is the preparation of the Alternatives Analysis Study Plan, which represents a roadmap of future activities related to the analysis of alternatives and those responsible for executing them. This study allows a total consideration of the potential trade-offs, and as a reference, it considers, among others, the following points depending on the scope of the analysis and the criteria used in the study.[16]

14 DAU DAG-CH-2
15 DODI 5000.84
16 DAU DAG-CH-2, 4–5.

4. Figure

U.S. DoD Alternatives Analysis Study Plan

(*Source*: DAU DAG-CH-2, 4–5.)

This analysis of alternatives is the main task within the phase of Material Solutions Analysis[17] (MSA) and its purpose in this phase is to evaluate the effectiveness of the mission, operational adequacy, and the cost of the life cycle estimate of potential alternative solutions.[18]

NATO, for its part, proposes in its technical document RTO-TR-SAS-054 "Methods and Models for Life Cycle Costing" analysis of alternatives based on the life cycle cost methodology, which is recommended for supporting the decision-making of the administrators, among the options presented within the program such as the evaluation of future spending, the administration of the assigned budget, assessment of an opportunity to reduce costs, a comparative analysis between potential solution alternatives and the different options. This analysis considers, among others, the use of methods and models such as estimation, simulation, optimization, and the decision support used.

In a similar way to the MSA analysis, the decision support tools are proposed to be used at the beginning of the program in the phases of “Mission need” and “Pre-feasibility” in order to have a two-dimensional vision of the alternatives to be evaluated, frequently using subjective judgments to make up for the lack of quantitative historical data that exist at the beginning of the program. Within these tools, several operations research models exist, whose main objective is the choice or ranking of

17 Can be “translated” to NATO’s PAPS “Prefeasibility” and ISO/IEC’s 15288 “Concept” life-cycle stages according to NATO’s RTO-TR-SAS-054 “Methods and Models for Life Cycle Costing”, (2007), 3.
18 DAU MSA.

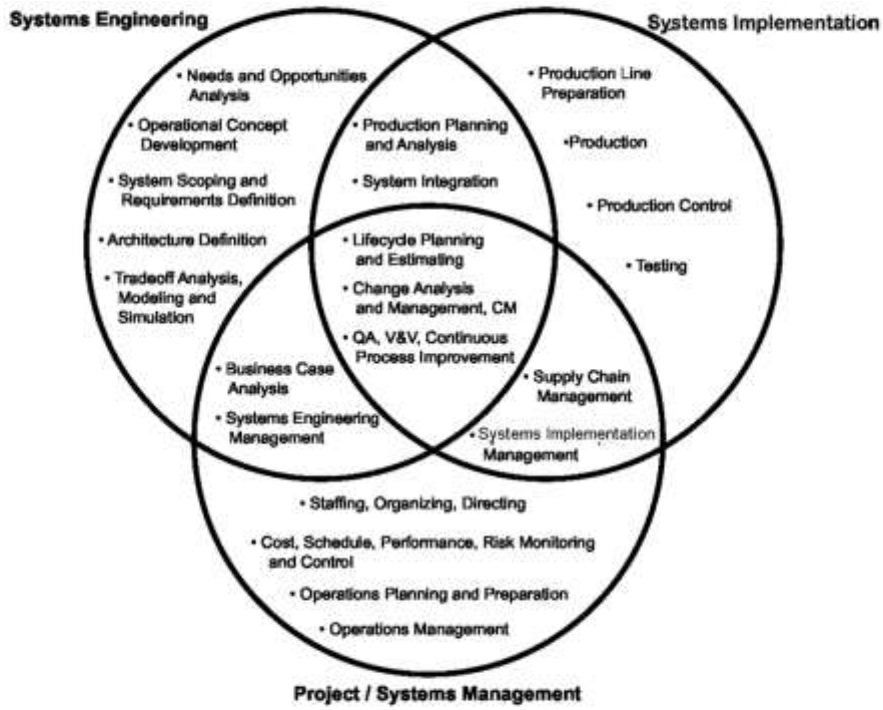
multiple potential solution alternatives, for which soft management models and tools are used such as the analytical hierarchical process (AHP) or in multi-objective decision analysis techniques (MODA), and studies applying these tools in the selection of alternatives.

Systems Decision Process (SDP) and value-focused thinking

The resolution of these decision-making problems requires a structured, systemic approach that allows identifying and discovering all the relevant objectives, making it easier to work with objectives expressed in many different units of measurement.[19] Within this a structured, systemic approach is needed in order to face the resolution of problems for complex decision making, systems engineering arises as a multidisciplinary approach whose primary focus is the definition of customer requirements with the functionality required at an early stage in the development stage of complex systems, also considering the whole problem with a holistic vision that includes operations, costs and programming, performance, training and support, testing, manufacturing and disposal activities.[20] Developed in the mid-20th century in academia and the defense industry to develop new weapons systems during the WWII, it has played a prominent role in developing procedures and methodologies for military R&D and its main contractors.

Systems engineering consists of two areas or disciplines such as the field of technical knowledge, and the area of systems engineering management. The technical components of the latter are essential elements of the 'approach of systems', which was a significant intellectual development of the 1950s and 1960s with strong references both in the academy and the military-industrial field, transforming systems management into a standardized methodology in the aerospace industry, later expanding to other industries in the US and other countries throughout the world.[21] In Figure 5, the boundaries of the systems engineering management according to the Systems Engineering Body of Knowledge[22] (SEBoK) are presented.

19 Melese, Francois et al. 2015, 198.
20 INCOSE 2015, 11.
21 Johnson 1997, 893.
22 Madachy and Roedler 2021.



5. Figure
Systems Engineering Management Boundaries
(*Source*: Madachy and Roedler 2021, 445.)

Systems engineering management differs from project management by its technical and engineering focus on project aspects, including exploratory research and development (R&D) activities in commercial and government operations. Among the activities considered by Systems Engineering Management are planning, assessment and control, risk management, measurement, decision management, configuration management, information management and quality management.

The decision management process is detailed in INCOSE's Systems Engineering Handbook, Body of Knowledge, and ISO/IEC 15288:2015, being the latter recommended to use in NATO’s RTO-TR-SAS-054 technical document for Life Cycle Cost Analysis and currently used by US DoD in conjunction with IEEE 15288.1-2014[23] for the application of Systems Engineering in Defense Programs. According to ISO/IEC 15288:2015, the purpose of decision management process is *"[...] to provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for a decision at any point in the life cycle and select the most beneficial course of action"*.[24] This framework supports the development of new systems that implicate a series

23 IEEE 15288.1-2014.
24 ISO/IEC 15288:2015, 36.

of decision "opportunities" such as those shown in Table 1. and which are commonly presented throughout the systems life cycle.

1. Table

Decisions "opportunities" throughout the life cycle

(*Source*: Extracted from the Systems Engineering Handbook. INCOSE 2015, 110.)

Life cycle stage	Decision situation (opportunity)
Concept	Assess technology opportunity/initial business case
	Craft a technology development strategy Inform, generate, and refine an initial capability document
	Inform, generate, and refine a capability development document
	Conduct analysis of alternatives supporting program initiation decision
	Select system architecture
Development	Select system element
	Select lower-level elements
	Select test and evaluation methods
Production	Perform make-or-buy decision
	Select production process and location
Utilization, support	Select maintenance approach
Retirement	Select disposal approach

Along with the systems engineering framework, there is the incorporation of decision models that add and translate operational data, development tests and the data generated by engineering, performance and cost models in terms of relevance to the various stakeholders and the decision-making authorities.[25] Among the most used models for defense applications are the multi-objective decision analysis techniques (MODA) mentioned above as one of the techniques proposed by NATO for Decision Support Analysis.

25 MacCalman, and Parnell 2016.

Value-Focused Thinking vs Alternative-Focused Thinking?

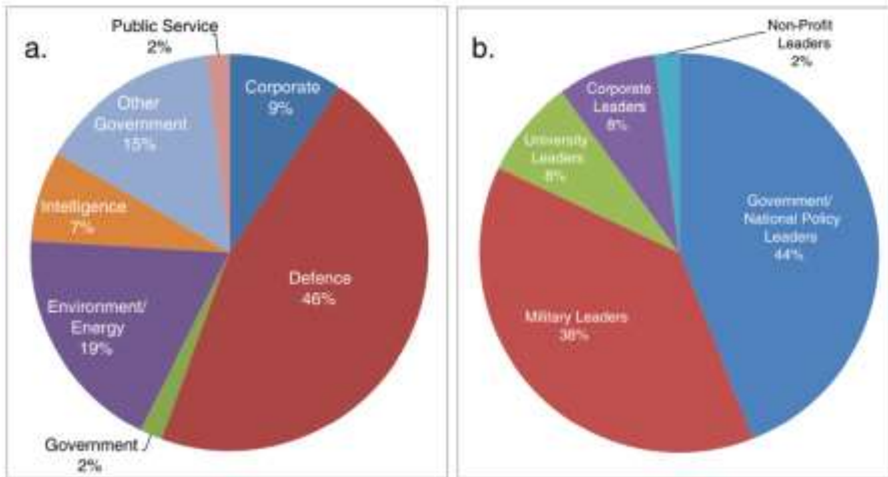
Regarding strategies for using the Systems Decision Process, two philosophies can be used in conjunction with MODA: Alternative-Focused Thinking (AFT) and Value-Focused Thinking (VFT), but the Systems Decision Process has decided to use VFT. MODA has been applied to various DoD problems, specifically in military applications in the last four decades. Created in 1976,[26] the first method employing MODA used by the DoD was Alternative-Focused Thinking (AFT). This method uses the traditional way for the generation of criteria for the analysis of decisions, which is through the study of alternatives. First by identifying these and only once these have been identified are the objectives and criteria evaluated.[27] Among its main characteristics, they highlight that it is a reactive and not proactive approach, it fails to achieve maximum effectiveness since it focuses the attention on the available alternatives. According to Keeney, the decision-making process is restricted to the available alternatives, which prevents the incorporation of criteria that could have a significant value for the decision-makers, perceiving the decision process as more of a problem than an opportunity to create something new. Creative problem solving typically involves redefining problems to accommodate new perspectives as well as solutions.[28] Considering this, AFT provides only insights about a limited set of alternatives, it fails into assessing the future capability needs, therefore it is not well aligned with capability-based planning and the capability implementation through new weapons systems development.

On the other hand, while the MODA can be traced back to 1976, VFT can be dated in 1992 with the publication of Kenney called *"Value Focused Thinking - A path to creative decision-making"*,[29] being VFT a philosophy that begins by identifying the values and then using these values to evaluate and then improve the alternatives delivered to the decision-makers. To quantify the values and evaluate the alternatives, using the mathematics of the Multiple Objective Decision Analysis (MODA),[30] this technique is most appropriate when facing conflicting objectives, more complex alternatives and more significant sources of uncertainty. It is the recommended technique to structure the decision-making for many decisions in the DoD,[31] gaining an increasing degree of acceptance as the DoD has increased its requirement for a more understandable and traceable study for the analysis of alternatives.

Among the benefits of using a MODA-VFT approach within the process of analyzing alternatives in decision-making, it stands out that it is a proven methodology that has been used in several disciplines and it encompasses domains such as defense being the discipline with the most significant application, followed by environment/energy and the Government. In addition, among the main clients

26 Keeney et al 1976.
27 Keeney 1994, 33.
28 Selart and Johansen 2011, 197.
29 Keeney 1996.
30 Parnell 2008, 5.
31 Dillon-Merrill et al 2008, 19.

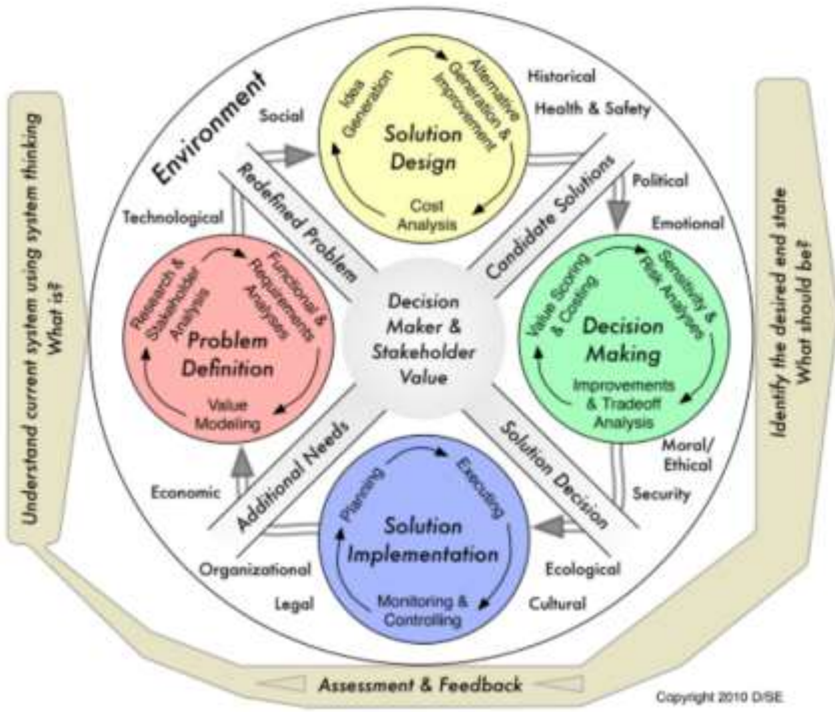
for using this methodology, the leaders of public/national policies and military leaders stand out, followed by university leaders, corporations, and non-profit organizations (Figure 6).



6. Figure
VFT Problem Domain (left) and Clients (right)
(*Source*: Parnell et al 2013, 53.)

Systems Decision Process (SDP) is a VFT-based general problem-solving methodology used to design solutions for complex problems that tailor the process to the system, the decision, and the stage of the system's life cycle.[32] Among their characteristics, the process itself considers that the current system/or baseline is the reference for assessments of user requirements and to compare the potential solution candidates. It focuses on the decision-maker, the stakeholder value and the creation of value defining the desired end state that is trying to achieve by using a value-focused thinking approach to improve the solutions. Finally, it has four phases[33] (problem definition, solution design, decision making, and solution implementation) embedded in the system's environment and the issues that arise with stakeholders and decision-makers in the environment.

32 Parnell and West 2010.
33 Parnell et al 2011, 17.



7. Figure
Systems Decision Process
(*Source*: Parnell et al, 2011. Figure 1.8.)

The SDP being a process, captures the iterative and cyclical flow of activities that is to be carried out prior to each decision points faced, highlighting that the modelling and the analysis flow generally accompanies the activities described by the SDP facilitate largely decomposing activities and assigning tasks to team members:

- *Problem Definition**:*** In this stage, as in any systems decision process, the main task is to identify and understand the problem defined previously, to understand the decision-makers and stakeholders' concerns, objectives, and constraints. This stage should be dealt in each stage in the system's life cycle, and the goal for this phase is a well-defined problem that meets the validation of key stakeholders, system's requirement or constraints that alternative solutions have to meet before they are fully designed, modelled and analyzed.
- *Solution Design:* Having understood and defined the problem correctly in the Problem Definition Phase, this stage focuses on finding a system solution to the problem by developing new ideas and generating, also improving alternative solutions to the problem. The sets of alternatives are refined as they grow, constantly contrasted against the problem definition and measured stakeholder objectives until the best solution is found. The final product is a process for solving a problem, determining candidate solutions to be presented

to the decision-maker, limited to one of two or more possibilities, each of them backed up with uncertainty and risk reduction techniques to make the decision-making more accurate.

- *Decision Making:* Inputs from previous stages are problem statement, requirements, value model, candidate solutions and the life cycle cost model. Additionally, some models and simulations could be added to the decision-making phase. At this moment, the following four tasks of the decision-making can be applied: score and cost the candidate solution, conduct sensitivity, and risk analyses, use value-focused thinking to improve the solutions, and apply trade-off analysis to compare value versus cost associated with candidate solutions. After the tasks are fully completed, the recommended solution is presented to the decision-maker to make the final decision.
- *Solution Implementation:* Finally, this stage is considered the most challenging of all stages in SDP as the activities focus on accomplishing all the client's expectations for the system into reality. Depending on the development of the implementation process, the possibility of returning to previous stages based on project achievements conditions always exists. The advantages of executing the solution implementation as a project is that all the principles and tools of project management are available to plan, execute, monitor and control the implementation.

In total, some of the advantages of applying an SDP into the defense acquisition system that can be highlighted are as follows:

➢ SDP contains the systems engineering activities. The same activities as mentioned previously are described in Systems Engineering standards and recommended to manage the life cycle of systems and apply systems engineering in defense programs.

➢ It is an iterative and collaborative process, concerned mainly with the values being delivered by the system in order to define the needs and objectives of stakeholders and key decision-makers.

➢ Its four stages inside the SDP have a logical and sequential progression, adopting a systemic framework and proven systems engineering approach and techniques to deliver a structured decision-making process.

➢ It considers the environment's factors, the interaction of the system of its operational environment, highlighting the necessity to count with multidisciplinary engineering teams.

➢ In addition to assessing alternatives using the traditional scoring and sensitivity analysis, it emphasizes value creation (value modelling, idea generation and alternative improvement, and value-focused thinking), more aligned with the assessment of capabilities and the implementation of those capabilities through defense programs.

Conclusions

This article is intended to illustrate the methodologies and models used in the assessment of capabilities and the Analysis of Alternatives (AoA) as part of the decision support analysis for the decision-making process, concluding that the use of Life Cycle Cost Analysis and Multi-Objective Decision Analysis (MODA) and methods are frequently used during the life cycle stages of new capabilities, requiring a systemic structured framework in order to deal with the decision-making of complex systems. Systems engineering and its decision management, already proved in defense programs, promotes the delivery of a systemic and structured approach in order to deal with the decision-making process of complex systems in complex operational environments. Additionally, the increased use of MODA in conjunction with a Value-Focused Thinking (VFT) approach in defense programmes may indicate a more appropriate approach for the assessment of defense capabilities and programs.

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